PLENARY SESSION

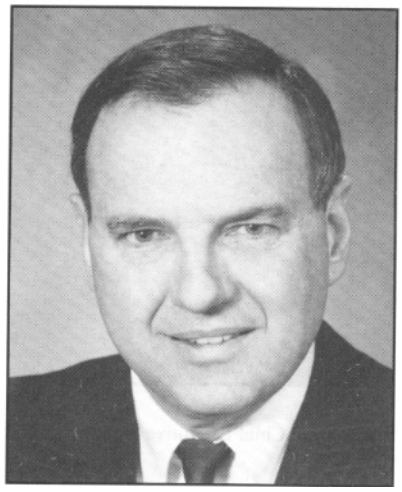
STACY, T.D., Chairman and President, Amoco Canada Petroleum Company Ltd., Calgary, Alberta T2P 2H8

Oil: an industry under renovation

Amoco Canada's history of growth by reinvestment served it well in the last years of the 1980's. Presented with a historical opportunity, Amoco's strong financial base and excellent industry position supported one of the largest business acquisitions in Canadian history.

Faced with global competition, increased administrative costs, and a pricing structure it cannot control, the North American petroleum industry has recognized the need for a massive restructuring. Although Alberta's maturing petroleum industry remains fraught with popular expectations of rapid growth, and continues to be regulated as though it were healthy, substantial work remains to be done before acceptable rates of return can be realized.

The new Amoco Canada's search for a viable corporate identity, following the merger of two distinct corporate cultures, provides the opportunity to define a strategy that will support the company in this changing environment.



SHULTZ, C.E., President and Chief Executive Officer, Gulf Canada Resources Limited, Calgary, Alberta T2P 2H7

International exploration: a Canadian perspective

Although there are good domestic oil and gas opportunities for Canadian companies, Canada's conventional oil reserves and production continue to decline. This fact, plus the probability of low oil prices throughout the nineties, should result in increased allocation of exploration dollars of independent Canadian companies to international ventures.

International exploration offers many attractions, including low-cost production and quick tie-in to markets. In addition, a large remaining oil potential awaits explorers in many established areas, and several countries are offering first-time access to relatively unexplored areas of high potential that require western oil field technology.

Under a low oil price scenario, many producing countries will be seeking, possibly competing for, increased private-sector investment, but Canadian investors should proceed only after careful assessment of the financial, political and geological risks. Development of good working relationships with state oil companies will be a good strategy in reducing fiscal and political risk.

Because of growing international recognition and acceptance of western oil field technology, technical capability will be an important factor in gaining concessions and signing joint ventures, but technical excellence alone will not guarantee success. International opportunities present a variety of demands for technical expertise, experience and management skills. The independent company must find its appropriate niche among the world players by identifying its strengths and developing focused strategies that will enable it to successfully employ its special areas of expertise.

BIRNIE, D.E., President and Chief Executive Officer, Mark Resources Inc., Calgary, Alberta T2P 4A4

The Western Canadian Basin — drain hydrocarbons or money drain?

During the past decade, the Western Canadian up-stream oil and gas industry has not been overly attractive to the investment community. With deregulation of both crude oil and natural gas, product prices have been market driven and have dropped considerably. During the same period the industry has had severe cutbacks in personnel in an effort to reduce costs.

An examination of the current status of the industry must consider the various internal and external factors and agencies that directly affect the viability of exploring for oil and natural gas.

The following major factors will be addressed:

Geology of the Basin. Does the basin contain sufficient recoverable reserves? Are the accumulations of hydrocarbons of sufficient size to make exploration economic?

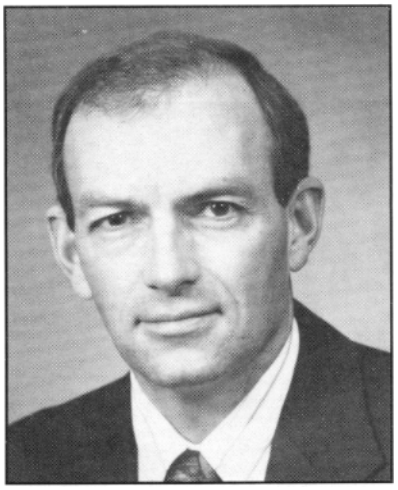
Markets and Transportation. Light crude remains a very sellable product. Heavier crudes have become give-aways. Natural gas markets appear to be available if economic transportation can be constructed.

Governments. Government incentives to the industry have almost gone. Government rents have not decreased. New environmental awareness continues to add to costs.

Exploration and Production Companies. What strategies and game plans will make success possible? Is the size of a company significant? Should companies be structured differently?

Financing. The industry remains highly capital intensive. Rate of return on investment has been dismally low. Can this be improved? Will product prices increase?

The People. Are changes needed in our approach to exploration? Can we replace the lost experience? Are we worth what we are being paid?



COLES, F.C., Chairman and President, Coles Gilbert Associates Ltd., Calgary, Alberta T2P 4H2

Natural gas economics — has the supply bubble burst?

A review of North American natural gas reserve-production ratios and reserve replacement statistics over the past decade shows that supply and demand are becoming more balanced. Because Canadian supply/demand is an integral part of the total North American supply/demand relationship, there will be opportunities for significant increases in annual deliveries plus real growth in natural gas wellhead prices during the nineties.

The critical question, as always, is what will be the increase in demand and how will natural gas prices respond? A review of the past decade statistics of supply, demand, prices and reserve-to-production ratios suggests that real growth in natural gas prices may not be as aggressive as many industry forecasts project.

Based on a more conservative view of the historical relationships plus a consideration of seasonality of demand, three alternate price projections have been prepared and are presented for review. The price forecasts reflect the sensitivity of future gas prices to increases in supply and demand, as well as a general relationship to future crude oil prices. It is suggested that a review of project economics using the three forecasts may assist with assigning priority to specific natural gas exploration projects.

TECHNICAL PROGRAMME (ORAL AND POSTER PRESENTATIONS)

SED2

AINSWORTH, R.B. and WALKER, R.G., McMaster University, Hamilton, Ontario L8S 4M1

Sandbody geometry of disconformity-bounded, stacked, marginal marine units, Bearpaw–Horseshoe Canyon transition, Drumheller, Alberta

The 60 m thick, Campanian–Maastrichtian, Bearpaw–Horseshoe Canyon transition is exposed along the Red Deer Valley, Drumheller, Alberta. These marine to marginal marine deposits can be divided into seven disconformity-bounded units (A to G). Each unit contains a transgressive and a regressive phase. Units are defined by marine flooding surfaces, which often occur above thin (0.3 to 2 m) coal seams. Erosional relief along these surfaces is minimal and depositional records of the transgressions are very thin or absent. Exceptions occur in Unit B, where an incised valley (up to 16 m deep and at least 20 km long) was infilled with fine to medium grained estuarine sand, sourced from the marine side during transgression, and in Units E and G where thin (1 to 4 m), bioturbated, transgressive sheet sands occur.

Most of the preserved deposits in the succession belong to highstand systems tracts. They are represented by prograding sandy shoreface systems (Units A, C and F) up to 18 m thick and at least 14 km long in the progradation direction. Shoreface systems are sealed up-dip by stratigraphic pinch-out into nonmarine shale and siltstone.

Vertical connectivity between sandbodies is generally poor except in the cases of Units A and B where the sand filled estuarine channel (B) erodes into shoreface sandstone (A), and Units E and F where shoreface sandstone (F) overlies a transgressive sandsheet (E).

In the marginal marine zone, sandbody geometry and location are determined by the relative interactions between tectonic subsidence, sea level change, sediment supply, and sediment point source during any particular disconformity-bounded depositional episode.

Each unit is estimated to represent about 140,000 years of deposition. This is an order of magnitude lower than the third order eustatic sea level cycles proposed for the Upper Cretaceous by Haq *et al.* (1.8 million years). The estimated periodicity suggests that autocyclic shifts in marginal marine depocentres, possibly with superimposed glacioeustatic sea level fluctuations, controlled sedimentation.

DIAG

AMTHOR, J.E., MOUNTJOY, E.W. and MACHEL, H.G. Department of Geological Sciences, McGill University, Montreal, Quebec H3A 2A7

Dolomite-rock textures of Leduc dolomites in the Leduc, Westerose, and Wizard Lake buildups in the Rimbey–Meadowbrook reef trend

Preliminary petrographic and geochemical data of replacement dolomites from several Leduc buildups indicate a selective replacement of the original components. Three petrographic types of replacement dolomite are present, suggesting different phases of dolomitization. The most abundant is first phase medium to coarse crystalline, planar matrix dolomite. It consists of dense mosaics of subhedral crystals, or forms porous zones characterized by intercrystalline porosity. Luminescence is orange-red mottled or blotchy. Isotope values cluster around +2.0 to +3.8°/∞δ^{13}C and −6.2 to −5.0°/∞δ^{18}O PDB.

Second phase coarse crystalline, planar, void-filling dolomite occurs mainly in reef-margin wells. Clear crystals are zoned, and have more negative δ^{18}O values (−8.4 to −6.5°/∞).

The third dolomite is nonplanar and nonmimically replaces fossil fragments. Cathodoluminescence and stable isotopes are similar, or commonly identical, to first phase planar replacement dolomites. Minor nonplanar dolomite cements (saddle dolomite) line vugs and fractures.

Geochemical bulk analyses of replacement dolomites have low concentrations of Sr (<150 ppm) and Mn (250 ppm), and Fe ranges from 860 to 8000 ppm.

The most pervasive are the first phase, planar matrix dolomites. They are similar texturally and geochemically, and also in terms of timing and probable origins, to early pervasive dolomites observed elsewhere in Devonian strata in widely separated parts of the Alberta basin.

EXPS

ARNOTT, R.W.C., Esso Resources Canada Ltd., Calgary, Alberta T2P 0H6

The conglomeratic Cardium Carrot Creek "K" Pool — a case study illustrating the importance of a geological framework

Although the relationship between geological framework and reservoir performance has long been recognized, it has only been in the last decade or so that detailed geological models have become an integral part of any reservoir maintenance plan. In a case study of the conglomeratic Cardium (Turonian–Coniacian) Carrot Creek "K" Pool (Twp. 51–52, Rge. 13W5M), it was recognized that the areal distribution of reservoir quality (porosity/permeability) was directly related to a predictable depositional framework — a wave-reworked distributary mouth-bar complex.

The Carrot Creek "K" Pool is a narrow, elongate, northwest–southeast trending conglomeratic reservoir unit. Detailed core and log analyses indicate that the reservoir consists of two lithostratigraphic units: an underlying, fine grained regressive unit (with little or no reservoir quality), and an overlying conglomeratic transgressive unit (representing the main reservoir). Separating the two units is a regional unconformity, or sequence boundary; remnant topography on this surface was an important factor controlling the areal distribution of gravel deposition during development of the reservoir-bearing transgressive unit. In addition, conglomerate of the transgressive unit consists of both matrix-supported and clast-supported types; reservoir quality is highest in the clast-supported type. Matrix-supported conglomerates are confined to the western (paleolandward) side of the "K" Pool area and are interpreted as braided distributary stream deposits associated with a conglomeratic distributary mouth-bar complex. Clast-supported conglomerates occur eastward (paleoseaward) of the matrix-supported conglomerates and are interpreted as having been deposited on an open marine shoreface/beachface. They are the result of wave reworking and redistribution of sediment sourced principally from the distributary mouth-bar complex. Knowledge of lithofacies distribution within the Carrot Creek "K" Pool is essential to an understanding of reservoir quality distribution and prediction of permeability pathways within the reservoir. This can be of benefit in the design and implementation of pressure maintenance programs or enhanced recovery techniques.

INTE

ATTAR, A. and CHAOUCH, A., Sonatrach, Hussein-Dey-Alger, Algeria

South border Saharian basins as a new play for oil exploration

The Hoggar and Eglab massifs are located in the north–central African continent, surrounded by Paleozoic outcrop cover. Geochemical analyses of the sedimentary series on the north Hoggar margin indicate that organic maturation was delayed in comparison with homologues in the centre of the Saharian basins.

Geochemical results challenge the idea that heat flow increases south toward the Hoggar Massif. According to certain authors, heat flow occurred during the Cretaceous, when the Hoggar Massif was uplifted.

The absence of Mesozoic cover in the central part of the Saharian basins is inferred from the lack of burial of the Paleozoic strata. Overmaturity is inherited from the Paleozoic. Oil window and gas generation in some cases had been reached in the early Paleozoic layers by the end of the Carboniferous. Since the beginning of Paleozoic sedimentation, the tectonic basement has had structural control on sedimentation in those areas.

The moderate heat flow around the old Targui Massif and Reguibat High, the presence of oil shows and even bitumen (south Hoggar) are well documented, and demonstrate that oil exploration could be successful if seals exist in the southern margin of the Saharian Platform.

SED2

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

Facies of the Glauconitic Sandstone in the Countess Field, southern Alberta

In the Countess Field, within the Mannville Group of strata, a series of shingled sandstone lenses with average dimensions of 8 km by 2 km by 20 m thick occur within a 50 to 55 m stratigraphic interval of interbedded sandstone and shale. This interval lies between a thin (<1 m) limestone marker below and a thin (1 to 2 m) coal seam marker above. The shingled lenses, which may coalesce to form either a linear or a tabular sandbody, are collectively referred to as the Glauconitic Sandstone, and exhibit the following six facies in the Countess Field:

Facies 1, gravelly, crossbedded, coarse grained sandstone interpreted as a tidal "strong current" facies. Facies 2, gravelly, parallel-bedded, coarse grained sandstone interpreted as a probable "storm" facies. Facies 3, medium grained, crossbedded, mud-draped sandstone with "bundle" sequences interpreted as a tidal "moderate current" facies. Facies 4, fine grained, flaser-bedded sandstone interpreted as a tidal "weak current" facies. Facies 5, wavy to lenticular-bedded, bioturbated, sandstone-shale alternations interpreted as "tidal flat" facies. Facies 6, wave-ripple-laminated or hummocky cross-stratified, fine grained sandstone interpreted as "storm" facies.

Palynological analysis of shale in Facies 5 yielded up to 11 species of open marine dinoflagellates. A tidal-delta-channel complex located within a wide-mouthed estuary that was migrating northwestward seems to be the most probable depositional model.

INTE

BEVER, J.M., Petro-Canada Inc., Calgary, Alberta T2P 3E3

Basin analysis and resource evaluation of Tertiary-aged sediments, north-central Tasmania

Three, small, Tertiary-aged onshore basins in north-central Tasmania (the Wesley Vale, Sassafras and Port Sorell) were analyzed with an emphasis on source rocks and reservoir quality. The basins are similar in age, structural history, and sedimentary/volcanic stratigraphy to the nearby, offshore Bass Basin. A geological model, using data from the study of the onshore basins, was constructed to assist in Bass Basin oil and gas exploration.

The onshore basins were initiated by Late Cretaceous rifting associated with the breakup of Gondwana. The resulting structural style is a horst and graben geometry with planar and rotational normal faults forming the basin margins and high-angle cross-basin faults.

Differential adjustment along fault planes during the Paleocene elevated some areas as subaerial, topographic highs. Erosion of these highs under tropical conditions resulted in large volumes of sediment accumulating in the adjacent lows in fluvial/lacustrine environments. Detrital grains in the resulting sandstones and mudrocks were derived from pre-tectonic palaeosols and contemporaneous soil profiles and consisted of well-ordered kaolinite clay. These sandstones lack any porosity or permeability; however, because of rapid deposition they are a potential Type II source rock.

Uplift on cross-basin faults during the Eocene produced restricted shallow water lakes, anoxic ponds and swamps. Within the restricted lakes there was an abundant accumulation of oil-prone organic matter that resulted in an oil shale deposit onshore and a potential oil source rock in the deeper subsurface.

Eocene fault reactivation also produced alluvial fans, slope deposits and eruptions of basaltic lava, which filled valleys and depressions. The fractured and jointed vesicular lava provides an aquifer for irrigation water onshore and a potential unconventional hydrocarbon reservoir in the Bass Basin.

SED2

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

Parasequence architecture of the Upper Cretaceous Chungo Member and Milk River Formation in southern Alberta

The Campanian Chungo Member of the Wapiabi Formation in the Foothills and the equivalent Milk River Formation in the southern Alberta subsurface prograde to the southeast. New correlation of previously described Chungo Member outcrops indicates that it comprises a set of offlapping parasequences terminated by a widespread ravinement surface marked by chert pebbles. The parasequences downlap to the northeast into a widespread log marker coinciding with the top of the First White Specks, which probably represents a condensed section.

The new correlations indicate that the "Chungo shoreface" interfingers southwestward with the Chungo nonmarine and passes southeastward into the mudstone of the Hanson and Thistle members, a relationship also indicated for the Milk River and its equivalents in the subsurface. The member boundaries are interfingering and diachronous, not sheet-like as previously interpreted.

Re-evaluation of the age of the Milk River Formation, based on palynological data, shows that it youngs to the northeast. These data support the new correlations. A widespread unconformity is also documented between the Milk River/Chungo and the overlying transgressive marine shale of the Nomad, which is probably coincident with the ravinement surface.

GEOC

BLOCH, J. and LECKIE, D.A., Geological Survey of Canada, Calgary, Alberta T2L 2A7; and SCHROEDER-ADAMS, C., Schroeder Paleoconsulting, Calgary, Alberta T3A 1S4

Shales of the Cretaceous Colorado Group in Western Canada – 2: environmental, mineralogical, and source-rock characterization of the Second White Speckled Shale

The Second White Speckled Shale (SWS; Cenomanian–Turonian) of the Colorado Group is a source and reservoir rock in the Western Canada Sedimentary Basin (WCSB). A sedimentological, paleontological, and geochemical study is underway to determine the depositional environments, mineralogy, and organic geochemical characteristics, and to identify hydrocarbon source and production potential of the SWS. The SWS is distinguished from adjacent shales by mineralogy and organic matter content. Calcite content (0.5 to >30%) is dominantly bioclastic in origin, and consists primarily of fecal pellets composed of nannofossil remains. In this deep water facies, the pelloidal sands were concentrated by current activity. Dolomite is commonly present. Most of the SWS comprises mixed-layer illite/smectite (15–50%), silt- to clay-sized quartz (15–45%), kaolinite (10–20%), and pyrite (3–7%), with minor K-feldspar and plagioclase. Rock-Eval analysis indicates a variable, dominantly Type II OM content (2–12%) with HI from 200–600 mgHC/gOC.

Micropaleontological data indicate an abundant but low-diversity assemblage of planktonic foraminifers within the SWS that suggests a shallow to open marine depositional environment. Marine algal cysts are also common, indicating high organic productivity. Preservation of abundant marine organic matter and the general absence of bioturbation indicate persistent anoxic depositional conditions under a stratified water column.

SWS hydrocarbon reserves produce from fractured, dominantly calcareous, current-reworked pelloidal sands in contrast to siliclastic reservoirs of the Fish Scale Marker Bed. Extrapolation of T_{max} values suggests that SWS organic matter enters the oil window (T_{max} = 435°C) at approximately 2500 m (present burial depth). Much of the SWS in the WCSB is therefore immature but may be a source of biogenic gas in eastern Alberta and Saskatchewan.

GEOC

BROOKS, P.W., MACQUEEN, R.W. and FOWLER, M.G., Geological Survey of Canada, Calgary, Alberta, T2L 2A7; and RIEDIGER, C.L., University of Waterloo, Waterloo, Ontario, N2L 3G1.

Source rock organic geochemistry and oil-source correlations, Western Canada Basin

The organic geochemical potential of six actual to potential source intervals from the Western Canada Basin (WCB) has been assessed by Rock-Eval pyrolysis and saturate and aromatic fraction biomarker geochemistry. Intervals studied include Second White Specks and Fish Scales (Upper Cretaceous), "Nordegg" (Jurassic), Doig (Triassic), Exshaw (Devonian/Mississippian), and Duvernay (Devonian). Second White Specks TOC values range from 2 to 12 per cent; Tmax and hydrogen index (HI)-based maturity ranges from immature to mature toward the west. Biomarker parameters including regular sterane distributions are distinctive: oils above the Viking Formation clearly correlate with this unit. "Nordegg" samples are distinguished by distributions of steroidal alkanes, Tx/Tm ratios and rearranged to regular sterane ratios, as are two Peace River Arch (PRA) area oils recognized to date from this unit. Doig samples from PRA area are mature to overmature and have TOC values from 2 to 11 per cent: most extracts and associated oils have abundant tricyclic terpanes relative to pentacyclic terpanes, and high Ts/Tm ratios. Duvernay TOC's from basin-centred samples range from 4 to 13 per cent; samples are moderately mature based on Tmax and HI values. Unique patterns of triaromatic steranes and the virtual absence of C_{30} desmethyl steranes allow Duvernay samples and derived oils to be distinguished from other WCB oils. Exshaw samples from PRA and more central parts of the basin resemble Duvernay samples in TOC, maturity level and biomarker distributions. None of these actual and potential source rocks have the specific geochemical characteristics of the enormous accumulations of Paleozoic and Mesozoic tar sands and heavy oils.

ECON

BURNS, J.C. and LEWIS, I.D., Bow Valley Industries Ltd., Calgary, Alberta T2P 3R2; and SICK, G.A., University of Calgary, Calgary, Alberta T2N 2N4

Valuing capital investments in petroleum exploration using binomial option pricing methods

The application of option pricing theory to the evaluation of capital investment decisions is rapidly gaining acceptance in the academic literature, and is being applied by some progressive organizations. The technique involves modelling the problem as a call option with the development cost being equivalent to the exercise price of a standard option such as that on a share of stock. The underlying asset is the reserve of oil being evaluated and its value is a function of oil prices. The volatility of oil prices and the convenience yield can be measured from oil futures price data and applied in the option context.

By using the binomial method, the problem is modelled as a large decision tree that determines the optimal decision, whether to develop or not, at each node of the binomial array. In addition, the minimum oil price at which development should occur at any point in time over the life of the option, or lease, can be determined. Binomial option pricing is a recursive certainty equivalent approach that allows the use of the risk-free rate of return, avoiding the need to arbitrarily specify a risk-adjusted discount rate. In the context of oil exploration, the method captures the value accruing to the owner of oil reserves during periods of rapid oil price increase.

This method is far superior to discounted cash flow methods when attempting to value projects with long lead times and high sensitivity to oil price fluctuations, such as exploration projects.

GEOC

BUSTIN, R.M., University of British Columbia, Vancouver, British Columbia V6T 2B4

Organic maturation in the Western Canada Sedimentary Basin

Organic maturation of strata in the Western Canada Sedimentary Basin has been investigated in numerous studies using petrological, chemical and physical methods. Compilation of existing data has facilitated a regional analysis of the maturation patterns and maturation history. Variation in maturation patterns occurs on three levels: basin wide (1st order), regional (2nd order) and local (3rd order). First order variations are manifest by an overall increase in maturity of strata of the same age from east to west, from the Plains to the Rocky Mountain Foothills and Front Ranges, in response to progressively deeper burial and higher paleo-geothermal gradients. Superimposed on this first order (basinal scale) variation in maturity are second and third order variations, which are interpreted as reflecting local differences in depth of burial, conductive and advective heat transport or affects of thrust faulting. The main component of maturation for most Phanerozoic strata occurred during deep burial by Late Cretaceous and/or Paleogene molasse in foredeeps developed in response to crustal loading associated with the easterly migration of the foreland fold and thrust belt. As a result of the west-to-east propagation of deformation during the Laramide Orogeny, deep burial, maturation, hydrocarbon generation and uplift occurred earlier in the foreland belt (Late Cretaceous) than in the Plains to the east, where the main component of maturation and hydrocarbon generation occurred as late as Eocene. A thick succession of strata currently are within the oil window in the Plains because of the low maturation gradients. In the deformed belt however, because of the higher maturation gradients, the thickness of strata within the oil window is corresponding less. In response to higher paleo-geothermal gradients, strata in the deformed belt matured more quickly, leading to more rapid hydrocarbon generation and migration than in areas to the east.

POST

CAPLAN, M.L. and MOSLOW, T.F., University of Alberta, Edmonton, Alberta T6G 2E3

Reservoir quality and characterization of the Halfway Formation, Peejay Field, northeastern British Columbia

The Middle Triassic (Ladinian) Halfway Formation of the Peejay Field, located in northeastern British Columbia, is an oil and gas play. It has been interpreted as a prograding barrier island shoreline sequence. A subsurface study involving the description of 120 cores and interpretation of 320 geophysical well logs has enabled the interpretation of reservoir facies, distribution, geometry, and quality. The construction of facies cross-sections and maps, extensive use of petrophysical information, and thin section samples has aided the location and interpretation of lateral and vertical heterogeneities in reservoir quality.

The tidal-inlet coquina sediments are of good reservoir quality, and their distribution and orientation form two laterally adjacent fairways striking northwest–southwest. Surrounding these sediments are crossbedded, porous, shoreface sands.

It has been observed that 82 per cent of the cores studied contain either bioclastic or coquina sediments. The average coquina and bioclastic sandstone thicknesses are 5.76 ft. and 3.42 ft., respectively, thus the pools are very thin. Only 38 per cent of these cores contain a stacked sequence of inlet-fill sediments. Present observations have shown that the reservoir quality of shoreface sands may be as good as that of the inlet-fill sediments. Reservoir lateral continuity may be better in the former, although diagenetic effects must also be considered and mapped.

Secondary diagenetic processes create biomouldic and interparticulate porosity by the leaching of the molluscan coquina inlet sediment, or may reduce reservoir quality by the precipitation of cements that plug up pore throats, reduce pore throat diameter, and increase the tortuosity.

INOV

CARROLL, S., Gico Ltd., Calgary, Alberta T2P 0J1

Three-dimensional seismic: a geological exploration tool for the 1990's

After a somewhat difficult start-up period, the use of the 3-D seismic method is now accepted as an important technique in the reservoir delineation of established oil and gas pools in the Western Canada Sedimentary Basin (WCSB).

The correct visualization of the depositional and structurally distinct entity that we call a "pool", is the key to efficiently exploring for and exploiting the resources within it. Until recently, we have had to "jerry-rig" this picture. Most geologists would greatly appreciate a methodology that would allow them to see that reservoir geology directly. Within certain constraints, 3-D seismic makes it possible to do just that. However, delineation of a producing reservoir is not the only advantage to the use of 3-D seismic. As an example, from an exploration point of view, it should be remembered that WCSB stratigraphic traps are initially only sideswiped by the 2-D seismic acquired in the normal course of events. It would be useful to transform that initial "glimpse" into a "vicinity" indicator, which could be used to explore for a specific play type. 3-D seismic makes it possible to test such geological concepts before drilling.

Several currently available 3-D seismic programs will be examined from this vantage point. Two such areas, Tableland and High Prairie, have very different depositional environments and provide a unique look at the geological use of 3-D seismic. In the course of examining these areas, this paper reviews the current use of the method and proposes that it can also be a cost-effective tool for grass-roots exploration.

EXPS

CEDERWALL, D.A., Poco Petroleums Ltd., Calgary, Alberta T2P 3H7

An overview of Lower Mannville hydrocarbon traps, Provost area, east-central Alberta

Within the Provost area of east-central Alberta, a major east–west trending sub-Cretaceous paleovalley occurs. This valley and its clastic lower Mannville fill form the eastern limb of the Edmonton Channel complex.

Erosion during pre-Cretaceous and lower Mannville time formed this valley, which is bounded to the north and south by Devonian and Mississippian carbonates and minor clastics. During lower Mannville time, clastics prograded from east to west in a dominantly fluvial environment. These clastics are preserved as the Ellerslie Formation and its equivalent, the Dina Member. This axis of fluvial deposition persisted into middle Mannville time and, in some areas, channel facies sandstone occur juxtaposed to the dominantly marine strata of the middle Mannville.

Hydrocarbon entrapment within the fluvial sediments of the Ellerslie Formation and Dina Member is largely stratigraphic in nature yet diverse in character, resulting in more than 50 known pools. These stratigraphic traps may be classified in four broad categories as:

1. traps due to sand/carbonate differential compaction
2. traps due to sand/shale differential compaction
3. late stage channelling and refill with sandstone
4. late stage channelling and refill with nonreservoir strata

A comparison of the geometry of these trap types is enhanced by the use of seismic data.

POST

CENTURY, J.R., Independent Geologist, Calgary, Alberta T2R 1L5

Cretaceous oil and gas pools: a full cycle case history

The nature of stacked producing pools in Alberta oil and gas fields presents numerous opportunities and challenges. It is important that geologists learn from examples covering these issues, before the fact. The following are the sequential phases in a Bonnie Glen Cretaceous full cycle case history: 1) prospect generation and acreage acquisition; 2) initial Belly River test; 3) Glauconite and Basal Quartz discoveries; 4) seismic program and development drilling; 5) production and facilities; 6) gross overriding royalty and farmout agreement issues; 7) dispute and settlement; 8) coalbed methane potential; and 9) lessons and conclusions.

There are still many thousands of profitable prospects to be drilled in the Western Canada Sedimentary Basin. Industry restructuring, oil price volatility, and pessimistic undiscovered resource assessments have caused massive professional and business inefficiencies. This has opened a competitive "window of opportunity" for discovery and development of the 15 billion barrels of conventional recoverable oil and 100 TCF of marketable natural gas yet to be proven. However, some of these potential fossil fuel supplies may not be produced due to the necessary transition to alternate, more benign energy sources and a cleaner environment over the next several decades.

POST

COFLIN, K.C., Geological Survey of Canada, Calgary, Alberta T2L 2A7

Proterozoic compressional deformation of the Anderson Plains

Reinterpretation of reflection seismic profiles shows a well defined Proterozoic compressional orogeny in the Anderson Plains of the Northwest Territories. Industry reflection seismic data reveal that beneath a thin (1–3 km) and relatively undeformed Phanerozoic section there are large, southeast-directed thrust faults. These faults have strike lengths at least as large as 60 to 70 km and individual displacements of approximately 5 to 10 km. The total shortening is estimated to be at least 20 per cent over 150 km. A northwest-dipping detachment to these faults is inferred to exist at 12 to 15 km, at or near the base of the seismic profiles. The age of the deformation is seen to be syn- and post- the deposition of the Dismal Lakes Group. It is also found that some Proterozoic-aged faults appear to have been reactivated during Phanerozoic deformation periods. The stratigraphy of the Proterozoic rocks is not well defined but with correlations from well data to the south and seismic character correlation ties from the Campbell Uplift, it is interpreted that the sub-Paleozoic unconformity overlies the Mackenzie Mountains supergroup in the western part of the study area and the Dismal Lakes Group in much of the eastern part. The Dismal Lakes unconformably overlies the Hornby Bay Group, the base of which may or may not be identified near the maximum record length of the seismic profiles.

STRU

COOK, D.G., MACLEAN, B.C. and COFLIN, K.C., Geological Survey of Canada, Calgary, Alberta T2L 2A7

Proterozoic and Laramide tectonics in the Colville Hills and Anderson Plains region, Northwest Territories

Regional seismic data in the Colville Hills and Anderson Plains record up to 15 km of strata comprising five seismic-stratigraphic packages considered equivalents of 1) seismic basement; 2) Hornby Bay Group; 3) Dismal Lakes Group and Coppermine basalts; 4) Rae Group and Mackenzie Mountains supergroup; and 5) Phanerozoic strata. Equivalents of Rae Group and Mackenzie Mountains supergroup underlie parts of Anderson Plains but are virtually missing from the Colville Hills area. Under Colville Hills, basement and Hornby Bay (1663 Ma) were compressively deformed into large, north-trending basement block uplifts with structural relief of up to 6 km. These uplifts were peneplained, resulting in a major unconformity at the base of the Dismal Lakes Group (pre-1267 Ma) and could represent intra-continental adjustments related to the Racklan Orogeny (pre-1268 Ma) in the northern Cordillera. Northward in Anderson Plains, younger, southeast-verging thrusts postdate the Dismal Lakes Group and predate the Rae Group, and may be related to pre-Rae Group deformation on Coppermine Homocline. Long-wavelength folding (70–90 km) affected Coppermine basalt and older strata in the Colville Hills area. Large Proterozoic extension faults, younger than Coppermine basalt, occur in the Colville Hills area, and are possibly related to the 778 Ma Hayhook rifting event documented in the northern Cordillera. Laramide, Colville Hills anticlinal ridges have been localized, at least partly, by reactivation along weaknesses inherent in both the north-trending and northeast-trending sets of older structures.

INTE

COSGROVE, J., Esso Resources, Calgary, Alberta T2P 3M9

Petroleum exploration in Queensland, Australia

The Permo–Triassic Cooper and Jura–Cretaceous Eromanga basins, together with the Surat/Bowen basins of similar age, form two of the most prolific hydrocarbon-bearing successor basins in Queensland, Australia. Recent renewed exploration in these basins has been highly successful, following the discovery of the Jackson oilfield in 1982, and subsequent widespread application of high resolution regional seismic coverage to identify structural and subtle traps.

Natural gas has been discovered in 29 fields in the Central Eromanga and Cooper basins of southwestern Queensland with total reserves in excess of 1.5 TCF. Fluvial sandstones of the Lower Permian Patchawarra and Upper Permian Toolachee formations contain most of the reserves. Considerable gas-liquid reserves are also found in these reservoirs.

Existing reserves are located primarily in extensional structural traps. Additional gas potential is identified in flank areas of the more prominent structural axes in fault-bounded, pinchout and subunconformity trapping configurations. Numerous untested prospects and leads are identified with the potential to contain approximately 1.5 TCF of gas.

In contrast, the more thoroughly explored Surat/Bowen basins do not contain large untested structural traps. However, detailed grids of high resolution seismic have refined the settings of various plays and lead to the identification of subtle combination traps in this important hydrocarbon province. Despite over 650 exploration wells drilled in the region, it is still relatively unexplored. There is a 50 per cent probability that 80 BCF will be found and a 20 per cent probability that 290 BCF will be discovered in the portion of the basin making up the Roma Shelf.

Future exploration and development will be constrained by the relatively small domestic gas markets. Historically this has been the case for these gas-prone terrigenously filled basins, despite low exploration risk.

POST

COX, J., Department of Geology and Petroleum Sciences, Mount Royal College, Calgary, Alberta T3E 6K6; and WILLIAMS, B.P.J., Department of Geology and Petroleum Geology, University of Aberdeen, Aberdeen, Scotland

Gas prone, incised valley-fill sediments within the Upper Albian Bow Island Formation, southwest Alberta

Regionally, the Bow Island Formation of southwest Alberta consists of three lithostratigraphic units. Unit 1, the lowest unit, is approximately 100 m thick and consists of stacked, upward-coarsening clastic parasequences separated by marine flooding surfaces. Unit 2 is an easterly thinning wedge of nonmarine, coastal plain deposits, which conformably overlies Unit 1. Unit 3 is up to 20 m thick and consists of tidally influenced and marine shelf sediments.

The incised valley-fill sediments cut into Units 2 and 3 with a maximum identified thickness of 35 m. Diagnostic features of these sediments include:

1. a basal scour surface commonly overlain by a gravel lag
2. variably interbedded sands and muds
3. bioturbation restricted to a small variety of trace fossils
4. numerous erosional surfaces, commonly overlain by graded sands and gravels exhibiting high-angle crossbedding
5. scattered gravel in bioturbated, muddy sandstone units

These features are consistent with an estuarine model of deposition, where the incised valleys filled with sediment during transgression of the Lower Colorado seas.

Bow Island estuarine reservoir rocks are typically heterogeneous with highly variable porosities and permeabilities, but are capable of hosting large volumes of gas in the Blood Field, which holds in excess of 30 BCF recoverable reserves.

POST

CZARNECKI, M., DE SILVA, N., DOHEY, W. and MCINTYRE, J., Canada-Newfoundland Offshore Petroleum Board, St. John's, Newfoundland

Regional geophysical maps of the Central Ridge, Flemish Pass and Carson-Bonnition basins

A series of geophysical maps of regional markers over the Grand Banks region of the Newfoundland Offshore Area have been constructed by the staff of the Canada-Newfoundland Offshore Petroleum Board (C-NOPB).

Present maps are a continuation of C-NOPB regional mapping project. The first phase was presented during CSPG Convention last year in Calgary.

The regional maps have been produced using seismic sections, industry and C-NOPB mapping and well data.

The maps cover the area between 44° to 48° north latitude and 46° to 50° west longitude and include Flemish Pass, Carson-Bonnition and South Jeanne d'Arc basins (Fig. 1). Bathymetric, time structure, isopachous, isochronous, gravity and stratigraphic sequence maps are presented at a scale of 1:250 000.

Structural maps of Base Tertiary unconformity, Cenomanian unconformity and Tithonian unconformity have been produced. Isochronous maps have been constructed using the time structure maps. The stratigraphic sequence map illustrates the likely sequence of stratigraphic units that would be penetrated by drilling in different regions. Five interpreted seismic sections are also included. The sequence map and seismic sections assist in the representation of the 3-dimensional relationship of stratigraphic sequences of the area.

The package of geophysical maps, available from the C-NOPB office, provides a framework for both regional studies and prospect identification and should be useful in a wide range of studies.

ENV2

DAMS, R.V., Radarsat International Inc., Calgary, Alberta T2P 3P4

Environmental applications of remote sensing

Satellite images of the Earth have been routinely collected for close to two decades, providing world-wide environmental information to resource managers and planners. This imagery has been largely provided by the American Landsat satellites, the first of which was launched in 1972. In 1986, France entered the spotlight with its higher resolution, dual-sensor satellite called SPOT. Both satellites are continuously providing environmental information across Canada and around the world; information that is being used by forest and range managers, wildlife habitat biologists, agrologists, and environmental planners for operational mapping and monitoring programs.

This paper presents a number of the most significant current operational programs using this imagery within Canada and to a limited extent internationally. Forest management agencies and private companies routinely purchase and analyze large volumes of Landsat Thematic Mapper (TM) and SPOT Panchromatic (P) imagery for cutover updating, insect and disease monitoring, change detection and other forest management planning purposes. Range managers are using Landsat TM information for range utilization assessment, biomass measurements and grazing management planning. Current wildlife habitat mapping applications range from a North America-wide wetland inventory and monitoring program using Landsat TM, to woodland caribou habitat mapping along potential pipeline routes. Agrologists use both Landsat and SPOT images to repetitively monitor crop conditions and productivity throughout the growing season; the shortwave infrared wavelengths of the imagery are critical to the detection and determination of areal extent of crop drought and damage. Finally, government and industry's environmental planners are employing this timely data for a wide variety of applications ranging from landfill site detection and inventory, to flood monitoring, control and preparedness, to global climate change and tropical deforestation monitoring.

These operational applications are a clear demonstration that satellite-derived information has come of age to the environmental/renewable-resource manager. The research and development conducted in the 1970's and continuing into the 1980's has been fruitful. Current applications-oriented research and development using airborne imagery to simulate the satellite sensors of the 1990's, such as RADARSAT, will provide even more precise and timely environmental information in this decade.

CBME

DAWSON, F.M. and KALKREUTH, W.D., Geological Survey of Canada, Calgary, Alberta T2L 2A7; and BURCHARD, K., Institut für Geologie, Freie Universität Berlin, Berlin 33, Germany

Coalbed methane potential of the Lower Cretaceous Luscar Group in the vicinity of Nordegg, Alberta

Lower Cretaceous Luscar Group strata containing coal resources of low- to medium-volatile bituminous rank represent a prime exploration target for coalbed methane in the Alberta Foothills. The Nordegg region is presently the focus of a coalbed methane resource assessment study being conducted by the Geological Survey of Canada. Structural mapping, coal seam sampling and geological modelling of subsurface data have been undertaken to produce a geological framework upon which coalbed methane resource estimates can be made.

The Gates Formation of the Luscar Group contains up to six coal seams in the Nordegg area with up to 11 m of cumulative coal thickness. Tectonic thickening occurs in local areas, such as the Nordegg minesite, where coal seams, (3-4 m), have been thickened to greater than 10 m. Detailed reflectance studies indicate that the rank of the coals at and near the surface ranges from high-volatile A bituminous to low-volatile bituminous. Low-volatile bituminous coals occur at surface in the Brazeau Thrust sheet near Nordegg. From there a significant decrease of rank is indicated along strike both to the south in the Ram River, Fall Creek areas and to the north in the Blackstone River area. Rank decreases also toward the west in the Bighorn Thrust sheet, where Luscar Group coals of mainly medium-volatile rank occur.

Outcrop localities and subsurface data have been utilized to prepare detailed maps illustrating coal rank variability. Surface and subsurface mapping were completed to assess the in situ coal resource potential. Geological structures and depth from surface parameters were applied, and several coalbed methane targets have been defined. Rank and thickness data obtained from exploration wells along a W-E transect through the Nordegg area appear to be consistent with the outcrop data and suggest that coals of the Luscar Group may have high coalbed methane potential at depths less than 1500 m west of the Brazeau Thrust.

INOV

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Exploration applications of remote sensing

Remote sensing is one of the most misunderstood and underused tools of the exploration toolbox. Explorationists either hate and ignore it, or love and preach it. For many explorationists, remote sensing is not a regular contributor to the everyday exploration and production business even though it has so much to offer; for innovative explorationists not even the sky is the limit anymore.

Images of the earth taken from airplanes and satellites have provided the oil industry's professionals with useful information for several decades. Remotely sensed data come in a variety of forms that can be custom processed and interpreted, then incorporated into exploration and development programs.

Satellite imagery has evolved into a very useful tool for geologists and geophysicists, surveyors and environmental planners. Since Landsat's launch in 1972, the sensors have undergone extensive improvements in terms of both spectral and spatial resolution. With the advent of the French SPOT satellite in 1986, a new range of operational applications has emerged. The high resolution (10 m) panchromatic SPOT data are currently used by the oil industry for geological evaluation, updating of seismic lines, planning of exploration programs, pipeline route selection, disaster contingency planning and wildlife habitat mapping, to name a few applications. However, SPOT has by no means replaced the old workhorse of remote sensing – the Landsat system.

Case histories from Canada, Pakistan, Papua New Guinea and Yemen illustrate the various applications of remote sensing in the oil and gas exploration business.

SED2

DEUTSCH, K.B. and KRAUSE, F.F., University of Calgary, Calgary, Alberta T2N 1N4

A comparison between sand- and mud-dominated shelf to shoreline sequences deposited into the Cretaceous Western Interior Seaway: examples from the Cardium Formation, Kakwa Region, west-central Alberta

The Cardium Formation in the Kakwa region of west-central Alberta is subdivided into three members. The basal, sandstone-dominated Ram Member is a relatively uniform lithosome with northwest- to southeast-trending thin and thick zones. The middle Moosehound Member is an eastwardly thinning terrestrial mudstone and sandstone lithosome that merges with the marine, mudstone dominated, eastwardly thickening lithosome of the Cardium zone Member.

The Ram Member grades from bioturbated sandy mudstones at its base upward through a sequence of rhythmites and gutter casts, low-angle inclined, trough- and planar tabular- cross-stratified sandstones, which are capped by an extensively bioturbated swash crossbedded and massive sandstone with a rooted and pedogenically altered upper surface. The Moosehound Member consists of extensive deposits of carbonaceous and pelecypod-rich mudstone, interlaminated, commonly, pedogenically altered, sandstone and mudstone, and wave and current bedded sandstone. The facies architecture of these two members is typical of a prograding, mesotidal barrier and backbarrier assemblage with modification by wave, storm and riverine processes.

The capping Cardium zone Member is characterized by extensive sandy mudstone deposits that are typically well bioturbated, and contain trace fossils belonging to ichnofacies ranging from *Nereites* through *Skolithos*. These dominantly mudstone deposits define a series of parasequences that geographically form either regional, sheet-like or local, elongate ridge-like features. The Cardium zone displays a facies architecture indicative of shallow-shelf to shoreface sedimentation along a relatively sand-starved, mud-dominated coastline.

POST

DIETRICH, J.R. and LANE, L.S., Geological Survey of Canada, Calgary, Alberta T2L 2A7

Tertiary structural evolution of the Beaufort-Mackenzie Basin

Beaufort-Mackenzie Basin sediments of Late Jurassic to Tertiary age were shortened in an arcuate trend during Tertiary Brookian orogenesis. A major pulse of Early Eocene folding and thrust faulting affected much of the central and western Beaufort-Mackenzie Basin. Concurrent longitudinal normal faulting occurred on land, in the western Beaufort and near the southeast basin margin (Taglu fault zone). A second major orogenic pulse of Miocene age caused deformation concentrated in the distal part of the deformed belt, in Demarcation subbasin-Herschel high, and between the Taglu and Tarsiut-Amauligak fault zones. A large area of southwestern Beaufort-Mackenzie Basin was largely undeformed by this pulse but was transported basinward on a decollement zone(s). Seismic images of many offshore structures show obvious asymmetry; other structures are clearly detached. Onshore, important decollement horizons occur at several stratigraphic levels. Concurrent extension occurred principally in the Tarsiut-Amauligak fault zone.

In general, the deformation shows a foreland-younging trend, away from the craton. Temporal and spatial variations in tectonic shortening require secondary accommodation by right-lateral transcurrent faulting, concentrated along the southeast basin margin and in a zone trending northeastward from near Kay Point through the Tarsiut area. Although minor at the basin scale, transcurrent faulting may be locally very significant at the scale of individual prospects.

RESM

DIMITRAKOPOULOS, R., Geostat Systems International Inc., Montreal, Quebec H2J 2X1; and CLARK, J., Westcoast Petroleum Ltd., Calgary, Alberta T2P 0T8

Transforming geological descriptions of reservoir heterogeneity to numerical reservoir grid block models: the Crystal Viking Field example

During the last few years, retrenchment of the oil industry from costly exploration programs has redirected activities toward the enhanced exploitation of known reservoirs. As a result, research and developments have focused on advanced and detailed reservoir description. A significant aspect of reservoir description is the transformation of qualitative geological characterization to the appropriate, numerical, reservoir grid block models, critically controlling reservoir performance forecasting.

This paper presents a two-step methodology for transforming detailed geological description of reservoir heterogeneity to engineering-useable models, incorporating all available information and interpretations. The first step consists of the simulation of the reservoir lithofacies, conditional to all available information and data. This simulation is performed using a novel technique, generating alternative images of reservoir heterogeneity at any desirable scale. The second step consists of the modelling of reservoir rock properties combining the simulated images of the reservoir lithofacies with geostatistical techniques, quantifying geological characteristics, such as continuity, trends, and anisotropies. Of particular importance is the determination of effective block permeability, which is performed using a new technique. Accordingly, block horizontal and vertical permeabilities are considered as spatial power averages of point support permeability values, which are generated within each block using the geological-statistical characteristics of the reservoir and available core data.

The two-step methodology and corresponding techniques described above are demonstrated in an application at the Crystal Viking Field, south-central Alberta. Crystal is a substantial and fully characterized reservoir, producing since the early eighties.

EXPS

DIXON, R.J., STOAKES, F.A. and CAMPBELL, C.V., Stoakes Campbell Geoconsulting Ltd., Calgary, Alberta T2P 3C8

Exploration for Nisku Formation isolate reefs of the Wood River area: a stratigraphic play-type in a structural world

Within recent years, significant new oil discoveries have been made in the Nisku Formation of the Bashaw area, central Alberta. Historically, structural drape has constituted the major play type in this area. Recent drilling activity has revealed the presence of purely stratigraphic traps in Nisku age pinnacle reefs of the Wood River area (Twp. 42, Rge. 23 W4M). Trapping of hydrocarbons occurs in isolated, dolomitized, thamnoporid coral dominated reef buildups of the normal marine lower Nisku phase. These buildups are encased in tight mudstone and evaporite of the later hypersaline upper Nisku phase.

Nisku pinnacle reef development in this area is primarily controlled by Leduc paleotopography, the pattern of Ireton Shale infill, and Camrose paleotopography.

Through construction of a residual isopach map of the Leduc Formation using all available deep penetrations, it can be demonstrated that Nisku age Wood River pinnacles develop on local topographic highs in an otherwise deeper water area of the Leduc surface.

Two distinct episodes of Ireton Shale infill affect the Wood River area: pre-Camrose and post-Camrose Ireton Shale infill. The incomplete nature of pre-Camrose Ireton Shale infill in the Wood River area, combined with pre-existing Leduc topography, directly controlled the distribution of Camrose shelf and basinal areas. Within the basinal or slightly deeper water areas, low-relief, isolated, Camrose age crinoidal grainstone shoals developed.

Post-Camrose Ireton Shale deposition appears to have largely bypassed an elongate area that extends from the Wood River area southeast to the Nevis area. Within this deeper water "moat" area, the Camrose age crinoidal shoals appear to act as precursors for later Nisku pinnacle reef development.

Using detailed mapping of the Leduc paleogeography, combined with an understanding of the pattern of Ireton Shale infill, a high-graded fairway for development of Camrose age shoal deposits can be identified. Within these shoal areas, further potential exists for the development of the prolific Wood River type Nisku age pinnacle reefs.

SED2

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Sedimentology and subsurface stratigraphy of the Bad Heart Formation of northwestern Alberta

The Bad Heart Formation of northwestern Alberta is a coarsening-upward package of marine siltstone and sandstone of the Upper Cretaceous Smoky Group. It rests erosionally on the Muskiki and Marshybank formations, the contact being marked by a sideritized pebble bed. It is disconformably overlain by the Dowling Member of the Puskwaskau Formation.

The Bad Heart is present in outcrop in two regions: to the south, it outcrops along the Smoky River, where thirteen sections have been measured. Here the Bad Heart is characterized by numerous, closely-spaced, erosional

surfaces and local facies changes, making correlation difficult. To the north of the Peace River, the Bad Heart outcrops in the Clear Hills. More than a thousand well logs have been used to determine the subsurface stratigraphy of the Bad Heart.

Along the Smoky River, the Bad Heart is capped by a persistent oolitic ironstone layer a few metres thick; in the Clear Hills however, this ironstone is much more extensive, forming low-grade deposits of several million tons, which have attracted interest in the past as an economically viable source of iron ore.

Subsurface work has revealed a marked lithological variation within the Bad Heart. To the west, the sandy oolitic sediments of the Clear Hills and Smoky River areas pass laterally into a siltstone facies. This may be the result of an underlying structural control on sedimentation during Bad Heart time.

DIAG

DRAVIS, J.J., Dravis Interests, Inc., Houston, Texas 77005; and MUIR, I.D., Esso Resources Canada Ltd., Calgary, Alberta T2P 0H6

Pervasive burial dissolution of early and late dolomites in Devonian pools, Alberta, Western Canada

Middle Devonian Keg River and Muskeg pools along the northern margin of Rainbow Basin in northern Alberta produce mainly from secondary porosity created by dissolution of replacement dolomites and cements, including saddle dolomites. Resultant pores are predominantly vug and moldic, and commonly microporous. Coarse, vuggy porosity is also developed in Zebra Dolomites.

Several relationships confirm the burial dissolution of dolomites in these sequences. First, dolomite crystals leached are those that replaced stylolitized sediment, including saddle dolomites, as shown by fluorescence microscopy. Second, high amounts of secondary porosity are commonly preserved in highly stylolitic dolomites, commonly directly adjacent to pressure solution seams. Third, pressure solution seams terminate directly into secondary porosity. And fourth, fractures, both open and healed, commonly terminate directly into secondary pores.

These petrographic relationships are consistent only if dolomite dissolution and secondary porosity development were contemporaneous with, or postdated, pressure solution. The spatial juxtaposition of fractures and stylolites with secondary porosity implies these diagenetic fabrics served as pathways for burial fluids promoting dolomite dissolution.

Given the regional extent of pervasive dolomite dissolution, dolomite stability in these sequences is not a function of the type or relative age of dolomite crystals precipitated. Rather, pore-fluid chemistry appears to be the major control. Calcium-rich burial fluids, responsible for emplacement of burial anhydrites and fluorite cements, are thought to promote the deep-burial dolomite dissolution and secondary porosity development in these pools.

CANF

ENACHESCU, M.E., MEEHAN, P.J. and SMEE, G.W., Husky Oil Operations Ltd., Calgary, Alberta T2P 3G7

Amauligak and beyond: the quest for a Canadian Beaufort Sea economic threshold

The Amauligak field, discovered by Gulf Canada and its partners in 1984, contains an estimated one billion barrels of oil-in-place and about 2 TCF of gas. To date, this field remains the only major oil discovery of the Beaufort-MacKenzie Basin. Plans for field production and construction of a MacKenzie Valley pipeline are hindered by the area's lack of sufficient reserves. New, encouraging regional exploration concepts can be developed, based on the interpretation of recently acquired seismic data and reassessment of drilling results. The Amauligak field is located in the Kugmallit Trough, an extensional sector of the Beaufort Sea, which underwent rifting up to Miocene time. Several observations, regarding the prospectivity of the eastern margin and northern plunge of the Kugmallit Trough can be made: a) a thick Oligocene sandstone interval should exist north of Amauligak, where the section is faulted down and not breached by the intra-Miocene Unconformity as previously assumed; b) abundant source rocks and large structural-stratigraphic traps of low complexity are present at depths from 3.5 to 4.5 km; c) direct hydrocarbon indicators are associated with some of these features; d) an eastern source of sediment along with the traditional southern one is possible; and e) high sand/shale ratios and porosity preservation at depth can be expected for the Kugmallit sequence. Other prospective features are compressional growth structure in the western Beaufort and faulted blocks in the shallow water (seismic transition zone).

SED1

FEJER, P.E., Shell Canada Limited, Calgary, Alberta T2P 3S6; and NARBONNE, G.M., Queen's University, Kingston, Ontario K7L 3N6

Cycle definition and controls, Nisku-equivalent strata, southeast British Columbia

Upper Frasnian, Nisku-equivalent strata in the southern Canadian Rocky Mountains consist of open shelf (Grotto Member) and peritidal (Arcs Member) carbonates that prograded basinward during an overall regressive phase of deposition. Both the 100 m thick Grotto and 12 m thick Arcs members consist of stacked, metre-scale, shallowing-upward cycles. Cycles in the Grotto Member are entirely subtidal and laterally continuous over the study area. Each cycle exhibits a gradual upward increase in the abundance, diversity and size of fossils, and a transition from a crinoid-brachiopod assemblage to a coral-stromatoporoid assemblage. Tops of the twenty cycles present are characterized by a sharp contact or by a subaqueous hardground. Seven peritidal cycles comprising the Arcs Member typically consist of a restricted mudstone that passes upward into a biolaminite which is, in turn, capped by a karstic erosion surface.

In the past, subtidal shallowing-upward cycles have generally been interpreted as reflecting eustacy (allocyclic) whereas peritidal cycles have been interpreted as the result of tidal flat progradation (autocyclic). Similarity in style and scale of the Grotto and Arcs cycles and regional facies-equivalency of these two members implies a single dominant controlling mechanism for the cyclicity. A glacio-eustatic cyclic control is most consistent with the nature of Grotto/Arcs cycles.

Correlation using these cycles provides a precise tool for paleoenvironmental and stratigraphic analysis within the Grotto-Arcs and equivalent strata of Western Canada.

POST

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Glacial sediments: implications for environmental geology

Within the Canadian Plains, glacial diamicton (till) and glacially deformed sediment (bedrock and drift) are of fundamental importance to environmental geology, as both are widespread and the least understood of the Quaternary units. Progress during the late 1970's and 1980's enhanced understanding of these sediments. However, maximizing foreknowledge about the structure, stratigraphy, orientation, dimension, and hydrology of these deposits is one of the opportunities for the nineties.

Till may be massive or layered, may contain abundant sand lenses, may be cut by horizontal and vertical fracture sets, and may function as a good aquifer. Glaciotectonic sediment is characterized by large-scale folding and/or faulting, small-scale crushing with or without compaction, a basal shear zone, upglacier-dipping shear planes, and subvertical shear surfaces below the basal zone.

Ramifications of the above include: 1) increased stratigraphic variability; 2) increased potential for slope failure; 3) alteration of permeability and aquifer disruption; and 4) increased variability in pedogenic and geotechnical soil types. This has implications for, among other things, slope stability, landfills, sumps, roads, pipelines, airstrips, settlements, land reclamation, soil degradation, casing depth, picking top of bedrock, groundwater recovery or contamination, and waste containment or disposal.

These sediment types and variations in their internal properties can now be detected by airphoto interpretation, pitwall and/or outcrop mapping, coring, downhole geophysical logging, and surface geophysics. One of the future challenges will be to obtain more quantitative information on the distribution and characteristics of these sediments.

EXPS

FORBES, D.M. and DIXON, R.J., Stoakes Campbell Geoconsulting Ltd., Calgary, Alberta T2P 3C8; and HASSLER, G.T., Total Petroleum Canada Ltd., Calgary, Alberta T2P 0M9

Stratigraphy and exploration potential of the Charlie Lake Formation, west-central Alberta

The Triassic Charlie Lake Formation of west-central Alberta represents a geologically complicated and underexploited sequence. Stratigraphic complexities within the formation necessitate detailed lithostratigraphic analysis for successful exploration. The complexities observed are a result of three

intra-Charlie Lake unconformity surfaces, identified as the Coplin, Boundary, and Worsley and by post-Triassic erosion at the base of the Jurassic Nordegg Formation. These unconformity surfaces bound four depositional sequences, the Lower Charlie Lake, Boundary, Upper Charlie Lake, and Worsley intervals. Erosional removal of each interval occurs as the unconformity surfaces converge toward an eastern Charlie Lake subcrop.

Recently, several significant oil pools within the Charlie Lake have been found in a fairway paralleling its subcrop edge (Manir, Kakut, Rycroft, Cecil). Production from reservoir quality dolomite and dolomitic sandstone along the subcrop edge is found within each of the four depositional sequences. The development of reservoir facies is controlled mainly by original depositional facies, whereas the present distribution of reservoir facies is primarily unconformity related. Three unconformity related play types are recognized: the regional updip subcrop edge of porous units, erosional remnants or outliers, and erosional inliers. Successful exploration for these play types requires continued detailed analysis of the depositional, erosional, and structural history of the Charlie Lake Formation.

DEV1

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Refining a simple geological model to explain anomalous reservoir behaviour: Muskeg C pool, Rainbow Field, Alberta

Historically, the Muskeg Formation has been a secondary target in the prolific Rainbow Field, where most of the oil is found in the Middle Devonian Keg River carbonate buildups. With the increasing production maturity of the Keg River pools, the Muskeg Formation has emerged as an attractive target for enhanced recovery. Reservoir description, which preceded waterflood design in the Muskeg C pool, has revealed a more complex reservoir than expected.

The Muskeg C pool appears to be characterized by simple geology. It consists of interbedded carbonates and evaporites deposited in a peritidal setting. The trap is formed by drape over an underlying Keg River buildup. Each bed can be correlated across the C pool, and as a result of a large thickness and porosity development, is related to structural elevation. Correlation between porosity and permeability is good.

Twenty years of production data, however, suggest a more complex reservoir. Reservoir pressure behaviour, water cut and water saturation are incompatible with a simple geological model. Geological, geophysical and engineering evidence suggests the presence of solution collapse breccia zones, which provide vertical communication between the Muskeg Formation and the underlying Keg River buildup. These zones explain not only the reservoir behaviour of the C pool, but also the distribution of oil in the Muskeg Formation overlying the neighbouring Keg River buildups.

DIAG

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Dissolution of silica in nature and its implications

Quartz is the most stable natural form of silica, normally resisting weathering. However, Precambrian quartz arenites of the Roraima Group in Venezuela clearly show evidence of abundant quartz dissolution in a highly organic-rich, acidic to neutral meteoric environment. The Roraima sediments occur in flat-topped mesas (200 m high) in a tropical environment of heavy rainfall. The degree of weathering varies from highly indurated, unweathered quartz arenites, away from and deeper than the outcrop surfaces, to highly degraded, crumbly, extremely porous sandstones on the outcrops. Petrographically, the tight arenites show abundant grain welding as a result of pervasive syntaxial quartz cement and sutured grain contacts. In the weathered samples, by contrast, an excellent network of lamellar porosity has formed through the dissolution of quartz cement. The silica dissolution has mainly followed along the compromise boundaries of adjacent overgrowths. The extensive dissolution and mobility of silica may be related to organic acids produced during the biodegradation of terrestrial organic matter. These organic acids or compounds can react with dissolved silica, lowering the activity of silicic acid and accelerating the dissolution of quartz and other aluminosilicates.

DEV2

GHOSH, S.K., Petroscan International Petrology Consultants, Calgary, Alberta T2E 6V2; and CROCE, J.D., Intevep S.A., Caracas, Venezuela

Retrogradational sand sheets, Misoa Formation, Venezuela

Numerous, shallow marine, stacked, coarsening upward bar sequences characterize the Eocene Misoa Formation ("B" sands), on the east coast of Lake Maracaibo. The sandy part of the bars varies from 5 to 15 m in thickness. Four sandstone subfacies and a heterolithic bioturbated unit constitute the bars. The typical coarsening-upward sequence implies upward shoaling with an increase in current and wave energies. As bars grow upward, grain size and sorting increase, along with current velocity. The nature of lithological stacking, *i.e.*, sandy intervals between marine shaly horizons, suggests that bar development is related to transgressive–regressive cycles. Cyclic repetition of smaller, sandy, regressive sequences may be related to periodic stillstands in an otherwise rising sea level. Sand distribution in space and time clearly indicates an eastward deepening of the basin. The coarsening-upward sand sheets show a progressive younging westward toward Lake Maracaibo. During transgression the retrogradational sand sheets were formed. Unlike many of the modern and ancient shelf bars, the Misoa bars are less elongated and more equidimensional in nature. The north-northwest–south-southeast orientation of the bars is parallel to the paleoshoreline of the basin to the west.

POST

GOLLOP, I.G. and SCHNITER, A., Eurocan Ventures Limited, Vancouver, B.C.

Structural style of the Cuyo–Bolsones basin complex of west-central Argentina

The Cuyo–Bolsones basin complex is part of a mosaic of basinal features that lie in the eastern Andean Foreland. The sedimentary section ranges in age from Ordovician to Tertiary, and the main petroleum source and reservoir potential are in Carboniferous to Triassic clastics.

Thick conglomerate units and widespread unconformities of both Permo-Carboniferous and Triassic age, as well as localized volcanics, indicate several periods of violent tectonic activity during late Paleozoic to early Mesozoic times.

Triassic and older sediments are affected by normal faulting that extends up into the Lower Cretaceous in basins directly to the south. In the Cuyo–Bolsones basinal area, however, this ancient tensional regime is entirely overprinted by relatively recent thrusting. This thrusting is Late Tertiary in age, generally trends east to west and has very substantial relief. These thrust sheets are cut in places by later northeast-southwest strike-slip fault zones that produce some localized flower structures. Nearly all the oil discovered in the Cuyo Basin is produced from Triassic clastic reservoirs in compressional anticlines related to this thrusting.

The major thrusts are well defined seismically and seismic interpretations fit easily on balanced sections.

ECON

GRECU, J.N., Ziff Energy Group, Calgary, Alberta T2G 2M8

Benchmarking the economic performance of Western Canadian upstream operations

As a result of a series of developments experienced by the Canadian oil patch over the last decade, the 1990's will be much more competitive and bottom-line driven, a significant shift away from past, self-sufficient attitudes.

The past environment was characterized by unpredictable Canadian energy policies; global commoditization of oil accompanied by wild price swings; natural gas deregulation and price deflation, but with the prospect of expanded access to the United States market; a bearish stock market; and a corporate free-for-all where all but the largest producers are potential take-over or restructuring candidates. All of the above created an impetus for a renewed focus on shareholder value and corporate profitability and on rigorous benchmarking.

Companies finally realize that they are *not* operating in a competitive vacuum and their performance is closely scrutinized by the marketplace. To survive or to attract new capital for growth, management has to prove to their boards and ultimate owners that their operation 1) generates a positive economic return, and 2) outperforms its peers. To do that, management requires carefully selected, meaningful, and consistent performance indicators that can measure performance and can relate it to that of other comparable producers.

Two such powerful performance evaluation criteria are the finding and development costs and the operating netbacks. The first of these focuses on longer term economics, *i.e.*, the cost of adding new reserves and replacing the depleting reserve inventories. The second indicator highlights the short term, cash-flow generating ability from current production.

STRU

GRUJENSCHI, C., Calgary, Alberta T3A 2G5

Structures above and below horizontal salt bodies: a new exploration play

Horizontal salt bodies are widespread sedimentary salt formations (*e.g.*, Prairie Evaporite-Williston Basin) or salt bodies tectonically moved into a basin (*e.g.*, Sigsbee Escarpment - Gulf of Mexico). Salt structures can be generated above and below horizontal salt bodies by holokinetic and holotectonic mobilization of the salt. The initial movement of salt in response to tectonism is commonly downward into synclines or grabens, forming thickened accumulations (salt bulges) within the horizontal salt bodies. Later holokinetic processes may create diapirs above these thickened salt bodies. Thus, in basins where both holotectonic and holokinetic mobilization has occurred, prospective structural hydrocarbon traps (*e.g.*, anticlines, horsts) below horizontal salt bodies lie between, rather than below, the salt diapirs.

POST

HARDING, S.C., Husky Oil Ltd., Calgary, Alberta T2P 3G7

A detailed look at estuarine valley fill in the Waseca Formation at Pike's Peak, western Saskatchewan

Following highstand deposition of the regional Waseca Formation, lowstand valleys were incised as relative sea level fell. Within one of these valleys, the reservoir succession at Pike's Peak accumulated. The exact nature of valley-fill accumulation in this and other valleys has been somewhat enigmatic. This investigation takes advantage of exceptional well control (160 wells/two sections) and presents a new slant on estuarine valley fill.

A generalized Waseca succession at Pike's Peak may be outlined as follows. A basal lithofacies consisting of planar tabular and trough crossbedded sandstones rests abruptly on regional highstand Waseca Formation or Sparky Formation lithologies. This unit grades upward or may be incised by an interbedded sandstone and shale succession that contains both flat lying and inclined attitude (IHS) bedding. This facies is in turn overlain and locally incised by a sideritic, ironstone-rich mudstone unit.

The entire succession accumulated during two primary events: 1) baymouth bar deposition, and 2) estuarine scour and fill. The basal sandstone lithology documents the initial event and has been interpreted as representing a composite baymouth bar complex of estuarine origin. The overlying interbedded sandstone and mudstone strata are the result of channel infill following subsequent incision into the baymouth bar as the estuarine complex prograded slightly seaward and collapsed. This incision/fill event can be documented with the identification and correlation of five time subunits (successive scour/fill episodes). Successive units display channel collapse upsection (sub-channel widths decrease), which corresponds with increased stagnation/clogging of the estuarine system. The uppermost sideritic-ironstone facies may correspond with sedimentation within the flocculation zone of the estuary, although it displays characteristics that typify channel abandonment and stagnation.

ENV1

HARDISTY, P.E. and DABROWSKI, T.L., Piteau Engineering Ltd., Calgary, Alberta T3B 0M6

Remediation of groundwater contamination at Alberta sour gas plants

Operations at sour gas processing facilities involve the production, storage, shipment, and disposal of a wide variety of substances, most of which have the potential to contaminate groundwater. A recent study of groundwater monitoring data from 45 Alberta sour gas plants revealed that all but one exhibited some form of impact on groundwater quality. Common sources of contamination at sour gas plants include evaporation/runoff ponds, process area, sulphur block, and on-site landfills. Contaminants that may be introduced into near-surface aquifers include process waters, sulphur products, process chemicals (sulphinol, amines, glycols), aromatic hydrocarbons (BTEX), and natural gas liquids (condensate). At several facilities in the province, work is underway to clean up, abate, or control migration of groundwater contamination; preliminary studies for the implementation of remedial action are proceeding at others. The complex hydrogeology and severe climatic conditions prevalent in Alberta, combined with the unique combinations of potential contaminants found at sour gas plants, make careful design and selection of remedial systems necessary. Groundwater clean-up can be expensive and time-consuming. A thorough site investigation program to define local geology, hydrogeological conditions, and the nature and distribution of contaminants is required for the design of a successful remediation program. Considerations in selecting a remedial strategy include the nature, type, and occurrence of contaminants in the subsurface, site hydrogeology, disposal options, regulatory constraints, and proximity and risk to potential receptors of environmental significance. Groundwater remediation systems may employ technologies such as pump-and-treat systems, in situ methods (chemical, biological, physical), hydrodynamic control, physical barriers, injection and reinfiltration, vapour-phase extraction, and excavation, singly or in combination.

POST

HASHEMI, M.E., Calgary, Alberta T2P 0H0

Triassic in the Peace River area, Townships 67-90, Ranges 1-15 W6M: sequence stratigraphy and hydrocarbon evaluation

The application of very high resolution stratigraphic controls to the study of the post-Montney/pre-Nordegg sequence in the Peace River area has made it possible to analyze its stratigraphy and facies at the reservoir scale. This high resolution control is based on differentiation of the sequence into 17 subunits, which were identified in more than 3000 well logs and complemented by core studies.

The post-Montney/pre-Nordegg sequence in the study area comprises four parasequences, separated by three unconformities of a regional magnitude, which are (base to top) the Halfway, Coplin and Baldonnel. These parasequences are the expression of four cycles of sedimentation. The lowermost cycle began with progradation of the phosphate beds and the Doig Formation to the west, which culminated in the Halfway unconformity. Subsequent movements along old faults in the area resulted in a temporary marine incursion or inundation associated with the deposition of the Halfway Formation. This cycle was followed by three others, each also consisting of: a) progradation, b) evolution of an unconformity, c) re-adjustment movements along old faults, and d) an inundation. The fourth cycle was interrupted near the end of Triassic time by a regional uplift that erased its upper levels with the Nordegg unconformity.

The four parasequences of the post-Montney/pre-Nordegg sequence represent different categories of tidal-flat sedimentation. The lowermost transitional parasequence is dominantly siliciclastic, whereas the other three are mixed silt-carbonate shoreline facies. The lateral continuity, facies changes and vertical stacking pattern of strata within these four parasequences are defined by the intermittent readjustment movements along old faults in the area. These faults are major, northwesterly trending step faults, downthrowing to the west. They have differentiated the area into blocks and played a decisive role in the distribution pattern of traps.

DEV1

HAWLANDER, H.M. and MACHEL, H.G., University of Alberta, Edmonton, Alberta T6G 2E3

Diagenetic and petrophysical types of dolomite, and their relationship to reservoir characteristics of the Grosmont Formation

Diagenesis, porosity, and bitumen saturation of the Grosmont Formation, as well as the underlying and overlying strata (where cored), have been studied in the area between ranges 16 W4 to 25 W4 and townships 80 to 95. Porosity of some facies has been significantly enhanced through diagenesis. Most bitumen is concentrated in secondary pores, in fractures, and in karst fillings.

Our data suggest that the best porosity-permeability relationship is displayed by the Upper Grosmont 2. In the other three Grosmont units, individual permeability values correspond to larger ranges in porosity, probably caused by the presence of various porosity types. Plots of the porosity-permeability data suggests that each Grosmont unit is dominated by a different type of porosity or combination of porosity types. Hg-capillary pressure measurements indicate that the dolomite samples can be classified into at least four petrophysical rock types defined by different pore throat properties. These types may be redefined, and more types may be discovered, as more samples are analyzed. The four preliminary petrophysical rock types are related to porosity types, crystal size and fabric, and mineralogy (calcite or dolomite).

In general our study indicates that the Grosmont dolomites can be subdivided into several diagenetic and petrophysical types and that the two groups do not necessarily coincide. Ongoing studies will reveal whether these relationships can be used for prediction of reservoir characteristics.

ENV1

HEADLEY, J.V., Environment Canada, Saskatoon, Saskatchewan S7N 3H5; and RAE, W., Chemex Labs Alberta Inc., Calgary, Alberta T2E 6P2

Sampling and analysis strategies for delineating petroleum-contaminated soils and groundwater

The importance of environmental impact assessments, possible litigation, and the need for cost effective remediation treatment-options have focused attention on sampling and analysis strategies for delineating petroleum-contaminated soils and groundwater.

Sampling and analytical strategies were evaluated for studies conducted to characterize surface and subsurface contaminants arising from gasoline, diesel, lubrication oil, and jet fuel. Salient points of concern are discussed pertaining to: 1) correct sampling equipment and containers; 2) recommended use of field blanks and laboratory blanks; 3) impact of holding times and sample preparation; 4) proper standard operating procedures; and 5) integrated approach to sample analysis.

Areas of relevance to treatment-options are evaluated for: 1) indicator compounds, primarily benzene, toluene, ethylbenzone, and xylene (BTEX), and polynuclear aromatic hydrocarbons (PAHs); 2) enhanced volatilization; 3) bioremediation; and 4) screening of contaminants with hydrocarbons above C_{30}.

Case studies are discussed to highlight appropriate application of data pertaining to oil and grease, total petroleum hydrocarbons, total purgeables, dissolved gases, gas chromatography scans, and mass spectrometry confirmations.

RESM

HEWITT, M.D. and BEVER, J.M., Petro-Canada Resources, Calgary, Alberta T2P 3E3

Reservoir modelling — an introduction

In the past few years, considerable interest has been generated in the management of uncertainty in oil and gas field appraisal and development, particularly by the creation of computer-based reservoir modelling systems. Reservoir modelling is a sequence of steps that takes raw reservoir information and predicts future field performance to prepare a field development plan. Input into reservoir modelling calls for a collaboration of both geological and engineering talents with a complete understanding of diverse data sets such as sedimentology, fluid flow, formation evaluation, three-dimensional seismic, DST/RFT interpretations, and core analysis. The geological uncertainties that are most commonly managed by reservoir modelling techniques are:

1. an accurate description and interpretation of sediment body genetic type (in both cored and uncored wells)
2. geometry, spatial arrangement (architecture), and connectivity of sediment bodies in interwell 3-D space
3. horizontal and vertical permeability distribution throughout all facies types
4. effects of diagenesis and the influences of fault displacement, fracturing, and tectonic joints
5. the "scaling-up" from details observed in core into mappable reservoir units

Reservoir modelling can improve the estimates for oil and gas recovery in reserve calculations and can also help locate development wells and improve development strategy. Finally, reservoir modelling can give a more accurate range of simulation predictions, which permit planning secondary/tertiary recovery methods that extend the production life of the reservoir.

ENV1

HEWITT, T.D., Hewitt Oil (Alberta) Ltd., Calgary, Alberta T2R 1L7

Golden Spike: an environmentally successful case history

The Golden Spike Field, nine miles (15 km) west of Edmonton, Alberta, is primarily known for Imperial Oil Limited's 1949 discovery of the Golden Spike South D3 Pool. There are, however, significant gas reserves in the Mannville Group, specifically the Glauconite and Ellerslie formations. The Ellerslie Formation contains small amounts of hydrogen sulphide (H_2S), which range in concentration from a few ppm to one quarter of one per cent.

Hewitt Oil (Alberta) Ltd. drilled the discovery wells in the Mannville A, B, and C Pools (1968–1971). The small quantities of H_2S in the gas stream were removed by Imperial's Golden Spike Gas Plant until September, 1984. At that time, Imperial elected to de-commission its sour gas facility and consequently the Hewitt gas stream was shut-in.

In 1985, Hewitt proposed the construction of a sour gas plant in order to resume gas sales. The Hewitt proposal included the use of a 100 per cent sulphur recovery technology called LO-CAT™. The volume of sulphur in the Hewitt gas, being insufficient to justify recovery for economic reasons, was recovered instead for environmental reasons. Hewitt assumed that this technology would relieve the community concerns regarding its project. Instead, the community reacted to the Hewitt proposal with violent opposition.

The presentation, through a slide program, illustrates the interaction between Hewitt, the community, and various government bodies that resulted in a landmark example of cooperation between the community and a resource company. The presentation illustrates Hewitt's initial public relations mistakes and how, over a two-year period, these mistakes were overcome and the conflict was resolved.

POST

HMIDI, Z., Enterprise Tunisienned' Activities Petrolieres, Tunis, Tunisia

Opportunities for oil exploration in Tunisia

An outline of the petroleum geology of Tunisia is introduced in order to promote oil and gas exploration in that country and to make potential investors aware of exploration opportunities. The Tunisian chronostratigraphic chart and tectonic structural map are presented here in order to illustrate the effect of tectonic deformation on the sedimentary deposits. A summary of the main producing oil fields in Tunisia, along with the different components that led to the discoveries (source rock, reservoir, seals, etc.) is also presented.

Tunisia has an interesting oil history. Four hundred exploratory wells have been drilled and 100 km of seismic data have been recorded up to now. We are convinced that interesting opportunities exist for new investors. Sixteen national and international companies are actually involved at present in hydrocarbon operations, but 31 open blocks are still unexplored or only partly investigated. We believe that technological developments in oil prospecting will lead to new discoveries.

Moreover, the laws governing hydrocarbon exploration and production were revised in 1985 and 1987, and today offer advantages such as:

1. year-long geological licences
2. five-year exploration permits with renewal rights and extension options
3. a system whereby new exploration costs can be offset against the production profits from another concession

ENV1

HO, D.Y.F., EBA Engineering Consultants Ltd., Edmonton, Alberta T5L 2M7

Petroleum hydrocarbon contaminant movement in glacial deposits

Public interest in environmental protection and enhancement has increased drastically in recent years. Various government agencies have been pressured to tighten regulations and stiffen penalties against offenders. Surface spills and leakage of petroleum products from distributary and storage facilities are major concerns of the oil industry. Cost effective remedial works often depend on understanding the movement of petroleum hydrocarbon contaminants in the ground.

Glacial lacustrine and till deposits are commonly found within the surficial stratigraphy in Western Canada. These soil deposits are often desiccated, have tension cracks, and are unsaturated. The cracks and fissures sometimes become preferred channels for contaminant flows. The movement of common petroleum fuel products in glacial lacustrine and till deposits is discussed, and case studies are presented.

ENV2

HORNER, W.N., Amoco Canada, Calgary, Alberta T3C 2H4

How changing climate affects the natural gas industry

Natural Gas marketers have noted a significant decline in the coldness of North American winters and a consequent falling off in winter gas consumption during the 1980's. This paper explains the scientific basis for the greenhouse effect and shows the increases in CO_2 concentrations and average global temperature. It explores the historic role of CO_2 in climate changes, particularly the ice ages, and explains why the greenhouse effect is exaggerated during North American winters. It provides a forecast of future warming.

Degree day data for major centres showing significant gas consumption declines are presented. The added impact of the El Nino Current on the gas market, particularly the California market, is also explained.

POST

HUSTEN, P., PATTERSON, D., GILL, S., and VOLK, W., Magnetic Pulse Incorporated, California 94538, U.S.A.

Ultra high pulse power acoustic logging with low frequency multipole transmitters and receivers — a discussion of interpretive techniques

Current technology of acoustic logging has been limited to monopole and dipole sources and receivers. The shear wave can be accurately recorded with this technique but has inferior results in softer formations. A method is presented for acoustic logging with many times the power of conventional technology for improved depth of investigation, and improved signal in soft formations. The technique uses electromagnetic transmitters to generate a broad band width signal. The formation propagates a particular frequency depending on how hard or soft the rock. This insures that a strong first arrival of shear wave is identified by the receivers. In addition to monopole and dipole, quadrupole transmitters and receivers are used in the configuration for logging through casing, which is discussed. Log examples are presented for hard, soft, and very soft formations from monopole, dipole and quadrupole sources both in open hole and cased hole. Interpretive techniques are discussed and applied to this data for the evaluation of porosity, rock mechanical properties, fracture detection, fracture prediction, correlation to shear seismic data, and hydrocarbon indication in clastics.

CBME/POST

JOHNSON, D.G.S. and SMITH, L.A., LAS Energy Associates Ltd., Calgary, Alberta T2P 0C5

Coalbed methane in southeast British Columbia

The British Columbia Ministry of Energy, Mines and Petroleum Resources initiated this study of coalbed methane (CBM) in the Elk Valley, Crowsnest and Flathead coalfields of southeast British Columbia in response to industry interest. These coalfields are located in the front ranges of the Rocky Mountains and have been mined since the 19th century. Rock bursts, methane explosions and gas production have been a problem to the point of closing down some collieries.

The Jurassic–Cretaceous Kootenay Group contains the continental/deltaic coal-bearing sequences. The formation with the greatest CBM potential, the Mist Mountain, averages 500 m in thickness in southeast British Columbia, with 30 to 80 m of coal in the section. The coal ranges between low volatile and high volatile "A" bituminous in rank. The coalfields are defined by tight overturned to broad open folds complicated by thrust and normal or retrothrust faults. Previous geological studies have relied on surface outcrop and relatively shallow subsurface data; deeper basin control is sparse. This study extrapolates into the basins and predicts where CBM resources may occur.

Extensive research of commercial CBM basins has developed CBM content and producible CBM models that are used to quantify southeast British Columbia resources. The high gas content coal seams occur at depths of between 300 and 2000 m. The potentially producible CBM gas is estimated to be 140 to 500 Gm^3 (5 to 18 TCF) in the Crowsnest coalfield and 80 to 200 Gm^3 (3 to 7 TCF) in the Elk Valley coalfield, with nominal amounts in the Flathead coalfield, making a total of 220 to 700 Gm^3 (8 to 25 TCF). Much of this resource occurs on lands with available petroleum and natural gas title.

STRU

JOHNSTON, S.T., Shell Canada Ltd., Calgary, Alberta T2P 2H5

Tectonostratigraphy of Jurassic and Cretaceous sediments of the east-central British Columbia Foothills near Kinuseo Creek

Jurassic and Cretaceous strata in the Foothills near Kinuseo Creek are divisible into three tectonostratigraphic packages. The lower package consists of Fernie Group strata and the lower part of the Minnes Group. Strata are characteristically folded and thickened by numerous thrust faults. Open anticlines and synclines are thought to overlie and be related to ramps in underlying thrust faults affecting Triassic and older strata. An intermediate package includes strata from the upper part of the Minnes Group to the top of the Fort St. John Group. There strata are characteristically folded into large chevron type synclines separated by complex, faulted anticlines. Smoky Group strata contained within the upper package are folded into broad open synclines characterized by gently dipping limbs. Major detachment surfaces, including a lower one within Minnes Group sands and shales and an upper one within Shaftesbury Formation shales, separate the tectonostratigraphic packages.

Strata within the lower two tectonostratigraphic packages are more shortened than strata within the upper package. A major east-dipping, west-verging backthurst underlies the west margin of the upper package and is thought to have accommodated much of this excess shortening.

SED2

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

Stratigraphic architecture of the Cardium Formation in the Pembina Field, west–central Alberta

Sandstones and mudstones of the Cardium Formation in the Pembina Field can be subdivided into a minimum of ten separate lobate, offlapping and prograding parasequences with an average southeast offlap direction. As presently mapped, the lobate parasequences cover a minimum of 400 sq. km. These mudstone to sandstone parasequences comprise a parasequence set that forms most of the reservoir at Pembina.

The upper surface of the parasequence set is modified by two, distinct, erosional surfaces. A lower erosional surface is manifested locally as a series of parallel, asymmetrical channels up to 5 m deep, 3 km wide and 10 to 20 km long. This surface is overlain by a package of well sorted, crossbedded conglomerate and bioturbated, conglomeratic, sandy mudstone. These rocks are in turn incised and overlain by poorly sorted conglomerate. Upper and lower erosional surfaces merge at the margins of the asymmetrical channels.

Within parasequence 4, current-bedded sandstones are laterally juxtaposed with bioturbated, muddy sandstones along southeast-trending lineaments. Significantly, these lineaments coincide with southeast-trending, sub-parallel troughs up to 10 m deep, 10's of kilometres long and several kilometres wide, which belong to the erosional surfaces at the top of the parasequence set.

In the study area, rocks were deposited in a marine environment during an episode of sea level oscillation. Sandstone parasequences formed during a relative sea level drop, while the overlying conglomeratic deposits formed during a relative sea level rise. The lithological characteristics and the spatial relationships of the various deposits are analogous to ones observed in modern subaqueous deltas or estuaries.

INOV

JONES, G.S., Husky Oil Limited, Calgary, Alberta T2P 3G7

Horizontal drilling of a pinnacle reef: a geologist's perspective

In the winter of 1990, Husky Oil drilled a second horizontal well in the Rainbow Basin. The wells were drilled into Keg River pinnacle reefs "G" and "E" pools, which are on secondary miscible flood. These wells are forecast to have twice the economic viability of vertical wells, with accelerated benefits and incremental recovery. A horizontal well in "E" pool was proposed for 1990 to reduce water and solvent coning.

A geological reef model was developed by means of 3-D seismic, a core study, and detailed petrophysical analysis. Integration of facies and petrophysical data showed distinctive porosity and permeability distribution. Slice maps of the reef were used to portray rock volume and fluid distribution. A drilling program was designed to both deplete known undeveloped reserves and evaluate potential reserves in an interpreted reef "skirt". Techniques such as MWD logging, TEC sampling, selective coring, and FMS logging maximized technical data acquisition.

Revision of the reef model was required after drilling the well. Although the postulated "skirt" was thinner than predicted, hydrocarbons were encountered beyond previously mapped reserves. The horizontal well was open-hole completed and is producing at several times the productivity of a vertical well.

ENV2

JONES, G.H., Alconsult International Ltd., Calgary, Alberta T2P 1E5

Canadian experience in frontier environmental protection

Early Canadian frontier exploration (from 1955 for onshore drilling and from 1966 for offshore) caused insignificant public concern. The 1967–68 *Torrey Canyon* tanker and Santa Barbara disasters roused public opinion and governments. In Canada, from 1969 to 1970, Arctic gas blowouts, a tanker disaster, and damage to the *Manhattan* exacerbated concerns, and resulted in new environmental regulatory constraints.

Since 1970, the Arctic Petroleum Operations' Association has learned to operate safely with environmental responsibility. It studied the physical environment for design criteria, and the biological and human environment to ameliorate impact. APOA's research projects covered sea ice, permafrost, sea bottom, oil spills, bird and mammal migration, fish habitat, food chains, oceanography, meteorology, hunters'/trappers' harvests, etc. In 1971, Eastcoast Petroleum Operators' Association and Alaska Oil and Gas Association followed APOA's cooperative research model. EPOA studies stressed icebergs and fisheries. Certain research was handled by the Canadian Offshore Oil Spill Research Association. By the mid-eighties these associations had undertaken $70,000,000 of environmentally oriented research, with equivalent additional work by member companies on specific needs, and similar sums by federal agencies often working with industry on complementary research. The frontier associations then merged with the Canadian Petroleum Association, already active environmentally in Western Canada.

Working with government and informing environmental interest groups, the public, natives, and local groups (fishermen, hunters, trappers, etc.), most Canadian frontier petroleum operations proceeded with minimal delay and environmental disturbance. Nevertheless, perceived potential environmental or fisheries disturbance led to moratoria on Georges Bank, the West Coast, and Lancaster Sound, and slowed Arctic drilling, production, or pipeline plans.

DIAG/POST

KIRKLAND, I.K. and HUTCHEON, I.E., University of Calgary, Calgary, Alberta T2N 1N4

Diagenesis and porosity distribution in the Upper Mississippian Kiskatinaw Formation, Peace River region

The Upper Mississippian Kiskatinaw Formation is an important sandstone reservoir in the Peace River region of northwestern Alberta and northeastern British Columbia. It exhibits complicated stratigraphy, sedimentology, and structure largely due to its location on the Peace River Arch. The primary gas reservoirs in the Kiskatinaw are basal channel sandstones up to 30 m thick, which have fluvial, estuarine, and tidal characteristics.

Porosity and permeability in the Kiskatinaw decrease substantially downdip from the subcrop edge. Thin section petrography of the producing basal sand near the erosional edge (Balsam and Josephine fields) indicates that diagenesis has played an important role in porosity preservation and creation. The quartzose sands are cemented with varying quantities of quartz overgrowths, dolomite, and anhydrite. Diagenetic textures indicate substantial porosity enhancement through dissolution of anhydrite, dolomite, and quartz. Microporous dolomite is very abundant and commonly occurs in oversized pores, which in some places contain ghosts of pre-existing grains, such as pellets. Microporosity has also been created by alteration of potassium feldspars to kaolinite, and of kaolinite to chlorite. Corroded chert, glauconite, pellets, ooids, and shale grains are present locally. Kaolinite, chlorite, and siderite occur as pore-filling and pore-lining authigenic minerals. Chlorite also occurs as replacement of pellets and shale clasts.

Enhanced porosity may be a product of greater contact at the unconformity surface with fluids, possibly less saline than evaporitic waters. Fluid flow may have been facilitated by faulting and the major unconformity truncating the Kiskatinaw.

CANF/POST

KONING, T., Texaco Canada Petroleum Inc., Calgary, Alberta T2P 3S2; and CARSWELL, A.B., Morrison Petroleums Ltd., Calgary, Alberta T2P 4H2

The geology of the East Georges Bank Basin, offshore Nova Scotia

The East Georges Bank Basin covers one million hectares and is undrilled. The geological interpretation is almost entirely based on 16,000 km of seismic data over the basin. Pertinent well control is limited to ten wells on the United States portion of Georges Bank (West Georges Bank Basin) and two wells on the Scotian shelf. Seismic-stratigraphic analysis of this data has led to a structural and stratigraphic model for the basin. The basin formed during the Triassic when the landmass of Pangea began separating along rift zones. A prominent Paleozoic basement high, the Yarmouth Arch, separated the East Georges Bank Basin from the West Georges Bank Basin and had a dominant influence on sedimentation until the Middle Jurassic. Early synrift sequences consist of lacustrine clastics and shales. Marine incursions began in the Late Triassic, resulting in massive salt deposits that reflect the restricted extent of the basin and the arid Triassic and Early Jurassic climate. Further continental separation during the Early Jurassic resulted in deposition of carbonates and evaporites followed by deposition of Middle Jurassic continental shelf carbonates and deltaic sands. During the Middle Jurassic, major growth faulting and halokinesis was initiated by progradation of the deltaic sands. Post Middle Jurassic continental spreading in combination with changing climatic conditions resulted in a steady decline of carbonate sedimentation and dominance of clastic deposition throughout the remaining history of the basin. The basin has been intensely structured by growth and block faults and by salt tectonics.

ENV2

KUPSCH, W.O., University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0

Public pressure on energy industries

Concerns of the public about the extraction, processing, transportation, distribution, storage, and other aspects of the energy industries (oil, gas, coal, hydro, and nuclear) have increased greatly since some concerns were expressed at the beginning of the seventeenth century.

At first, these concerns dealt mainly with health and safety. Later, economic considerations, particularly resource depletion, led to demands for conservation. Only since the late 1960's have concerns regarding the environment become predominant. Public concerns have found expression in political, and more recently judicial, pressure on the industry.

In response, the industry has little choice but to become more open to outside inspection of contentious procedures and techniques, as well as to become more involved in education about science and technology at all levels.

CBME

LAMBERSON, M.N. and BUSTIN, R.M., University of British Columbia, Vancouver, British Columbia V6T 2B4

Coal composition and facies variation in Gates Formation (Falher equivalent) seams, Rocky Mountain Foothills, northeastern British Columbia

A study of the coal-bearing Albian Gates Formation (Falher equivalent) in northeastern British Columbia was undertaken in order to ascertain the factors controlling coal facies variation, as well as to obtain a better understanding of gas generation and retention capacity in the coals. Lithotype (coal facies) samples collected from mines and coal and petroleum drill core were analysed for maceral composition. Compositional boundaries between lithotypes are gradational. From bright to dull coals, there is a progressive decrease in vitrinite and increase in inertinite; liptinite is negligible (<1%). Compositional differences between lithotypes reflect differences in vegetational characteristics, accumulation rate and decomposition rate of wetland plant communities. Lateral and vertical variation in composition was controlled by groundwater levels (due to sea level variations and climatic conditions?) and proximity to active fluvial systems. The lithotypes represent depositional environments ranging from forest swamps to dry, herbaceous and/or shrubby marshes. Swamps were dominated by coniferous trees with a significant component of ferns as herbs or low trees. Angiosperms and cycads contributed to the vegetation in the form of shrubs. Angiosperms were probably also present as marginal herbs.

A representative suite of lithotype samples was analysed for surface area. Differences in maceral composition of the individual lithotypes is believed to be an important control on the differences in surface area. Determining the controls on coal facies variations (compositional variations) is important in understanding variations in the gas generation and retention capacity of coals.

POST

LANDWER, W.R., N.S. Niedell & Associates, Houston, Texas 77042

Colour imaging of velocity variations due to fracture porosity and fluid content

Consolidated reservoir formations are defined as those having consistently higher acoustic impedance (density and velocity product) than similarly aged, normally pressured shales. For such formations, porosity and hydrocarbon effects can be effectively imaged via seismic velocity changes over a substantial range of depths (to 16,000+ feet/4877+ m). Additionally, the velocity variations that could be noted had quantitative significance in terms of reservoir quality and production potential.

The goal of this exposition is to illustrate the technology, which has been verified in a number of diverse examples. We shall note consolidated sand and carbonate reservoirs from South Texas, northern Oklahoma and the North Sea. Fractured reservoir plays of current interest encompassing such formations would include the Austin Chalk (Cret.), Mississippian Osage Lime, and Niobrara as well as others.

The effectiveness of spatially dense seismic velocity measurements and colour inversion sections scaled in velocity is clearly demonstrated by the variety of successful examples reviewed. Velocity drops observed for gas presence (greater than 1,000 ft./sec) approach those typically seen for unconsolidated reservoirs. Smaller, but significant velocity drops are noted for oil-filled reservoirs (400 to 800 ft./sec) as in the case of the Austin Chalk. Such effects can not be viewed on conventional black and white displays of normally processed seismic data. "Coarse" processing loses the detailed information, and visual dynamic range limitations are severe.

Colour inversion displays from properly processed seismic data can image these target zones quite clearly. Additional analysis such as "DIVA" can also indicate the orientation of fracture zones using conventionally processed seismic data.

POST

LANGDON, G., Centre for Earth Resources Research, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5

Recent research related to new opportunities for exploration in the Carboniferous of western Newfoundland and nearby areas

Several parcels of land have recently been leased for petroleum development in the western Newfoundland offshore, where potential is recognized within the Carboniferous sediments of the Maritimes Basin and its associated subbasins. Recent research has involved the combined interpretation of geological mapping and onshore and offshore geophysical data in the Sydney Basin, the eastern Magdalen Basin, and the Bay St. George subbasin. We are interested in mapping sedimentary distribution and in studying the genesis of small, faultbounded subbasins within the overall Maritimes Basin area, especially those that appear to be related to fundamental transcurrent faults. This requires an understanding of the relations between such elements as the following: the deformation histories of slightly older Paleozoic rocks, fluid activity and associated diagenesis and mineralization during Carboniferous time, and the timing of movement on large-scale, lateral faults identified from various data.

We believe that such studies will lead to a better understanding of the distribution of reservoir and source rocks, and the prediction of traps that could contain significant petroleum accumulations.

CBME

LANGENBERG, W., Alberta Geological Survey, Edmonton, Alberta T6H 5X2

Coal-bed methane potential of the Foothills in the Cadomin area, Alberta

Three cross-sections through the area were obtained by the TRIPOD Structural Geological Information System. After balancing, the sections show between 27 and 35 per cent shortening. The major structures of the area are, from north to south: the Pedley Thrust, Coalspur Triangle Zone (formerly called Coalspur Anticline), Entrance Syncline, Mercoal Thrust, Brazeau Flats, Brazeau Thrust, Brazeau Syncline, Grave Flats Thrust, Cadomin Syncline, and Nikanassin Thrust. The Pedley Thrust appears to have at least 1 km of southwest-directed displacement. This fault defines the Coalspur Triangle Zone. The Mercoal Thrust may have about 2 km of southwest-directed displacement and defines a triangle zone that probably formed before the Coalspur Triangle Zone. The Brazeau Thrust shows at least 3 km of northeast-directed movement and places Blackstone shale on top of the Brazeau Formation. The Brazeau Syncline has an overturned southwest limb and is a tight fold. The Nikanassin Thrust forms the boundary with the Front Ranges.

The economic coal seams of the Tertiary Coalspur Formation are of high volatile C rank and are present in three parallel bands in the Entrance Syncline and the Coalspur Triangle Zone. The Mercoal band is the southernmost and dips about 30 degrees to the northeast. The Coalspur band is in the middle and dips generally to the southwest. The Robb band is the northernmost band, contains northeast-dipping strata, and is less deformed than the Coalspur band. In the Entrance Syncline, the Coalspur coals are buried at various depths (up to 1 km) and may form exploration targets for coal-bed methane. The Lower Cretaceous coals of the Luscar Group are exploited in the Cadomin-Luscar Coalfield. The rank of these coals ranges from high volatile A to low volatile bituminous. Where buried (for example, underneath the town of Cadomin), they form exploration targets for coal-bed methane.

GEOC

LECKIE, D.A. and BLOCH, J., Geological Survey of Canada, Calgary, Alberta T2L 2A7; SINGH, C., Alberta Geological Survey, Edmonton, Alberta T6H 5X2; WALL, J., Geological Survey of Canada, Calgary, Alberta T2L 2A7; and WILSON, M., University of Alberta, Edmonton, Alberta T6G 2E9

Shales of the Cretaceous Colorado Group in Western Canada – 1: what is the Fish Scale Marker Bed and can it produce hydrocarbons?

The Fish Scale Marker Bed (FSMB; Albian–Cenomanian boundary) and contiguous strata from Smoky River, Alberta indicate two shale facies. Shale below the FSMB has high foraminiferal and dinoflagellate species diversity, low Total Organic Carbon (TOC) content (1–2%), low HI (11–101 mgHC/gOC) and a predominance of Type III OM indicating a stable, well oxygenated, well circulated environment. The FSMB basal contact is knife-sharp and overlain by interbedded sandstone, siltstone, and shale with no bioturbation. This unit is overlain by 8 cm of phosphatic, fish-hash conglomerate. These last two units suggest shallowing followed by deepening and the formation of a ravinement surface and lag. Above the conglomerate is 1.2 m of shale with no benthonic foraminifers, low dinoflagellate diversity, no bioturbation, high TOC values (2–7%), high HI (70–254 mgHC/gOC) and Type II OM. This shale represents a condensed section during the peak of marine transgression with anoxic bottom water and well oxygenated surface water. The anoxic event may have been caused by mixing of water of different salinity and temperature from the Arctic Ocean and the Gulf of Mexico. The upper shale is similar to the FSMB but has increased Type III OM and decreased TOC, characteristics of progradational clinoforms above a condensed section.

A basin-wide unconformity occurs at the base of the FSMB, characterized by coarse fish debris or well sorted, medium to coarse grained, crossbedded sandstone and conglomerate with some mud drapes (?tidal). Hydrocarbon reservoirs such as the Barons Sandstone in southwestern Alberta are related to the unconformity and are typically thin, discontinuous, and in direct contact with potential source beds; they are an ideal target for horizontal drilling. Hydrocarbon reservoirs associated with the FSMB produce from nonfractured siliciclastic sediment, in contrast to reservoirs in the Second White Speckled Shales, which produce from fractured calcareous pelloids.

INOV

LETOURNEAU, J.P., Canadian Institute of Formation Evaluation Ltd., Calgary, Alberta T2G 4T8

Petroleum hydrogeology of the Jean Marie Member, northeastern British Columbia

The Jean Marie Member of the Redknife Formation in northeast British Columbia (NTS 94-I and 94-P) is a unique, gas-bearing silty limestone. A detailed evaluation of fluids and pressures from over 200 wells illustrates the presence of anomalously low fluid potential. Pressure/depth ratios range from 8.0 to 4.4 kPa/m. A comparison with water gradients from adjacent aquifers illustrates that pressures are 30 to 3000 kPa below regional pore pressures and 2000 to 7000 kPa below normal pore pressures. Formation damage is common on drill-stem tests because of the large pressure differentials between formation pressure and hydrostatic drilling fluid pressure.

Very few wells have produced water during testing or production. Examination of chemical analyses of "water" samples indicates that most of the samples were of mud filtrate. It is gas, not water that forms the continuous reservoir phase of the Jean Marie Member.

Recent pressure tests are commonly several hundred kPa below regional pressure trends. These tests are from pools where there is gas production. The removal of gas can cause a lowering of formation pressures several kilometres from the producing well.

Numerous hypotheses exist to explain the subnormal fluid pressures. All require the existence of "seals" or low permeability strata. Regional trends in the Jean Marie Member are interpreted in terms of these hypotheses. The regional investigation of fluids and pressures has identified considerable potential for additional gas discoveries.

CBME

LEVINE, J.R., The University of Alabama, Tuscaloosa, Alabama 35487

Compositional controls on natural gas yields from selected Fruitland coals, San Juan Basin, Colorado

Coal is conventionally regarded as a solid fuel, but in fact comprises a complex admixture of volatile and nonvolatile constituents. Volatile components include water, sorbed gases, and oils, all of which compete for accessible sites within the coal structure. Ten core samples from the Fruitland Formation (San Juan Basin, CO), representing three coal intervals from three different wells, were subject to a battery of analyses to assess the influence of

the volatile components on gas reservoir characteristics. Preliminary results are tentative, owing to the small number of samples analyzed.

Rock-Eval pyrolysis S1 peaks indicate higher concentrations of free hydrocarbons in samples from the lower Fruitland as compared with overlying benches from the same wells. Methylene chloride solvent extracts show little difference in EOM, but indicate higher concentrations of saturated C_{15+} (waxy) hydrocarbons in lower Fruitland coals. Petrographically, the oil-enriched coals contain a higher proportion of micrinite.

Equilibrium moisture capacities and CO_2 surface areas are lower in the waxy coals, indicating lower sorbate accessibility. Laboratory desorption tests indicate lower in situ gas concentrations and lower percentages of desorbed CO_2 from the waxy coal. In contrast, experimental high pressure isotherms indicate little difference in methane sorption capacity of waxy versus non-waxy coals. Solvent extraction produces a significant increase in CO_2 and CH_4 sorption capacity in some of the samples, but has little effect on others.

INOV

LINDSETH, R.O., Teknica Petroleum Services Ltd., Calgary, Alberta T2P 3T7

Extracting geological information from seismic data

A borehole sonic log (with some effects of density) and a seismic trace are both signal carriers of the same geological information, but with different emphasis. Whereas the sonic log provides a continuous profile of the rocks that make up the sedimentary section, the seismic trace principally describes the contact boundaries between adjacent, different geological units.

Thus the interpretation of seismic sections tends to emphasize the structure and morphology of rock units at the expense of other information. Fortunately, these differences can be described mathematically and compensated for within the constraints of resolution and the information-carrying capacity of seismic and sonic log signals.

In addition to structure, information regarding lithology, porosity and maturation parameters of sedimentary rocks can all be derived from seismic reflection data with some greater or lesser degree of certainty. In one example, the use of such methods resulted in the ability to separate and predict the contributions of faulting, facies changes, structure and erosion to variations in recovery from a large petroleum reservoir and thereby assist in the design of an optimum program for enhanced production and extension to the field.

STRU

MACKAY, P.A. and SPRATT, D.A., University of Calgary, Calgary, Alberta T2N 1N4

The triangle zone of the Canadian Cordillera — Turner Valley, Alberta

The Turner Valley structure is a triangle zone located at the leading edge of the foreland fold and thrust belt of the Canadian Cordillera. Detailed surface mapping, good quality seismic data, and abundant well control demonstrate that the structure is a complexly faulted duplex within undeformed autochthonous strata of the Plains. The upper and lower detachment surfaces, which are common to the entire deformed belt, bound the upper and lower surfaces of this duplex.

A significant hanging wall lateral ramp exists within one of the larger thrust blocks of the duplex. This ramp cuts upsection to the south from Paleozoic strata in the north to Mesozoic strata in the south. The effect of this ramp is to increase the size and displacement of the duplex to the north. As the deformed wedge increases in size to the north, the upper detachment surface is folded, uplifted, eroded, and eventually abandoned.

Restored, balanced cross-sections indicate that up to 50 per cent shortening has occurred within the wedge. Much of the shortening has occurred along extensive flats within the Exshaw and Fernie formations.

POST

MACLEAN, B.C. and COOK, D.G., Geological Survey of Canada, Calgary, Alberta T2L 2A7

Multi-phase compression and extension involving basement under the Colville Hills, Northwest Territories

On a regional grid of seismic lines from the Colville Hills in the northern Interior Plains of Canada, subsurface strata can be subdivided into four seismic-stratigraphic packages, each of which has been affected by one or more of four compressional and one extensional phases of deformation. The tentative Proterozoic stratigraphy (Hornby Bay Group, Dismal Lakes Group, and Coppermine basalts) can be mapped regionally but can be tied neither to outcrop nor good well control. It is the result of comparison of unconformities, structures and deformation phases mapped in outcrop to the east and a chemical comparison of basalts cored in the area with the Coppermine basalts. The Proterozoic compressional events involved faults that soled deep within basement and produced minor shortening. The extensional phase reversed the throw on some of the older faults. The location of structures produced during the last compressional phase (Laramide) has been influenced by pre-existing Proterozoic features. These interpretations are at odds with the published literature, which invokes up to 200 km of shortening on shallow detachments and backthrust faults. They are, however, consistent across the regional grid and link to a similar study to the north.

STRU

MCDONOUGH, M.R., Geological Survey of Canada, Calgary, Alberta T2L 2A7; and LIU, S. and DIXON, J.M., Queen's University Kingston, Ontario K7L 3N6

Centrifuge modelling of oblique slip on external zone thrusts: implications for cross-section balancing

We investigate oblique slip in external zone (foreland) thrust systems by deforming analogy models constructed of plasticine and silicone putty in the Experimental Tectonics Laboratory at Queen's University. Horizontally laminated forelands were shortened by gravitational collapse and spreading of a hinterland wedge of plasticine, the frontal edge of which had an oblique strike relative to the direction of gravitational spreading ($\varnothing = 15°$, $30°$, and $45°$).

Models contain either a single strong unit over a weak unit, or two strong units overlying two weak units. The models deform by thrusting, folding, layer-parallel shortening (LPS), and orogen-parallel extension (OPE). Thrusts are mostly foreland-propagating, and crop out at the top (free) surface in two-unit models.

By tracking particle displacement paths on the free surface we demonstrate that the hanging walls of thrusts were displaced primarily updip relative to their immediate footwalls (fixed), with a lesser component of orogen-parallel displacement in zones of high strain that are associated with thrusts. Thus, the net thrust displacement is oblique, but this is not revealed by serial-sections cut parallel to the boundaries of the models. Oblique displacement and OPE are increased when space is provided for strike-parallel motion of material.

Volume is conserved in the centrifuge, making three-dimensional balancing of a set of serial cross-sections routine. However, restoration of the sections requires a quantitative knowledge of fault displacement, and partitioning of the strain mechanisms OPE, LPS, folding and thrusting. Our results suggest that many natural external zone thrust faults may have a concealed component of orogen-parallel displacement.

STRU

MCPHEE, D.A., University of Alberta, Edmonton, Alberta T6E 2K6; and WIGHTMAN, D.M., Alberta Research Council, Edmonton, Alberta T6H 5X2

Timing of the dissolution of Middle Devonian Elk Point Group evaporites — Townships 47 to 103 and Ranges 15 W3M to 20 W4M

Evaporite components of the Elk Point Group, primarily consisting of salt, comprise in ascending order, the Lower and Upper Lotsberg units, and the Cold Lake and Prairie formations. The Lotsberg salts are restricted to the central Alberta sub-basin. The Cold Lake salt occurs in both the central and northern Alberta sub-basins. The Prairie salt extends from North Dakota to northern Alberta. Dissolution occurred along the updip limit of only the upper three salts, generating narrow, linear, north-northwest-trending salt scarps. Successive salt scarps are offset farther and farther to the west.

The updip limit of bitumen deposits in the Lower Cretaceous Mannville Group coincides with the crest of the asymmetrical Athabasca Anticline, which was produced primarily by post-Early Cretaceous dissolution along the Prairie salt scarp. Prior to Mannville deposition, the present location of the Prairie salt scarp had been established and salt removal was nearly complete to the east of the salt scarp in the Fort McMurray area and the area southeast of the Meadow Lake Escarpment in Saskatchewan. The bulk of post-Early Cretaceous salt removal occurred post-Second White Specks and was primarily removed from along the toe of the salt scarps. Up to 75 m thick intervals of salt were removed from along the Prairie salt scarp. Maximum removal (100 m) occurred over the Cold Lake and Upper Lotsberg salt scarps, adjacent to the Meadow Lake Escarpment. Bitumen migrated across the crest of the Athabasca Anticline north of Township 86, where there was less than 50 m of post-Mannville collapse.

Pre-Mannville salt dissolution was related to groundwater flowing from the Canadian Shield, whereas later dissolution is suggested to have been primarily a function of gravity driven, west-to-east meteoric flow in the Western Canada Sedimentary Basin.

POST

MCPHEE, D.A. and PEMBERTON, S.G., University of Alberta, Edmonton, Alberta T6E 2K6

Speculations on the origin of the Lower Cretaceous Wabiskaw Member sandstone in the Primrose area, Alberta

During the initial southerly advance of the Lower Albian Clearwater Sea into the area of northeast Alberta, littoral sandstones were deposited along the flanks of Paleozoic ridges (Red Earth Highlands and Wainwright Ridge) while an extensive, shale-dominated succession was deposited basinward. These sediments make up the Wabiskaw Member, which averages 15 to 20 m in thickness. Regional correlations of the Wabiskaw, based on about 1300 well logs and 30 cores, are facilitated by a distinctive transgressive sand at the base and a widespread 2 to 3 m thick bentonite bed higher up. The Wabiskaw Member was deposited over an earlier, broad coastal plain incised by a major northward-flowing drainage system, controlled by salt dissolution along the Middle Devonian Prairie Evaporite salt scarp. Well beyond the ridges, out into the basin, a wedge-shaped sand was deposited in the Primrose area. Here, the sand may reach thicknesses of up to 39 m as it infills the underlying fluvial topography, although the basal transgressive sand is missing in these areas.

The Wabiskaw sand of the Primrose area may have been deposited in two stages. Following the initial flooding, the shoreline readvanced northward into the Primrose area while a deltaic system began to form in deeper embayments attributed to the drowned fluvial topography of the McMurray surface. Ensuing sea level rise led to the widespread deposition of marine shale and may have cut the delta system from its source. During the subsequent sea level fall, fluvial systems incised into the marine shales and reactivated deposition over the drowned Wabiskaw delta.

INTE

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Oil exploration opportunities and risks on the North West Shelf of Australia

The North West Shelf of Australia is a vast offshore area of over 500,000 sq. km (200,000 sq. mi.), where fewer than 300 exploration wells have been drilled since offshore activity began in 1964. This offshore region comprises a series of variably superimposed Paleozoic–Mesozoic extensional basins, overlain by a thick, prograding, Tertiary carbonate shelf. Thermal subsidence during the Tertiary has been disrupted in the northern basins by the Miocene–Recent collision of the Australian plate with the Indonesian island arc complex. The potential for significant oil accumulations has only been realized in the past few years, with major commercial successes in Mesozoic sandstone reservoirs of the North Carnarvon and Bonaparte basins. More than half of the shelf is currently open acreage; offshore permit areas are now being posted every six months. Unlike other international regions, well and seismic data are available through an open file system at minimal cost. Using this well and selected seismic data, burial history curves have been constructed for several offshore areas on the North West Shelf. These are used to assess the opportunities and risks for source beds, maturation, reservoir units and migration, relative to trap formation.

POST

MEIJER DREES, N.C., Geological Survey of Canada, Calgary, Alberta T2L 2A7; and JOHNSTON, D.I., University of Alberta, Edmonton, Alberta T6G 2E3

The Upper Devonian Palliser Formation in the type area near Exshaw, Alberta

A 298.5 m thick, composite section of the Palliser near Exshaw includes 5 units. It was sampled for conodonts and correlated with incomplete sections near Canmore and Lake Minnewanka.

The basal, dark grey dolostone of unit 1 did not yield conodonts, but the dolomitic limestone of unit 2 includes conodonts of the Famennian, Lower to Upper *crepida* zones. The peloidal limestones of unit 3 contain conodonts of the Lower *rhomboidea* to Lower *marginifera* zones. Unit 4 did not yield diagnostic conodonts. The fossiliferous limestones of unit 5 include conodonts of the *expansa* to Lower *praesulcata* zones.

It appears that the interbedded dolostones, carbonate breccia, laminated and silty limestones and stromatolitic limestones of unit 4 represent the lower part of the Costigan Member and correlate with the anhydritic deposits of the upper part of the Wabamun Formation in the Gap Lake 06-04-24-07 W5M well. The fossiliferous beds of unit 5 represent the upper part of the Costigan Member and correlate with the Big Valley Member of the Wabamun Formation. Because unit 5 and the Big Valley include conodonts of the same zone as found in the overlying dark shales of the subsurface Exshaw Formation, it is assumed that the sharp contact between the Palliser and the Exshaw formations does not represent a major unconformity.

GEOC

MORROW, D.W., POTTER, J., RICHARDS, B.C. and GOODARZI, F., Geological Survey of Canada, Calgary, Alberta T2L 2A7

Thermal organic maturation in the Liard Basin, northern Canada

The vitrinite reflectances (%R_o) of well-cutting samples from two wells from the Liard Basin range from 0.26 to 4.6 and display a uniform downhole increase. Similarly, R_o values for a well in the Interior Plains immediately east of the Liard Basin increase downhole from 0.58 to 2.00. Other maturation indicators, such as T_{max} from Rock-Eval data, percentage of mixed layer clays, illite crystallinity data, reflectance of bitumens, conodont alteration indices (CAI), and palynomorph thermal alteration indices (TAI) from both well and outcrop samples provide independent verification of the vitrinite reflectance profiles. The reflectance profiles of the post-Silurian Phanerozoic sequence in the Liard Basin and the Interior Plains provide a basis for the determination of the history of organic thermal maturation. The contrasting burial history of the Liard Basin *versus* the Interior Plains and fluid inclusion homogenization temperatures from minerals precipitated during burial provide constraints on possible model solutions for the burial and thermal history of these wells, provided that the entire region underwent a similar history of heat flow fluctuation.

A thermal event in Late Devonian time, as suggested by previous workers, provides the most consistent interpretation for the observed vitrinite reflectance profiles for each of these wells and for the fluid inclusion data. Other hypotheses, one involving a time invariant or uniform heat flow, and the other involving a Tertiary event of high heat flow, provide less consistent fits with the observed data. Migration of liquid hydrocarbons probably occurred in late Paleozoic to early Mesozoic time regardless of temporary heat flow perturbations. The bitumen-bearing Manetoe gas field reservoirs in the Liard Basin must have formed before hydrocarbon generation and migration in order to have received these hydrocarbons. This is consistent with the suggestion of previous workers that the Manetoe Facies formed in Late Devonian time.

DEV1

MOUNTJOY, E.W. and AMTHOR, J.E., Department of Geological Sciences, McGill University, Montreal, Quebec H3A 2A7; and MACHEL, H.G., Department of Geology, University of Alberta, Edmonton, Alberta T6G 2E3

A new look at Leduc dolomites — implications for fluid-flow systems

The Leduc Rimbey–Meadowbrook reefs have produced prolific amounts of oil and gas for more than 40 years, yet their diagenesis is poorly known. We have initiated a study of their diagenesis and reservoir characteristics in order to determine whether a) they have served as a preferential conduit for fluid flow, and b) there are hitherto unrecognized diagenetic traps associated with the reef trend.

Petrographic and geochemical characteristics of Leduc dolomites suggest that replacement dolomitization was probably related to a major preferential conduit system in the Cooking Lake platform. Dolomitization being related to this conduit system explains several features of replacement matrix dolomites in buildups along the Rimbey–Meadowbrook trend: the similar selective replacement of limestone components, the relative homogeneous petrography and cathodoluminescence, their narrow range of carbon and oxygen isotopes (+2.2 to +3.5°/∞ $\delta^{13}C$ PDB, −6.7 to −5.0°/∞ $\delta^{18}O$ PDB), and low Sr (<150 ppm) and Mn (<250 ppm) concentrations. The presence of fabric-destructive dolomitization in the interior of the buildups and in the underlying Cooking Lake platform suggests that these were the zones where fluid flow was most active.

Similar features occur in matrix dolomites in Devonian buildups in the Rocky Mountains. Ongoing analyses of Leduc and Cooking Lake dolomites along the Rimbey–Meadowbrook trend, in conjunction with the study of Devonian dolomites elsewhere in the basin, will help to better determine their origin. This has implications for petroleum exploration and development.

DEV1

MUNDAY, R.J., Esso Resources Canada Ltd., Calgary, Alberta T2P 3L8

A strategy for bitumen resource evaluation, Athabasca tar sands — development and reservoir geology

Most of the Athabasca tar sand leases face their second renewal beginning the year 2000. Present regulations indicate that the awarding of a third term to these leases will be contingent upon strong resource exploitation plans. This paper outlines one way Esso Resources Canada Ltd. is evaluating the bitumen content of its lease interests in order to establish such plans.

Bitumen is contained within McMurray Formation sands, especially the Middle Member, which accumulated in fluvial/estuarine "channels" and clinoforming sheets. Strata penetrated by any single well possibly accumulated in just a few years, hence well data represent only "snapshots in time". Even 10 acre SU (200 in spacing) wells are difficult to correlate; strata in each having accumulated in different time "snapshots".

Away from potential commercial sites, drill density is 160 wells to 640 acres, inadequate for any conventional geological extrapolation of pay zones, placing uncertainty on the validity of computer-generated resource maps. But these same commercial sites show that laterally continuous exploitable bituminous sands do exist, over several sections.

Alternative mechanisms of extrapolation are discussed, together with a means of categorizing contained "bitumen-in-place" (BIP) numbers, which are computed assuming some sort of pay continuity between isolated wells.

SED1

MUNROE, H.D., I.G.C., Calgary, Alberta T2G 0P8; and MOSLOW, T.F., University of Alberta, Edmonton, Alberta T6G 2E3

Depositional models for the Doig Formation of northeastern British Columbia

A subsurface investigation of the Triassic Doig Formation of northeastern British Columbia documented two reservoir facies. Both are a product of mass movement of sediment gravity flow processes on a tectonically active continental margin. A basinward thickening of the entire Triassic section indicates basin subsidence during deposition. Wave set-up, perhaps in conjunction with seismic activity, initiated sediment movement. Sedimentary facies and reservoir parameters were determined from analysis of approximately 150 cores and 900 well logs.

Laterally discontinuous Doig sandstones are up to 60 m thick and trend northeasterly within the project area. The main reservoir facies are incised density flow deposits and laterally extensive slump deposits. Reservoir quality within these sands is extremely variable, with porosity ranging from less than 5 to 15 per cent. In core, these deposits consist of moderately well sorted, very fine grained sandstones with no vertical grain size variation. The sandstone is generally massive but contains intervals of oversteepened bedding, disturbed clay laminae, fragmented shell material, and rip-up clasts of fine grained shelf sediments. These deposits have a sharp basal contact and a blocky gamma-ray signature, very similar to fluvial channel-fill sequences. The channelized density flow deposits form thick but laterally restricted reservoirs. Both reservoir types are enclosed in fine grained shelf deposits that constitute good seals to hydrocarbon migration. The best production to date is in the Buick Creek Field, with initial flows of 346 BOPD. The slump deposits are thinner and tend to be more elongate parallel to paleoshoreline. These sands were subject to some wave reworking. Modern analogues where similar processes and products of deposition are known to occur include the Gulf of Alaska continental shelf and the Fraser River Delta slope.

Successful development of Doig reservoirs must incorporate geological models that assist in understanding the complex and highly variable reservoir quality of sandstone units. Modern-day analogues provide a basis for developing applicable geological models.

SED1

MUWAIS, W.K., Syncrude Canada Ltd., Fort McMurray, Alberta T9H 3L1; and STROBL, R.S., Alberta Research Council, Edmonton, Alberta T6H 5X2

Sedimentology of McMurray Formation channel-fill deposits

Field observations, combined with extensive core data and geophysical log signatures indicate that most of the McMurray Formation at the Syncrude open pit mine, in northeastern Alberta, consists of channel-fill deposits.

Body and trace fossils, clay mineralogy, and sedimentary textures and structures indicate an upward increase in marine influence within vertically stacked channel sequences of the McMurray Formation.

The lithologies of these channel fills are quite variable. Sand, an alternation of sand and mud, and mud-filled channels are equally abundant. However, there is growing evidence, indicative of the overall transgressive nature of the McMurray Formation, that the sand-filled and mud-filled channels are more common in the lower and upper sequences of the formation, respectively.

The cross-sectional geometry, geometry of the component beds, and grain size trends within the channel fills indicate that there were two types of channels: migrating (active), and stationary (passive). Published literature on the McMurray Formation has discussed the sedimentology of active-type channel deposits. This paper will share with the reader observations on the nature and sedimentation styles of both types of channel fill. Recognition of each channel type has a great impact on reservoir modelling of the McMurray Formation.

CANF

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Petrography, reservoir properties and wireline log responses in cored intervals: Kugmallit sequence (Oligocene), Beaufort–Mackenzie Basin, Arctic Canada

The Paleogene Kugmallit sequence underlies over 20,000 sq. km of the Mackenzie Delta–Beaufort Sea. Selected drill cores from 13 widely spaced wells penetrating Kugmallit delta-plain to distal delta-front facies at depths of 919 to 3937 m contain mainly massive to parallel-bedded siliciclastics with variable bioturbation. Both grain size and sorting decrease in an offshore direction in the modern sediments as well as in the Kugmallit sequence. By analogy with modern sedimentation in the area, most of the Kugmallit offshore sandstones studied were probably deposited in water less than 10 m deep. The petrography of about 170 core samples studied in polished thin sections, supplemented by XRD, SEM and EDXRA data, is compared to corresponding measured values of porosity and permeability and to wireline log response. The results show that improved sorting and an exponential increase in detrital quartzose framework-grain content accompany increasing median grain size. These variations are reflected in reservoir properties and log responses. Coarser grained, better sorted sandstones are characterized by total gamma ray values lower than those of finer grained sandstones. Further, the differences between the neutron and density log porosity values in the coarser sandstones are markedly less than those for finer grained sandstones. Low-magnesian ferroan calcites or calcian to calcian/ferroan dolomites form prominent cements in some of the sandstones, which can be distinguished from noncemented sandstones by high sonic velocities on logs.

POST

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Timing of tectonic activity in the Carboniferous Moncton subbasin, New Brunswick

The Moncton subbasin of southern New Brunswick forms the southwestern corner of the Carboniferous Maritimes Sedimentary Basin, which underlies much of the Gulf of St. Lawrence and outcrops in all four Atlantic provinces. The subbasin includes the only productive oil and gas field in the Maritimes.

Seismic reflection data collected by industry in southern New Brunswick is being interpreted in light of recent surface geological mapping and field data, with the goal of better understanding the tectonic evolution of the basin.

Preliminary results indicate that Carboniferous rocks have undergone at least three distinct phases of deformation in the Permo-Carboniferous: extensional faulting in the Late Devonian to Tournasian; compression evidenced by basin inversion during late Tournasian or early Visean time; and segmentation of the subbasin by strike–slip faults, which have moved since the early Westphalian. Timing of major fault movements, and structural styles observed, are compared to those found in fault-bounded subbasins at the opposite end of the Maritimes Basin, in western Newfoundland.

EXPS

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The Red Sea/Gulf of Aden Regional Hydrocarbon Project: an overview

The Red Sea and Gulf of Aden rift basin has an exploration well density of approximately one well per 12,700 km^2, largely due to the areas's reputa-

tion for high heat flow, and apparent gas-proneness. Available evidence, however, suggests that there is considerable petroleum potential.

The Red Sea/Gulf of Aden Regional Hydrocarbon Study Project was conceived in 1987 with the objective of reactivating oil and gas exploration in this basin, through a complete re-evaluation of the basin's database. Executed by the World Bank, the project has been financed by grants from the UNDP, and several donor governments, including that of Canada, with government participation by all countries that share the basin.

Oil company views were obtained from a series of in-depth interviews as to why they were not actively exploring the basin, and the results were incorporated into the project design. Methods were developed to ensure that the results were relevant to the requirements of industry and the scientific community.

Using a basin-wide approach, the comprehensive government-supplied database was integrated into regional overviews of structural evolution, sedimentary response, geothermal heat flow, and source rock maturity and kitchen depocentres. A computerized index of databases available in each country has been established. The results of this work are progressively published as they are obtained. The results confirm that the basin is prospective for the exploration of both petroleum and natural gas.

POST

PATTERSON, D., HARKINS, J., HITCHCOCK, S., Magnetic Pulse Incorporated, Fremont, California 94538, U.S.A.

True resistivity of thin dipping sands

Employing a pulsed power deep induction device (XHR*) allows the application of a one foot layered resistivity model that includes apparent dip magnitude and produces a solution of R_t in dipping beds. This approach illustrates the problems and confusion created over conventional devices with various depths of investigation, magnified by the effects of dip. An example is presented in which the inversion solution for resistivity considering dip, is substantiated by the core evaluation. In this case, the new resistivity agreed with the core indicating that the thin sands were near irreducible water saturation. Once the resistivity is resolved of the sands considering dip in the one foot model inversion solution, an interbedded sand analysis can be applied to further improve the vertical resolution and data accuracy for beds thinner than one foot. Again, a simple approach can be applied to the evaluation of water saturation based on an assumed porosity.

*Mark of MPI

POST

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Interbedded sand analysis using a pulsed power deep induction tool: a turbidite example

Interbedded Sand Analysis (XISA) is a bimodal model that computes a resistivity profile which makes use of a new, extended range, high resolution induction tool (XHR*) along with existing high resolution shale indicators such as a shallow dielectric log.

The XHR is used to provide an accurate resistivity profile in thinly bedded turbidites where the conventional devices show low contrast in these hydrocarbon-bearing intervals. This unique device uses a pulse source and two simultaneously sampled receiver arrays that are offset. Each array provides a digitally sampled log representing the average resistivity over a 12-inch interval. Since the two assemblies are offset, they do not measure the same 12-inch interval and therefore overlap to provide greater coverage and information. The logs from the two assemblies combine to form a composite curve that can be correlated with other high resolution devices.

In this turbidite example, the XISA analysis uses the XHR and EPT** logs to generate a resistivity profile for thin beds. XISA uses the EPT as a shale indicator and reconstructs the resistivity based on the assumption of a constant shale resistivity, R_{shale}, and computes R_{sand}. From this information, XISA computes high resolution resistivity with the combination of the maximum value of the two XHR curves. This new deep resistivity (XISA=Rt) can then be used in a straightforward water saturation evaluation based on as assumed constant porosity in the clean layers as defined by the shale indicator.

* Mark of MPI

** Mark of Schlumberger

SED1

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Evolution of a Middle Proterozoic paleokarst unconformity and associated sedimentary rocks, Elu Basin, NWT

A major paleokarst erosion surface is developed within the middle Proterozoic Elu Basin, northwestern Canada. This paleokarst is named the sub-Kanuyak unconformity and truncates the Parry Bay Formation, a sequence of shallow-marine dolostones that were deposited within a north-facing carbonate platform in a semiarid climate.

The sub-Kanuyak unconformity exhibits up to 90 m of local relief, and also formed under semiarid conditions, when Parry Bay dolostones were subaerially exposed during a relative sea level drop of about 180 m. Caves and various karren developed within the meteoric vadose and phreatic zones. Their geometry, size and orientation were largely controlled by northwest- and northeast-trending antecedent joints, bedding, and lithology. Near-surface caves later collapsed, forming valleys and intervening towers or walls, and plains. Minor terra rossa formed on top of highs. Karstification was most pronounced in southern parts of Bathurst Inlet decreasing northward, probably reflecting varying lengths of exposure time along a north-dipping slope.

The Kanuyak Formation is up to 65 m thick, and partially covers the underlying paleokarst. It consists of six lithofacies: 1) breccia, formed during collapse of caves, as reworked collapse breccia and regolith; 2) conglomerate, representing gravel-dominated braided-fluvial deposits; 3) sandstone, deposited as braided-fluvial, and storm-dominated lacustrine deposits; (4) interbedded sandstone, siltstone and mudstone representing sheet flood deposits; 5) dolostones, comprising calcretes, and quiet-water lacustrine deposits; and 6) red-beds, representing intertidal-marine mud flat deposits. Rivers flowed toward the northwest and northeast within karst valleys and caves; lakes were also situated within valleys; and marine mud flat sediments completely cover the paleokarst to the north.

A regional correlation of the sub-Kanuyak unconformity with the intra-Greenhorn Lakes disconformity within the Coppermine homocline suggests that similar styles of karstification occurred over an extensive region. The Elu Basin paleokarst, however, developed more landward, and was exposed longer than the Coppermine homocline paleokarst.

SED2

PLINT, A.G., Department of Geology, University of Western Ontario, London, Ontario N6A 5B7; and BHATTACHARYA, J., Alberta Geological Survey, Edmonton, Alberta T6H 5X2

Allostratigraphy in outcrop: initial results of subsurface to outcrop correlation in the Upper Cretaceous Dunvegan Formation, Alberta and British Columbia

Bhattacharya (1988) divided the Dunvegan Formation in the subsurface into seven allomembers separated by regional marine flooding surfaces. His study area encompassed Townships 51 to 67 and Ranges 15 W5M to the edge of the deformed belt. This study is now being extended northward to encompass the Peace River Plains and Foothills, where Plint has measured more than 30 outcrop sections. Our aim is to integrate parasequences in outcrop with those documented in regional subsurface correlation lines, which currently extend 350 km from Beatton River (Twp. 86) to Berland River (Twp. 54). These lines show the Dunvegan to consist of a series of shingled, sandier-upward parasequences that downlap toward the southeast.

A section on the Muskeg River can be closely correlated with the subsurface, enabling the allomembers defined by Bhattacharya to be identified in outcrop. Facies and parasequence thickness trends, well defined in the subsurface, enable several closely spaced but nevertheless very different outcrop sections around Grande Cache to be correlated with some confidence. We correlate major incised fluvial units, up to 30 m thick in outcrop, with similar channels observed in allomember E in the subsurface. Paleocurrent directions in the channels and associated marine successions suggest a northeast–southwest to north–south paleoshoreline trend.

Many shoreface sandstones in outcrop are sharp based and suggest that shoreline progradation took place as a result of relative sea level fall. This supports the suggestion that progradation of the Dunvegan may have been driven, at least in part, by a major mid-Cenomanian eustatic fall at about 94 ma.

INOV

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Significance of regional rhomboidal fault patterns in the search for hydrocarbons within the Western Canada Basin using Thematic Mapper images

Most lineament interpretations from satellite imagery display the idealized picture of "single line" regional linear features generally trending northwest–southeast and northeast–southwest in the plains of Western Canada.

Thematic Mapper imagery, however, reveals distinctive and complex zones of intensive faulting and mega-fracturing, which may vary in width from a few kilometres to about 20 km. Most of these features have been active during the latest orogenies. However, a number of them must have been developed earlier as a result of interaction of repeatedly reactivated, deep-seated basement faults and "thin skin tectonics" of the overlying sedimentary sequences.

The regionally predominant rhomboidal pattern of faults appears to have played a significant role in the following geological processes, which are essential for successful exploration:

1. depositional control and diversification of facies
2. migration of hydrocarbons along concentrated pathways
3. creation of reservoirs and porosity; secondary migration

The mechanism that has reactivated faulting and controlled development of these regional fault patterns should be interpreted in the light of plate tectonics. Of particular importance is the recognition of westward continental drift, combined with collision(?), rotation, and transpressional underthrusting of the Canadian Shield Plate beneath the Cordilleran "semiplate". The interaction of "thin skin tectonics" with the basement structural grain has been combined with apparent eastward sliding of the top sedimentary sequences. This has resulted in partly displaced regional fault patterns at the surface, relative to the present position of basement faults.

DIAG

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Origin of Presq'ile dolomite at Pine Point and adjacent subsurface: evidence from petrography, geochemistry, and fluid inclusions

Four types of dolomite are recognized in the Middle Devonian Presqu'ile barrier: fine crystalline (FCD), medium crystalline (MCD), coarse crystalline (CCD), and saddle (SD). The distinct petrographic features and geochemical signatures of these dolomites suggest three stages of dolomitization, with FCD and MCD forming prior to stylolitization. The late-stage CCD and associated SD are also called Presqu'ile dolomite, which hosts Mississippi Valley Type (MVT) deposits at Pine Point and also serves as important subsurface hydrocarbon reservoir rocks.

Presqu'ile dolomites: 1) replace blocky sparry calcite cements; 2) postdate stylolites; 3) overlap with mineralization at Pine Point; and 4) locally occur continuously across the Watt Mountain unconformity into the overlying Slave Point Formation. Homogenization temperatures (Th) of SD cements increase from 100°C at Pine Point, to 110–145°C in the Northwest Territories, and 150–170°C in northeastern British Columbia; the present burial depths of these three areas increase from 50 m, to 500–1900 m, and 2200 m, respectively. As Th and $^{87}Sr/^{86}Sr$ increase, $\delta^{18}O$ decreases. Homogenization temperatures of SD suggest that Presqu'ile dolomitization took place after the basin was tilted and at a minimum burial depth of about 2000 m for Pine Point, and progressively deeper to the southwest. This could only happen at or near the maximum burial conditions during the Late Cretaceous to early Tertiary.

DEV1

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Reservoir development and resource emplacement in selected Paleozoic carbonates of northeastern British Columbia and northwestern Alberta

A significant natural gas resource occurs in selected Paleozoic carbonates of northeastern British Columbia and adjacent northwestern Alberta. Proven reservoirs include the Debolt, Jean Marie, Slave Point, Keg River, Pine Point, and Nahanni formations. We have observed that many of these reservoirs exhibit similar diagenetic fabrics, on the basis of evidence from in-house core studies and the literature. These fabrics include intense fracturing, leached pinpoint to locally cavernous porosity, saddle dolomite cement, occasional sulphide/sulphate mineralization, and the presence of bitumen. The widespread distribution of these fabrics suggests that a common diagenetic mechanism has affected these rocks on a regional scale. Thermochemical sulphate reduction (TSR), combined with active paleohydrogeological flow, is one possible mechanism. In our model, TSR reaction "furnaces" developed within pre-existing oil pools, and sulphate was supplied from various sources via groundwater transport. We envisage four main stages to this process:

1. fracturing of the surrounding rock, due to a pressure increase from the hydrocarbon phase change, which opened new vertical and lateral conduits for fluid migration
2. porosity enhancement in and around these conduits by thermal cooling and weak acid leaching from excess CO_2
3. precipitation of dolomite cement and sulphur minerals in the emerging void space
4. concurrent infusion of methane and other byproducts

We conclude that the TSR process both created and was the source for its own reservoirs. Therefore, we predict the existence of economic pools in stable platform settings, liquid-rich fields peripheral to the main reaction sites, and additional resources in overlooked units. The challenge facing our industry is to develop these ideas into new exploration techniques for this expansive gas theatre.

GEOC

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The Lower Jurassic "Nordegg Member", Western Canada Sedimentary Basin

The "Nordegg Member" of northwestern Alberta and northeastern B.C. (WCSB), is an organic-rich, highly radioactive, micritic limestone of Early Jurassic (Pliensbachian) age. This unit has been used as a marker horizon by petroleum personnel for many years. The petroleum potential of this unit, however, has largely been ignored. The organic and inorganic composition of the "Nordegg Member" are reported, in order to document the hydrocarbon potential of the "Nordegg", and the fate of hydrocarbons generated within this organic-rich unit. Analytical procedures employed in the study include Rock-Eval/TOC analysis, biomarker studies, organic petrographic techniques, and X-ray diffraction and scanning electron microscope with energy dispersive X-ray analysis.

Geochemical and geological data indicate that the deepest and most reducing conditions within the "Nordegg" basin (*e.g.*, Pr/Ph <1.0, low clastic input, diasterane/regular sterane ratios <0.3) approximately coincide with a line joining T72, R24W5 and T84, R2W6. The "Nordegg" has excellent source rock characteristics (Type I/II kerogen, TOC's up to 28 per cent, large area in the "oil window"). However, comparison of the "Nordegg" biomarker signatures with those of oils trapped within the WCSB reveals that few conventional oils have been sourced by the "Nordegg". Also, the "Nordegg" does not appear to have been a major contributor to the Alberta heavy oil and tar sand deposits. We speculate that much of the oil generated by the "Nordegg" has not been expelled, and that this unit may be an important candidate for horizontal drilling plays.

SED1

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The Bluesky Formation: an estuarine valley fill, Edson and Pine Creek field areas, west-central Alberta

A study of the Lower Cretaceous Bluesky Formation in west-central Alberta reveals the presence of anomalously thick Bluesky sediments in the Edson and Pine Creek field areas. Detailed core and well log examination indicates Bluesky sediments were deposited as an unconformity-bounded, estuarine, valley-fill sequence.

An unconformity at the base of the Bluesky Formation is interpreted to have formed during a fall in relative sea level following Gething deposition. During this lowstand, two northeast-trending valleys (Edson and Pine Creek field areas) incised into the underlying coastal plain and nearshore/shallow shelf sediments of the Gething Formation. During the subsequent rise in relative sea level, sediment backfilled within the valleys, and accumulated as transgressive estuarine deposits. The transgression reworked shoreface sandstones into shallow marine bars and shelf sandstones in inter-valley regions. A transgressive erosional surface and accompanying sandstone lag occurs at the

top of the Bluesky Formation. Bluesky sediments are overlain by offshore shales of the Wilrich Formation.

Twenty-two lithofacies were identified from 54 cored wells within the study area (Twp. 51–58, Rge. 15W5–6th meridian). Nine depositional environments were interpreted from a combination of lithofacies assemblages. The valley-fill sequence comprises multiple, stacked, sand-filled estuarine channels, muddy (mixed sandstone/mudstone) estuarine point bars, sandstone shoals, and a wedge of open marine shales and siltstones. Inter-valley deposits include reworked shoreline sandstones, shallow marine bars and shelf sandstones.

The Edson and Pine Creek fields have cumulative oil and gas production to date of 1195 x 10^3m^3 (1.2 MMBO) and 7174 x 10^6m^3 (231 BCF), respectively. The primary reservoir units within the Bluesky Formation are thick (>30 m) estuarine channel sandstones with porosities that range from 9 to 16 per cent. The primary trapping mechanism of the Bluesky Formation within the valley-fill strata is a seaward pinchout of channel sandstones updip into tight marine mudstones, siltstones, and low permeability, muddy, estuarine point-bar deposits.

STRU

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Evolution of the Beaufort Sea Fold and Thrust Belt, northwestern Canada

The northeasternmost segment of the Cordilleran Thrust Belt of western North America underlies the Beaufort Sea continental margin. Folds and associated northeast-directed thrusts in this region formed synchronously with Tertiary sedimentation. As a result, the times of fold development can be determined from reflection seismic data by analyzing lateral thickness changes in stratigraphic sequences of known ages, and onlap and truncation relationships at unconformities.

Many thrusts were active simultaneously during the Late Paleocene – Pliocene development of the thrust belt. The thrust belt propagated along, as well as across, strike. During the Late Paleocene – Middle Eocene, the area of active thrusting was bounded on the southeast by poorly-imaged zones of right-lateral strike–slip faults that apparently are the northern, offshore continuation of the Rapid Fault Array. During the Late Eocene Pliocene these strike–slip zones were largely inactive, and the southeastern boundary of the belt shifted along strike about 100 km southeast to the right-lateral Donna River Fault. The change in the age of thrusting along strike results in no obvious geometric anomalies, and could not be deduced without timing information. This has an important implication: temporal data cannot necessarily be projected along strike in a thrust belt.

The thrusts probably formed within a broad zone of right-lateral shear based on the presence, within the thrust belt, of northeast-striking right-lateral strike–slip faults, east-striking left-lateral antithetic strike–slip faults, and possible rotations of fault-bounded regions about vertical axes.

CBME

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Coal bed methane in the Alberta Basin - a resource estimation

Alberta contains at least 6000 gigatonnes (6 x 10^{12} tonnes) of coal ranging in rank from sub-bituminous to low-volatile bituminous. Our calculations show the amount of coal bed gas potentially in place is in the order of 73.5 x 10^{12} cubic metres (2.6 x 10^{15} cubic feet). This is an enormous resource, and the numbers are being updated continuously as new data become available. Estimates of the maximum coal gas-in-place for the United States are approximately 4 x 10^{14} cubic feet.

In the Alberta portion of the Western Canada Sedimentary Basin the coals are distributed throughout the Foothills and Plains regions and range from Jurassic to Tertiary in age. The potential of these coals for generating sufficient gas to be considered a significant commercial fuel source has only been realized in the last several years.

Because of the relative infancy of this resource development in Alberta, only limited direct data are available. The coals in Alberta have not been extensively tested for gas content, however, the evaluation of coal bed methane resources are possible through the use of indirect data such as thickness, rank, depth, as well as proximate analysis to obtain an estimate of the gas content.

This paper reviews the formations and geographic areas of gas potential and the reasoning used to derive the coal and gas content resource estimates.

INTE

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Potential for petroleum exploration in marine strata of south China

Marine sediments of late Sinian through Early Triassic age in south China are mainly carbonates. The carbonate has an area of about 2,000,000 sq. km and a thickness of more than 1,000 m. There are multiple petroleum prospects vertically and source rocks thousands of metres thick. Multiple generative source models include platforms, ancient slopes, isolated platforms, and folds. During geological history, ancient uplifts and lithofacies belts controlled the formation of large oil pools (Majiang in Guizhou, the eastern part of the Niushou Mountains in east Yunnan, and Taishan in Zhejiang, etc.) in petroliferous basins along and around Xuefeng and the Jiangnan Uplift. Continental orogeny and plate tectonic movements of Indo-China altered or destroyed conditions of oil and gas generation in the crude sea basin. Because oil and gas seepage is serious, and the geological structures are extremely complex, exploration is quite difficult. Our research indicates that the prospecting region for oil and gas is still large because of the imbalance of tectonic movements. Areas such as synclinoria, the area covered by Mesozoic–Cenozoic continental basins, and overthrust tectonic belts could be prospects for oil and gas searches by means of advanced exploration techniques and methods.

POST

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Cathodoluminescence zones in calcite cements: weak statistical correlation with the Fe-Mn pair

The intensities of cathodoluminescence (CL) in calcite — nonluminescent, dull, luminescent — are believed to reflect the relative concentrations of Mn and Fe, an activator and a quencher of luminescence, respectively. Such interpretation leads to a common perception that the luminescence of cements and the redox state of the diagenetic environment are directly related. To test these propositions, pure CL zones in meteoric and burial calcite cements from the Sverdrup Basin were visually identified and their Fe, Mn, Mg, and Ca contents were measured by Secondary Ion Mass Spectrometry (SIMS). Factor analysis of these data confirmed that CL intensity, Mn, and Fe load on a common factor, but the positive loading of Mn and the negative one of Fe are weak. Three domains emerge clearly in the Fe–Mn space. All spots with more than 1000 to 1500 ppm Fe are dull. Below this threshold, points with more than 225 ppm Mn are luminescent. The third domain, with lesser Mn and Fe contents, can display any of the above listed CL intensities. This shows that the Fe–Mn pair alone cannot explain the luminescence zones in calcite.

DIAG

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Recrystallized marine cements: textural preservation and geochemical signatures

Isotopic composition of past oceans has usually been deduced from studies based either on low-Mg calcitic shells (*e.g.*, foraminifers, brachiopods) or on early marine cements. The latter, originally of aragonitic or high-Mg calcitic mineralogy, exist today as neomorphic low-Mg calcites. It is not clear how much of the initial geochemical signal is sequestered into the successor phases, but their nonluminescent nature is considered to be the an indication for strong retention of the signal. In the upper Paleozoic cements of the Sverdrup Basin, five stages of preservation for calcitized aragonite and four for former HMC were recognized. The stages of preservation (CL patterns) have been based on the proportion and distribution of CL microzones. To test the correlation between textural and isotopic preservation states, 62 spot measurements for Sr, Mg, Fe and Mn, 133 determinations of $\delta^{18}O$ and $\delta^{13}C$, and 20 of $^{87}Sr/^{86}Sr$ were performed on the diverse CL patterns. The results prove equivocal. Many texturally well preserved domains showed clearly altered isotopic signatures and vice versa. The utility of early marine cements for paleoceanographic studies is not to be discounted, but the causes of their isotopic signal retention are not clear.

POST

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Bedding scales of a complex eolian dune using ground-penetrating radar

Ground-penetrating radar was used on a large, complex, eolian dune along the margin of Great Sand Dunes National Monument, Colorado, to delineate the two-dimensional length scales of internal sediment packages for input to eolian hydrocarbon reservoir models. The ground-penetrating radar illustrated internal structures in the dune to a depth of 16 m, in a transect approximately 280 m long. Radar reflectors defined a main dune set 5 to 8 m thick, with foresets as long as 23 m. Thickness of other wedge- and tabular-planar sets ranged from 0.75 to 1.5 m, averaging 1 m; set lengths ranged from 6 to 12 m, averaging 8.5 m. Trough-shaped sets ranged in thickness from 0.5 to 3 m, averaging 1.1 m, and ranged in width from 5 to 22 m, averaging 10 m. Trough structures are the result of migration of superimposed dunes, or scour fills from reversing winds. Reversing winds resulted in the formation of numerous, subtle bounding surfaces along the lee slope of the dune as it migrated, defining sets ranging in thickness from 0.5 to 2 m, averaging 1 m, and with foreset lengths ranging from 15 to 23 m, averaging 20 m. This study demonstrates the potential of ground-penetrating radar in resolving the length scales of internal sedimentary units in modern sands. Work is in progress on delineating the three-dimensional length scales of these complex eolian dune sands.

DEV2

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Sedimentology and reservoir quality of the Kiskatinaw Formation, Alberta

The Lower Carboniferous Kiskatinaw Formation extends over a large area in the subsurface of the Peace River region of Alberta and British Columbia. The reservoirs of this formation are prolific gas producers containing high reserves. They are currently the object of intense exploration.

The Kiskatinaw sediments are predominantly tidal deposits laid down in an estuary system affected by macrotidal processes. The recognition of allocyclic and autocyclic subdivisions within the formation facilitate determination of lithofacies distribution. The principal reservoirs are quartz-rich sandstones, characterized by the development of secondary porosity. In general, porosity and permeability are low and commonly vary dramatically from place to place over short distances. Subdividing the Kiskatinaw rocks into parasequences and separately mapping and modelling each parasequence greatly facilitates an understanding of reservoir distribution within the formation.

Formation damage is a major problem in the Kiskatinaw and is attributed largely to the presence of interstitial clay introduced by the action of tidal currents, soil-forming processes, and diagenesis. Chemical reactions between introduced fluids and carbonate, sulphate, and sulphide cements further promote formation damage. A thorough understanding of the physical and chemical properties of both pore-lining minerals and framework grains is vital in planning reservoir treatments that minimize damage and enhance reservoir yields.

INTE

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Source/maturation evaluation and hydrocarbon potential of the western Red Sea and southern Gulf of Aden

The hydrocarbon potential assessment is based on data from 35 wells, geochemistry on 19 wells, and regional interpretation of 20,000 km of seismic. Mesozoic pre-rift source-reservoir sequences, seen in the western onshore areas of the Red Sea, are absent in offshore wells, probably due to pre-Miocene erosion over horsts or insufficient well penetration. The middle Miocene syn-rift sequence, containing fair to good Type II/III source rocks in northern Red Sea wells and poor to fair source rocks elsewhere, is marginally mature over highs and may have a greater generative potential in structural lows due to better preservation of source units. The post-evaporite sequence, containing thin, gas-prone source beds, is partially mature in thick late Miocene–Pliocene depocentres, and has generated gas and condensate.

Geothermal gradients in Red Sea wells are similar to, or slightly higher than, those in the productive Gulf of Suez. The top of the oil window often coincides with the base of thick salt. A steep underlying gradient implies that about 750 m of the uppermost pre-salt section lies within the oil window.

In the Gulf of Aden, a high geothermal/maturation gradient results in the maturation of source-rich pre-rift Upper Jurassic, Upper Cretaceous, Paleocene, and syn-rift Oligocene–Miocene sequences at depths of less than 2,000 m. The Oligocene–Miocene clastics are relatively thin and lack a thick evaporite seal; hydrocarbon potential is thus restricted to pre-rift rocks.

EXPS

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Defining the focused exploration strategy

"Exploration strategy" is one of the terms most frequently used by oil and gas industry management and analysts. It is a key aspect in assessing the potential for growth and development of hydrocarbon exploration and production firms. Porter identifies three generic strategies that are easily applied to the oil and gas industry: cost leadership, differentiation, and focusing. Since focusing is currently the most commonly acknowledged strategy among Western Canadian exploration organizations, a discussion of this particular strategy will dominate the remainder of the paper. A focused exploration strategy may take three distinct directions — focusing geographically, stratigraphically, or on product. The focusing process may be seen as the process through which basins, plays and prospects are subjected to a series of tests or filters in order to identify and select the value-added prospect. The value-added prospect is defined as the prospect that meets specific and clearly identified technical, economic and strategic criteria that are derived from the corporation's goals, objectives, and vision. These filters — scoping, technical, and economic — when applied to basins, plays, and ultimately prospects, will yield the value-added prospect. A focused exploration strategy has many obvious advantages, such as lower G&A costs, but there are also corresponding risks that must be acknowledged. For a focused strategy to be successful, however, exploration organizations must integrate aspects of cost leadership and differentiation strategies.

POST

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Early diagenesis in the Fraser River Delta

The Fraser River Delta, with its high organic matter content, mixed water setting and accessibility, provides an ideal site for investigating early diagenetic reactions.

In ancient deltaic rocks calcite is often considered a very early diagenetic cement. Calcite concretions have been reported forming in the present-day tidal channels of the Fraser River Delta, although their mode of formation has not been fully resolved. In order to study the formation of calcite concretions and other diagenetic reactions occurring in the delta, thirteen shallow vibracored holes and five, deeper, sonic and rotary-cored holes have been drilled across the delta. Approximately 90 sediment samples have been obtained from these holes. All of the samples were unlithified, although a number of calcite concretions were found in one of the holes. Analyses of pore waters is a sensitive method of studying diagenetic reactions, therefore the sediment samples were "squeezed" to release their pore waters. The pore waters have been analyzed for pH, alkalinity, cations, anions, oxygen and hydrogen isotopes, carbon isotopes in dissolved carbonate species and sulphur isotopes in dissolved sulphide and sulphate. The sediment samples have been examined by SEM and XRD techniques to characterize the diagenetic minerals. A geochemical thermodynamic computer modelling technique is being used to study mineral reactions within the sediments, as well as to quantify the mode of origin of calcite concretions and its relationship to marine-meteoric water mixing in the shallow subsurface of the Fraser Delta.

POST

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Coalbed methane potential in northeast British Columbia, Gates and Gething formations

Extensive coal deposits occur in the Lower Cretaceous Gething Formation (Aptian) and Gates Formation (Albian) in northeast British Columbia. The outcrop zone has been extensively explored for coal since Scott's GSC Bulletin 152 was published in 1968. Initial exploration by Coalition Mining, Denison Mines and McIntyre Mines and others has resulted in two large open pit coal mines opening in 1982.

The Gething and Gates formations are each characterized as a series of continental margin transgressive/regressive sequences consisting of interstratified nonmarine to marine sediments deposited in deltaic coastal plain or paralic environments. They are separated from one another by the marine Moosebar Formation. These deposits dip northeastward from outcrop along the disturbed belt into the Deep Basin and wrap over the Peace River Arch.

Paralleling the outcrop, the zone applicable to commercial extraction of coalbed methane locally contains up to 60 Bcf per square mile of in-situ potential. Commercial possibilities are indicated by localized artesian hydrological conditions and gas kick anomalies from coal seams.

ECON

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Portfolio concepts applied to exploration investments

The "garbage in–garbage out" rule applies to exploration investment decision making. Good decisions are not possible if a firm's assessments are not representative of its prospects. Wealth maximization and risk minimization goals may be used to make decisions based on good assessments. A method of doing this is Expected Value {E(V)} – Expected Loss {E(L)} Capital Budgeting, in which interests in prospects are considered collectively. In this method the firm's wealth is maximized by maximizing the E(V) of its portfolio, and the firm's risk is minimized by minimizing the E(L) of its portfolio.

The following investment questions can be addressed using E(V) – E(L) Capital Budgeting:

1. What interest should a firm take in each of several prospects?
2. What is the cost to the firm of a decision not to farm out strategic prospects?
3. What is the impact on investment decisions of transaction costs associated with farming out?

The E(V) - E(L) Capital Budgeting method can be illustrated using an example of a firm with ten Western Canadian prospects. The results of this method compare favourably with alternate investment decision techniques.

DEV2

STEVENS, L.M. and STEFFES, D., PanCanadian Petroleum Limited, Calgary, Alberta T2P 2S5

Reservoir characterization of low permeability, gas productive sandstones: Upper Mannville, Countess-Makepeace area, southern Alberta

An integrated petrographic, sedimentological and petrophysical analysis of Upper Mannville sandstones in the Countess-Makepeace area (Twp. 21–24, Rge. 16–19 W4M) was conducted to determine the geological controls on reservoir quality and production performance.

Low permeability, gas productive, Upper Mannville sandstones occur in a 40 m thick interval immediately overlying the Ostracode zone and underlying an areally extensive coal marker.

The Upper Mannville sandstone sequence consists of three sandstone units. In descending order, they are the Upper Mannville A, B, and C units. The Upper Mannville sandstone sequence was deposited in a complex estuarine/coastal-plain setting. It represents a stacking of prograding, shallow water, upward-coarsening sandstone bodies with associated tidal channel deposits.

The reservoir quality sandstones are very fine to medium grained, poor to moderately well sorted feldspathic litharenites and lithic arkoses. Grain size and mineralogy are variable and have a major effect on reservoir and quality and production performance.

Average *in situ* effective porosity and permeability are 15 per cent and 1 millidarcy, respectively. As a result of the low permeability, all wells require fracture stimulation in order to be economic producers. This case history demonstrates the value of an integrated approach to reservoir characterization. A complete understanding was obtained by combining depositional-diagenetic environment interpretation, facies interpretation, mineralogy and pore system evaluation with recognition of reservoir quality rock types on wireline logs.

DEV2

STEVENS, L.M. and VOLCKO, M.D., PanCanadian Petroleum Limited, Calgary, Alberta T2P 2S5

The Rycroft Halfway C Pool: importance of an accurate and detailed geological model in pool development

The Rycroft Halfway C Pool is located approximately 400 km northwest of Edmonton. The pool currently produces 466 m^3/d of 38° API oil from 20 wells and contains 4.4 x $10^6 m^3$ OOIP. The waterflood secondary recovery scheme currently in place is expected to recover 37 per cent of the OOIP. The pool was discovered in 1984 and waterflooding commenced in 1987.

The geological history of the area is very complex. Facies variations associated with minor faulting have created 10 individual hydrocarbon productive reservoirs within the Rycroft Halfway C Pool. The Halfway was subdivided into two units, a lower Stacked Bar Sequence (SBS) and an upper Tidal Flat Sequence (TFS). Depositional environment of the TFS ranges from nearshore marine/intertidal to supratidal/coastal sabkha. The productive facies range from very fine grained dolomitic sandstone to finely crystalline dolomitized algal mats. Depositional environment of the SBS was a prograding beach/barrier island system. The productive facies display gradations from very fine grained dolomitic sandstone to sandy, very finely crystalline dolomite (coquina).

In order to optimize pool development and to design an effective secondary recovery scheme, all potentially productive hydrocarbon reservoirs had to be evaluated thoroughly. Detailed core examination, core analysis (including petrography), and well log evaluation provided the key to creating the geological model.

This case history illustrates that recognition of depositional environments and the subsequent detailed geological evaluation of a complex reservoir are essential to the delineation of the pool and the design of an effective secondary recovery scheme.

RESM

STROBL, R.S. and YUAN, L.P., Alberta Research Council, Edmonton, Alberta T6H 5X2; and MUWAIS, W.K., Syncrude Canada Ltd., Fort McMurray, Alberta T9H 3L1

Reservoir geological modelling of the McMurray Formation, Alberta

A detailed study area, located within the Syncrude oil sands mine, contained over 200 drill holes in an area approximately 1 sq. km in size. Drill hole spacing averages 80 m to 100 m, with spacings as close as 40 m in the vicinity of active mining benches. All drill holes were supported by dipmeter logs and alternate holes were cored. Mapping was carried out on a 1:500 scale, with the aim of characterizing major reservoir facies, heterogeneities, and permeability barriers. Syncrude's high-wall mapping program and exploration test pits provided additional verification. With this quantity and quality of data, detailed models of a McMurray-type reservoir were developed.

The McMurray Formation consists of 50 m to 70 m of uncemented quartzose sands and associated shale, deposited in an estuarine valley-fill complex. The richest oil sands (reservoir) are contained in the Middle McMurray tidal channel successions. Repetitive scour and fill cycles result in stacked channel deposits.

Little, if any, cementation or clay authigenesis has occurred, so the porosity and permeability patterns are a direct function of the primary facies distribution. With the absence of diagenetic factors, reservoir characterization is simplified considerably. An understanding of the facies controls and facies architecture (vertical and lateral extent of each facies) leads to a better understanding of reservoir behaviour. Studies are underway to quantitatively assess each reservoir facies on the basis of permeability, porosity, grain size, oil saturation, and analysis of pore systems.

ENV1

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Coal bed methane — environmental concerns in Alberta

The potential recovery of coal seam gas has raised a series of environmental concerns. The majority of these concerns are similar to those associated with conventional oil and gas. Included are: surface disturbance, spacing of wells, emissions, and produced water disposal.

The geology of the producing basins in the United States is similar to that of the Alberta basin. Since the impacts are a function of the surficial and subsurface geology, a strong analogy between the U.S. experience and the Canadian experience can be made. The current environmental practices and regulations governing coal bed methane production in the United States are examined. Existing Alberta conventional oil and gas regulations are com-

pared. It appears that coal bed methane development in Alberta will not require additional regulations and will not be worse, and possibly environmentally more friendly, than conventional oil and gas recovery.

DEV1

STYAN, W. and MULLANE, T., Shell Canada Limited, Calgary, Alberta T2P 2H5

Water and miscible flood optimization in a layered reservoir

Approximately 33 E^6m^3 (200 m bbls) of 832 kg/m^3 (38 API) crude and over 36.2 E^9m^3 (1.3 TCF) of condensate rich natural gas was originally trapped in karsted Turner Valley carbonates along the Mississippian subcrop at Harmattan. Discovered one year after the gas cap, in 1957, the oil column was produced by solution gas and gas cap expansion until 1974 when a field wide waterflood was implemented. A limited CO_2 miscible flood was initiated in 1988.

Predominantly vuggy, leached fossil moldic porosity is developed in dolomitized crinoidal mud supported fabrics near the top of storm generated fining upward cycles. Syntaxially cemented crinoidal grainstones at the base of each cycle are impermeable and effectively segregate the reservoir into layers. In intershoal areas, where grain supported fabrics are absent, horizontal stratification with limited kv replaces distinct permeability barriers. Near the top of overall restricting upward mega-cycles, dolomitization occurs prior to calcite stabilization. In this environment, thin but areally extensive, high permeability layers are developed in grainstone fabrics. Low permeability wackestones and mudstones intercalated with green shales cap the sequence to form a laterally continuous horizontal flow barrier.

Both inverted 9 spot and line drive patterns were configured on 80 acre spacing during initiation of the waterflood. Completion of all injector well pay occurred during this phase of development with offset producers perforated only in lowermost poorer reservoir layers. Following breakthrough, wells were completed uphole with limited success. High water volumes with limited incremental oil suggested large scale migration of oil had occurred in more permeable layers. Bubble maps, production and perforation history plots integrated with both pressure surveys and reservoir models were used to follow fluid migration. Periodic injection and production logging in gas lift wells confirmed that the waterflood was effectively sweeping the more permeable uppermost layers, and that several poorer reservoir units near the base contributed little and may contain bypassed pay. Updip migration of oil is being captured by large pumpjacks and ESP's.

Early breakthrough by CO_2 in the miscible flood mimicked fluid migration behavior observed during waterflood confirmed the geological/ reservoir model, but contradicted early reservoir simulations. Experience has shown that a detailed cross sectional model must be employed to properly model early breakthrough caused by override and vertical permeability variations. Profile logging has shown that gravity override plays a significant role in this reservoir. A field test will be conducted to examine performance at higher injection rates by injecting the fixed volume of CO_2 to fewer injectors at a time (3 to 1).

DEV2

STYAN, W. and SHAW, J., Shell Canada, Calgary, Alberta T2P 2H5

An overview of Triassic Halfway pools in the Progress area

Significant accumulations of hydrocarbons have been trapped in Halfway-aged deltaic sediments in the Progress Area, Township 77 to 79, Range 8 to 10 W6M. Integration of sequence stratigraphic concepts with reservoir engineering data explains hydrocarbon distribution, reservoir quality and production performance of these pools.

Reservoir quality inner fringe sands of the Lower Halfway Formation grade upward from prodelta silts and shales of the Doig Formation and are overlain by progradational beach and lower shoreface facies of the Upper Halfway. Laterally, to the north and east, these clastics grade into a tight evaporitic sequence. Deeply incised channels, which mark the culmination of the highstand systems tract, and a major sea level fall, abruptly terminate the sequence to the south and west. Mud dominated fluvial and estuarine fill sediments in these channels comprise the lowstand and transgressive systems tracts of the next sequence. Conformable sedimentation continues into overlying and areally widespread evaporitic seals of the Charlie Lake Formation.

Lower Halfway sands, composed primarily of very fine quartz, contain mainly intergranular porosity which is partly occluded by a paragenetic sequence of silica overgrowths, dolomite and anhydrite cements. Reservoir quality, which ranges from 8 to 12 per cent and 1.5 to 14 mD decreases to the west as dolomitic mud increases. In contrast, Upper Halfway sands are coarser, contain more lithic rock fragments and chert, and have both intergranular and vuggy porosity. Reservoir development, which ranges from 3 to 12 per cent, increases in an orderly manner to the west. A petrographically distinct, well sorted, medium grained sandstone with 15 to 20 per cent porosity and up to 300 mD permeability occasionally caps the Upper Halfway. Occurrence of this sand as elongate lenses over estuarine fill sediments precludes affinity to the highstand systems tract of the first sequence.

Gas wells currently producing from only deltaic sands have an average deliverability of 150 E^3m^3 (after stimulation) while those containing medium grained sand attain deliverabilities of 250 E^3m^3. Although some downdip oil producers are in pressure communication with the gas cap, many appear from static gradient data to be separate, suggesting the presence of an estuarine filled channel. Small individual pools with variable hydrocarbon charge have accumulated where medium grained sand lenses occur over mud-filled channels. Material balance and pressure matching of these pools suggest sizes ranging from 64 to 390 hectares.

ENV2

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The Cretaceous–Tertiary boundary: a worldwide biological crisis within an environmentally dynamic ecosystem

Was the transitory Cretaceous–Tertiary (K–T) boundary event by itself the instrument of destruction of much of the Earth's biota, including the dinosaurs, or was the Earth's biota already critically stressed? The boundary event occurred during the Laramide Orogeny and during a time of sea level regression. A general trend toward an increasingly wet environment, starting in the latest Maastrichtian, is recorded by the occurrence of gleyed soils and coal immediately below the boundary and by pervasive Paleocene coal-bearing and lacustrine sediments.

The initial evidence for a physically identifiable datum at the K–T boundary was the recognition of a geochemical (iridium) anomaly within a claystone intercalated between paleontologically defined Maastrichtian and Paleocene limestones at Gubbio, Italy. Subsequent studies have demonstrated the association of a worldwide boundary claystone containing anomalous elemental abundances, shocked quartz, soot, microspherules, and isotopic anomalies involving carbon, oxygen, and nitrogen, confirming a universal datum compatible with a paleontologically based K–T boundary. The above features and plant and animal extinctions support the hypothesis that one or more catastrophic events occurred at the end of the Cretaceous. Possible physical changes in the environment, postulated to result from the causal or associated events, include acid rain, an increased amount of pyrotoxins, the destruction of the ozone layer, and a greenhouse effect from increased atmospheric water and carbon dioxide. These are familiar environmental factors within a modern context.

Paleontology continues to direct the search for this unique boundary horizon. Once found, it provides a physically definable time line, formed by a geologically instantaneous event, against which regional and international biological events can be referenced. In this way, it is a useful stratigraphic datum for developing an understanding of the degree of abruptness of extinction events, the reasons for their selectiveness, and the recovery rate and resilience of the biota following a biological crisis. Microfossils such as the pollen and spores of terrestrial plants provide the high stratigraphic resolution necessary to address such aspects of change.

DIAG

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Interrelation between clastic and carbonate diagenesis in the Cambrian rocks in the subsurface of southern Alberta

The Cambrian section in the subsurface of southern Alberta is composed of quartzarenite, glauconitic sandstone, shale, limestone, and dolomite. These facies were deposited in environments ranging from supratidal to subtidal.

Both clastic and carbonate rocks were subjected to the same diagenetic and burial history. Diagenesis occurred in the shallow phreatic, marine phreatic, mixing, and deep-burial zones.

Blocky calcite cement and syntaxial rims around echinoderm fragments were precipitated in the carbonates in the fresh water zone. Precipitation of hematite and dissolution of K-feldspars occurred in the sandstone in this zone. Fibrous calcite cement formed in the carbonate in the marine-phreatic zone.

Mixing of fresh and marine formation waters at shallow burial depths resulted in a large number of diagenetic products in both carbonate and clastic rocks; *e.g.*, dolomitization of limestone, and the precipitation of illite, kaolinite, authigenic K-feldspars, quartz overgrowths, and carbonate cements in the sandstone.

Ferroan dolomite formed either under reducing conditions or in response to a high sedimentation rate. Consequently, ferroan dolomite is more abundant in dolomites that have been subjected to deep burial and in dolomite-cemented sandstones. At deep burial depths, mixing of upward-moving hydrothermal fluids with marine formation water resulted in the formation of ferroan and saddle dolomites. Chlorite formed in the sandstones in the deep-burial zone when Fe^{++} was available for diagenetic reactions.

RESM

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Reservoir quality analysis: an overview

Reservoir quality can be defined as a qualitative estimate of the ability of a rock to produce fluid, preferably hydrocarbon. It is generally determined using thin section petrography, scanning electron microscopy (SEM), and X-ray diffraction (XRD) techniques.

Potential problems that may affect reservoir quality include fine fraction migration, acid sensitivity, and swelling clays. The type and quantity of potentially damaging minerals, plus the position and morphology of this material with respect to the pore system, are significant.

In addition, porosity and permeability are obviously important with respect to reservoir quality. In general, exploration and development geologists use log and core analysis derived porosity (*i.e.*, total porosity). In many reservoirs, a significant proportion of the pore system consists of isolated pores that do not contribute to permeability. It is important to determine the proportion of effective *versus* noneffective porosity.

Drill cuttings can be small pieces of a prospective reservoir, though the information available from this material is not commonly incorporated into completion decisions. Most reservoir quality information that can be obtained from core samples can also be obtained from thin section and SEM examination of drill cuttings (*e.g.*, framework mineralogy, diagenetic mineral suite, pore types, etc.) In many cases, permeability and core analysis porosity can be empirically derived from cuttings.

The value of reservoir quality analysis in the determination of porosity and permeability controls plus drill cuttings analysis is illustrated in two case studies.

ENV1

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Assessment of potential groundwater contamination by migration of EOR production fluids

Enhanced oil recovery processes are potential sources of groundwater contamination. In areas such as Lloydminster and Cold Lake, Alberta, where heavy oil is produced from shallow deposits, production fluids may migrate and contaminate surficial aquifers containing potable water. The possible routes of contaminant migration include poorly or improperly abandoned wells, poorly completed wells, corroded operating wells, and natural or induced fractures in the geological material overlying the production zone.

A study site was identified at which shallow aquifers had been contaminated as a result of enhanced oil recovery activities. A modelling study was conducted to examine the potential routes by which contamination could have occurred, as well as the time frame required for production fluids to migrate to the affected aquifers. The results of the study are presented.

ECON

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Gas Transportation in the 1990's

Access to the natural gas pipeline system is the largest single constraint for a gas producer. The North American transportation grid will be significantly expanded in the early 1990's. New pipeline projects have been proposed that will provide for increased shipments of Alberta gas to California, the U.S. Midwest, New England and Eastern Canada. The underlying causes of the current round of expansions include deregulation of natural gas markets, open access to interstate pipelines, and increasing market demand.

These expansions will have significant implications for NOVA. Expansion will be needed to satisfy the export demands of producers. The cost of this expansion will ultimately be reflected in a higher cost of service. New marketing opportunities for Canadian gas producers will be created as a result. Examples of the new opportunities include: enhanced oil recovery demand in California, electricity generation in Ontario and New England, and increased demand by local gas utilities in the Midwest. Canadian gas exporters will benefit from expansion of the North American pipeline network, increasing from 1.5 Tcf in 1990 to 2.0 to 2.2 Tcf by 2000. The anticipated growth in exports from deregulation in 1985 through to the late 1990's will be discussed.

RESM

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Application of reservoir geology studies to enhanced oil recovery schemes in Upper Devonian Nisku reef reservoirs, Alberta

The Bigoray Nisku "C" pool and the Pembina Nisku "L" pool are two examples that illustrate the sedimentology, diagenesis and reservoir geology of the important West Pembina reef fairway. The Bigoray Nisku "C" pool is a partially dolomitized reef, measures 1.1 by 0.85 km and contains a productive area of 89 hectares. The ERCB recognizes an OOIP of 1209 10^3m^3 for the Nisku "C" pool. Ultimate recovery is estimated to be in the order of 523 10^3m^3 or approximately 43 per cent of the OOIP. This hydrocarbon recovery will be accomplished using a displacement type waterflood scheme. In contrast the Nisku "L" pool is a completely dolomitized reef and is being exploited by means of a crestal vertical displacement miscible slug EOR scheme. This pool measures approximately 2.0 by 1.5 km, and contains a productive area of about 219 hectares. With an estimated 5,000 10^3m^3 of OOIP, the Nisku "L" pool constitutes one of the largest pinnacle reefs discovered in the Nisku reef trend. Ultimate recovery is estimated to be in the order of 3,860 10^3m^3 or approximately 77 per cent of the OOIP. This high projected ultimate recovery is due to the miscible displacement enhanced oil recovery scheme and to the overall suitability of the reservoir to this type of scheme. These two pools illustrate the interplay between sedimentary and diagenetic processes, which have to be considered when evaluating proposed or ongoing EOR schemes. By understanding the geology of the partially dolomitized "C" pool, the morphology, internal geometry, diagenesis and control on reef development has been deduced for the dolomitized "L" pool. Consequently, these geological studies, in effect, help ensure a good "fit" between the engineers' simulation model and the actual reservoir. In turn, a realistic simulation will most likely determine the optimum design and operational parameters for the EOR scheme being evaluated.

CANF

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Understanding Canada's east coast hydrocarbon resource in the 1990's

A multidisciplinary research effort underway at the Atlantic Geoscience Centre attempts to develop a quantitative understanding of the hydrocarbon charge history of Canada's east coast basins. The usefulness of such research will lie in the capability of the models to predict the probable distribution, volume, and composition of undiscovered hydrocarbons for both well explored and under explored basins. Such models, ranging in scale from the molecular to the sedimentary basin, are being developed for four major elements within the project.

1. Source rock studies focus on predicting the probability of source rock occurrence.
2. Primary migration studies aim to establish the thermal, maturity, and pressure framework of the basins through time. A detailed source facies analysis will evaluate primary migration efficiency, which influences the volume and composition of hydrocarbons expelled from the primary system.
3. Second migration studies model fluid flow through aquifers, taking in account permeability barrier distribution and evolution. Emphasis is on the temporal and spatial relationship of migration and diagenetic events, together with the physical connectivity of the maturing source and aquifer systems.
4. Entrapment studies investigate trapping mechanisms and dynamics with an emphasis on detailed case studies.

Initially developed for high data volume areas of the Jeanne d'Arc and Sable basins, the predictive models and general processes are applicable in

other less well known basins. Attributes of the models will be subsequently melded into comprehensive, numerically constrained, hydrocarbon charge-risk analyses of east coast basins. The current status of these projects and plans for the next four years are discussed.

CANF

WILLIAMSON, M.A., Atlantic Geoscience Centre, Dartmouth, Nova Scotia B2Y 4A2; MUDFORD, B.S., Unocal Corporation, Brea, California 92621; and Smyth, C., University of Victoria, Victoria, British Columbia

A comparative study of the Venture and Glenelg gas fields offshore Nova Scotia: implications for gas migration dynamics

A comparative study of the Venture and Glenelg gas fields yields some insight into their respective gas migration history. Gas accumulations at Venture are geopressured and are associated with rollover into major east–west faults. These faults do not extend upward to breach the hydropressure-geopressure transition, which occurs (at 4500 m) in sediments that have a relatively high sand/shale ratio (1:1). Entrapment is provided by simple closure associated with the fault rollover. Fault closure, if present, is a minor element. Gas pay at Venture occurs in reservoirs that currently reside in the mature for gas zone (R_O = 1.2+). Conversely, Glenelg accumulations are hydropressured, and associated with major growth faults that not only penetrate the top geopressure zone but also extend upward to very shallow depths. Entrapment seems to be entirely fault seal dependent. The hydro-geopressure transition occurs at 3900 m in sediments that have a relatively low sand/shale ratio (0.45:1). Gas pay occurs in reservoirs that are not currently mature for gas (R_O = 0.9).

Numerical modelling of the maturity and pore pressure evolution of the two fields provides clues to their gas charge dynamics. In situ gas generation at Venture is an insignificant contributor to observed geopressures. A lateral gas charge has to be invoked to account for in-place reserves. At Glenelg, a significant vertical component to gas charge is required. It is postulated that the geopressure-penetrating growth faults in the Glenelg area have acted as conduits to gas migration, requiring that fault transmissivity for gas has changed through time.

DEV2/POST

WILLIS, A.J. and MOSLOW, T.F., University of Alberta, Edmonton, Alberta T6G 2E3

Reservoir architecture of the Middle Triassic Halfway Formation, Wembley Field, Alberta

The Middle Triassic Halfway Formation of the western Alberta subsurface is interpreted as a prograding barrier island shoreline deposit. A detailed sedimentological study based on 130 cored sequences and 300 well logs in the Wembley area (Twp. 72–73, Rge. 7–9, W6) has enabled us to delineate the geometry of reservoir units, interpreted as tidal inlet fill, upper shoreface, and flood-tidal delta sandstones.

Complete shoreface sequences average 15 m in thickness and form mappable trends tens of kilometres along depositional strike, but are only continuous for a few kilometres across dip, with the intervening areas having been reworked by one or more migrating tidal inlets. The strike-elongate inlet-fill sequences cover more than 50 per cent of the field area. They are typically 10 m thick and exhibit the best porosities due to leaching of bioclastic material in the lower part of the fill, but the downcutting of successive inlets makes the reservoir sands laterally discontinuous. Inlet sands extend updip into flood tidal delta sandbodies, which average 4 m in thickness and pinch out in lagoonal muds. Although also averaging 4 m in thickness and showing much greater lateral continuity than the other reservoir units, the upper shoreface sandstones do not exhibit biomouldic porosity and constitute a less productive unit. An understanding of the architecture of the various reservoir components present in a barrier island shoreline system is essential when planning a secondary recovery program.

POST

WITTENBERG, J. and MOSLOW, T.F., University of Alberta, Edmonton, Alberta T2G 2E3

Origin and facies variability of overthickened sandstones in the Doig Formation, west-central Alberta

Within the Middle Triassic Doig Formation of west-central Alberta, a number of anomalous sandstones occur that attain thicknesses of up to 60 m. These sandstone bodies have been previously interpreted as channel or valley-fill deposits. Evidence from core, dipmetre logs and regional cross-sections suggests that these sand bodies are deposited penecontemporaneously with the laterally adjacent sedimentary facies.

The fine grain size, oversteepened bedding - extensive elongation of sand body geometry along depositional strike, the confinement of the sand bodies to narrow trends generally less than 2 km wide, and the lack of bifurcating trends, suggest that these bodies are not related to channels. In core, the abundance of soft sediment deformation features, and presence of synsedimentary fault zones and lack of exposure surfaces also preclude the interpretation of these features as channels. Instead, it is proposed that the overthickening and linear geometry of the Doig sandstone is a product of eastward-verging, synsedimentary, listric normal faults at or near the shelf margin. Continued rotation and subsidence of slump blocks provide more room for the accommodation of sediment. Rotation of these blocks also accounts for the oversteepening and divergence of the dips of the strata in overthickened sandstones, as observed in core and dipmetre logs.

The overthickened sandstones are deposited as a series of normally graded beds or bedsets 0.5 to 5 m thick, are generally sharp based, and are interpreted as amalgamated sediment gravity flow deposits. These deposits have been reworked at their tops as a result of subsequent transgression preceding the initiation of the next progradational parasequence.

RESM

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Can variograms characterize reservoir continuity?

Reservoir continuity is an essential property for the characterization and development of heterogeneous reservoirs. Discontinuous permeable zones (*e.g.*, sand bodies) are usually associated with highly continuous permeability barriers (*e.g.*, shales) that cut through permeable zones. On the other hand, highly continuous, permeable areas often coexist with less continuous, low permeability rocks that are separated by the permeable areas. In terms of two phase spatial continuity, there is generally an opposite relationship between the two phases, *i.e.*, one phase is more continuous, whereas the other phase is less continuous.

Variograms have been extensively used to quantify spatial distribution of certain parameters, such as permeability. They provide information on the similarities for various distances and are a type of size measurement for all the features within a region. They also provide directional measurements and can be used to quantify reservoir anisotropy. However, variograms cannot be used to examine a single phase. A variogram always characterizes an entire region, which may contain both continuous phases and discontinuous phases. Variograms lack the capability to distinguish such different phases, and therefore are not adequate for characterizing the continuity of a reservoir.

POST

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Reservoir heterogeneities in lacustrine delta-front sandstones, based on outcrop studies

Unit III of the Jurassic Yan'an Formation in the northeastern Ordos Basin, China, is interpreted to have been deposited in a series of lacustrine deltas. Details of these deltaic deposits, particularly the delta front, are well exposed in the Kokawusu Valley, which runs perpendicular to the paleo- flow direction.

Outcrop-scale heterogeneities in the delta-front sandstones can be classified using the bounding surface heirarchy of Miall (1988). Delta-front deposits, comprising mouthbar and subaqueous channel sediments consisting of sandstone-siltstone alternations, are bound by fifth-order surfaces. Fourth-order surfaces define subaqueous channel sandstone bodies, and comprise the most important reservoir boundaries in these deltaic rocks. Channel sandbodies may be lensoid (a few tens of metres wide) to sheetlike, typically 200 to 400 m wide. Subaqueous channel sandstones have much better reservoir characteristics than do those of channel mouth bars. The former may have acted as major conduits for hydrocarbon migration. It is possible that three-dimensional, high-resolution seismic exploration may be capable of locating these channel sandbodies.

Third-order surfaces within channel sandstone bodies reflect the direction of accretion and aggradation of individual lithosomes. First- and second-order surfaces bound discrete lithofacies units within lithosomes.