SYMPOSIUM ABSTRACTS

EXPLORATION AND DEVELOPMENT: SUKUNKA-BULLMOOSE GAS FIELD, BRITISH COLUMBIA

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Two commercial gas accumulations have been confirmed at Sukunka and Bullmoose in the Rocky Mountain Foothills of British Columbia, 103 km (64 miles) southwest of the city of Dawson Creek. The gas is trapped in complex anticlines involving low-grade carbonate reservoirs of Triassic age. In addition, three separate discoveries, two in Triassic carbonates and one in Cretaceous sandstones, have been made in the general area. Proven and probable reserves of sour gas are estimated at 3.32 x $10^9 m^3$ (1.18 tcf). Sales gas is estimated to be in the order of 16.6 x $10^9 m^3$ (590 bcf).

The sequence of events leading to the pooling of Triassic gas are as follows:

- The gas is believed to have had its origin in the Upper Triassic. The relatively high H_2S and CO_2 content suggest an association with the anhydrites present in the underlying Charlie Lake Formation.
- Following minor erosion, the Triassic reservoir and source rocks were sealed by deeper water muds of the Jurassic Fernie Formation and were covered by a 3 660+ m (12 000+ ft) Cretaceous clastic sequence.
- Throughout the burial history, short distance migration of the hydrocarbons into locally permeable and porous carbonates and segregation in very low porosity, non-permeable sediments of the Upper Triassic occurred.
- The last significant event leading to the accumulation of gas in Triassic rocks was folding, faulting and fracturing of the more competent Pardonet/Baldonnel carbonates during the Laramide orogeny. This event resulted in re-migration of gas into closed anticlinal traps. Fracturing is also responsible for permeability enhancement of the original low-grade reservoir. AOF tests as high as 3.1 x $10^6 m^3/d$ (110 MMcf/d) have been recorded.

The events leading to the discovery of the Sukunka-Bullmoose gas field provide an interesting exploration case history. The Sukunka a-43-B discovery well drilled in 1965 followed nine years of geological surface mapping, geophysical work and drilling in what was then a frontier exploration region. Delineation drilling of three dry holes and unsuccessful geophysical work by Triad and other operators demonstrated the difficulty of geological and geophysical interpretation of the area.

The modern and successful phase of exploration came in 1975, 19 years after the start of exploration when the Bullmoose d-77-E well discovered gas in a separate structure. Two successful wells on the Sukunka, one on the Bullmoose structure as well as discoveries at E. Sukunka and Murray River have been drilled in 1976 and 1977. To the end of 1977, BP and partners have spent $49 000 000 in the area. Production is expected to start in 1980.

PETROLEUM POTENTIAL AND POSSIBILITIES ON THE NORWEGIAN CONTINENTAL SHELF

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The exact size of the Norwegian Continental Margin is not clear, since the delineation towards the deep Atlantic Ocean and U.S.S.R. in the Barents Sea is not finalized, but the area with significant sediment thickness is of the order of 1.5 x $10^6 km^2$.

Memoir 6 (1980)

Only the North Sea south of 62°N, approximately 150 000 km^2, has been exposed to exploratory drilling. 183 exploration and 75 production wells were spudded by September 15, 1975. 1.4 x 10^9 tonne oil/oil equivalents recoverable reserves have been discovered, of which about half is gas. The fields are located along the Central and Viking Graben, a N-S running Mesozoic basin along the central North Sea. Three horizons have proven to be the main reservoir rocks:

- Middle Jurassic sandstone. Statfjord most prominent field.
- Maastrichtian/Danian chalk. Ekofisk most prominent field.
- Paleocene/Eocene sandstone. Frigg most prominent field.

NPD has risk evaluated undrilled structures and concluded that another 2 x 10^9 tonne oil/oil equivalent recoverable reserves are to be found. Structural and stratigraphic possiblities of further reserves will be discussed.

Evaluation of the area north of 62°N is based mainly on NPD's seismic surveys. The three main areas to be discussed are:

- The Møre-Lofoten between 62°N-69°N
- Barents Sea north of 70°N
- The Jan Mayen area

The first two areas are the most extensively explored and considered to be the most prospective. A number of basin developments of different types are defined. Favourable conditions for formation and accumulation of substantial amounts of hydrocarbons prevail over extensive parts. The two areas are generally considered highly prospective, but variations within them will be discussed.

The Jan Mayen ridge is a continental block with sediments of considerable thickness. The possibility of commercial HC-deposits is highly questionable but should not be ruled out.

ORGANIC TYPE AND COLOUR, AND HYDROCARBON POTENTIAL: OFFSHORE EASTERN CANADA

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Diverse views on the meaning of the term kerogen highlight the general absence of a standard terminology in visual studies on dispersed organic matter. At present there is no objective, purely morphological classification of organic material observed in transmitted light. Thus the terms amorphogen, phyrogen, hylogen and melanogen have been proposed for the four types recognized in our studies. Over 250 000 m of sediments from 75 wells drilled on the Scotian Shelf, Grand Banks and Labrador Shelf have been examined for organic type and colour. Organic type is closely related to the age of sediments, geographic location and depositional environments; amorphogen being most common in marine strata and hylogen in nonmarine sediments. In most wells examined the combination of organic type and colour indicates poor source rock potential for hydrocarbons. Exceptions are the Labrador Shelf and locally on the Scotian Shelf and Grand Banks, where the organic matter may reach maturity.

FIFTY YEARS OF EXPLORATION PROGRESS — MICROPALEONTOLOGY STILL SITTING IN A RESEARCH LABORATORY

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Apropos to the spirit of the Canadian Society of Petroleum Geologists' 50th Anniversary and World Oil Occurrence, we should ensure that our applied exploration technology is not falling behind the rest of

the world as recently reported by the Canadian Science Secretariat for other industries. We pioneered Paleozoic carbonate and reef technology and apply the techniques on most well site work. Mesozoic clastic and deltaic technology has not utilized available well site techniques such as micropaleontology. Similar oil exploration programs in other parts of the world staff the well site complement with biostratigraphers.

A review of rock types and laboratory extraction for recovering micro-fossils is compared with suggested well site procedures and equipment. The advantages and limitations of utilizing a biostratigrapher at a well site are also compared with the generally accepted practice of operating with a lithostratigrapher. Future economic considerations including conservation of energy with regard to air shipment of samples, are equally applicable to exploration by the energy industry. This may dictate more self-contained units at the drill site, in particular at locations such as the new frontier areas of the offshore and the arctic.

HYDRODYNAMIC FRAMEWORK OF THE EASTERN ALGERIAN SAHARA: ITS INFLUENCE ON HYDROCARBON OCCURRENCE

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The purpose of this presentation is to show how patterns of water pressure, salinity and chemical content within a basin can give much useful information for oil exploration. The Eastern Algerian Sahara is a good example where a substantial increase in exploration efficiency has been achieved by combining regional hydrodynamic studies with classic geological and geophysical studies. This prolific area shows a wide variety of hydrodynamic phenomena. Two distinct areas, each with its own "style" are present.

The *Northeast Sahara basin* roughly coincides with the limit of Triassic salt occurrence. Within this basin, reservoir beds are sealed both vertically and laterally, and are under abnormally high pressure. No flushing has taken place. The chemical characteristics of underground water are uniform within the basin.

The *Southern basin* coincides with the *Illizi sedimentary basin.* Slightly saline water moves hydrodynamically from the outcrops towards the central part of the basin. Hydrodynamic studies are of value here in defining the most prospective zone; in understanding the oil entrapment mechanism, and in facilitating correlations between different reservoirs.

CHEMICAL AND ISOTOPIC EVIDENCE OF THE ORIGINS OF NATURAL GASES

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Natural gas is generated throughout the burial history of sedimentary rocks. Three principal stages of gas generation are recognized. In the first stage, anaerobic bacteria reduce carbon dioxide to form methane during the earliest, low-temperature stage. Later, methane is generated along with other gaseous and liquid hydrocarbons during the thermochemical transformation of organic matter to petroleum. Finally, methane is formed as a stable residual end-product when increased burial temperatures result in the thermal destruction of organic matter. The gas formed during each of these stages has a characteristic chemical composition and stable carbon isotope ratio of methane. Bacterial gas is predominantly methane that is isotopically light ($\delta^{13}C$ = -90 to -50 per mil). Methane originating during the thermal generation of petroleum is always accompanied by ethane and heavier hydrocarbons, and is isotopically heavier ($\delta^{13}C$ = -55 to -35 per mil). Natural gas formed as a result of prolonged high temperatures becomes increasingly devoid of heavier hydrocarbons, but has higher contents of inorganic gases (CO_2, H_2S, N_2). The isotopic composition of methane produced in this final stage

approaches that of the parent organic matter ($\delta^{13}C$ = -30 to -25 per mil). Natural gas accumulations show a continuous gradation of chemical and isotopic compositions between these characteristic end-member types. Three major factors produce these gradations:

1) mixing of gases of different origins;
2) temperature-dependent isotopic fractionation; and
3) source-dependent chemical fractionation.

For any given gas accumulation it may be difficult to determine the controlling factors on the basis of gas analysis alone. Consequently, a knowledge of the chemical nature of the organic matter and of the geologic history of a source bed is needed. Examples of gas accumulations and the relative importance of mixing vs. fractionation, as they relate to isotopic and chemical composition, are illustrated with examples from the Cook Inlet, Alaska; Texas-Louisiana offshore, Gulf of Mexico; Cretaceous of the northern Great Plains; and Devonian black shales of the Appalachian basin.

GEOMETRY AND DISTRIBUTION OF SAND BODIES IN DELTAIC ROCKS

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Subsurface deltaic sand bodies have produced considerable quantities of hydrocarbon. Recognition of these features and understanding of their geometry and distribution are essential for efficient exploitation. In low-tidal, low-wave-energy deltas that debouch large volumes of sediment, three major types of sand bodies are formed that display reservoir characteristics: crevasse splay or bay fills, distributary mouth bars, and downslope displaced slump deposits. Each of these sand bodies displays characteristic, recognizable vertical sequences and lateral relationships with adjacent deposits. The displaced slump deposits are highly productive in Tertiary sequences. Deltas prograding into regions characterized by high tidal range display three major sand facies: offshore tidal ridges, distributary channel fill, and tidal channel sands. The offshore tidal ridges are exceptionally large, clean sand accumulations and have distinctive isopach characteristics. Channel fill and tidal channels display less lateral continuity but can accumulate to thicknesses on the order of 18-21 m (60-70 feet) and normally display sharp erosional basal contacts. Extreme wave energy along some delta coasts results in the formation of extensive beach-dune complexes that often form laterally continuous blanket sand facies. These sand bodies are normally massive in nature and show little variation in grain size. High quartz content is commonly associated with these deposits. In basins where high tides and high wave energy levels exist, thin (6-9m, 20-30 ft) but laterally persistent tidal flat deposits often form the major sand body type within the delta sequence. Scour and sandy infilling of distributary channels through the tidal flat deposits results in highly complex geometry. In these instances, porosity and permeability relationships often control hydrocarbon accumulation.

Each of the sand bodies will be described in terms of their environmental setting, and processes and descriptions of their internal bedding will be illustrated. Schematic sand body isopachs and log characteristics and variations will be illustrated.

RESEARCH TRENDS IN THE FUTURE SEARCH FOR WORLD PETROLEUM

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Review of the past ten years of research and development in petroleum exploration throughout the world demonstrates the frequently changing pattern of emphasis and identifies the controlling factors and principles. Changing political and commercial attitudes, environmental controls, the pressures of population and energy demand, as well as availability, are among the parameters which will be reviewed. Against this background an attempt will be made to identify forward trends of research, not only in the technological fields of petroleum geology — geophysics, geochemistry, reservoir analysis, geotechnical engineering — but also in the environments that lie ahead and the pressures on commercial exploration.

PROS AND CONS OF ZIPF'S LAW AS A RESOURCE APPRAISAL TOOL

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A hopefully accurate prediction of the total amount of a resource material, of which only a part has been discovered and produced, is the major objective of a resource assessment. Such points as how many deposits remain to be discovered; how rich will they be as individuals and what will be their total volume must be addressed. Inferences from empirical or mathematical models generally based on analogs are generally utilized.

Zipf's Law (Zipf, 1949), when applied to mineral resource populations, postulates most simply that the largest will be twice the size of the second, three times as great as the third, and one hundred times bigger than the hundredth, etc. This implies that deposits become infinitesimally small as their number goes to infinity. When deposit or pool size versus rank is plotted on double logarithmic paper, the law graphs as a straight line with a slope of minus one. The Y intercept, with size as the ordinate, equals that of the item designated as first rank. The correspondence of actual sets of hydrocarbon, uranium and metallic resource data to the Zipf line is tantalizingly tight in many instances, though heroic assumptions must often be made.

With Zipf's Law, Follinsbee (1977), from 300 giant fields, predicted a worldwide initial reserve of 149 x 10^9m^3 (942 billion barrels) to be yielded by 300 fields and 288 x 10^9m^3 (1814 billion barrels) accounted for by 100 000 pools of greater than 238 x 10^3m^3 (1.5 million barrels) (if they can be found).

Rowlands and Sampey (1977) concluded from Zipf that 65% of the Zambian stratiform copper deposits still remain to be discovered.

Zipf's Law suggests also (assuming Provost to be the largest) that 660 Viking oil pools, with initial in-place reserves of at least 159 x 10^3m^3 (a million barrels), exist in Western Canada. If Provost is really the *second largest* Viking pool, the Law proclaims the existence of a yet-to-be discovered pool of greater than 159 x 10^6m^3 (a billion barrels), a real exploration plum!

PROBABILITY METHODS AND ASSESSMENT OF DRILLING OUTCOMES IN FRONTIER AREAS

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Accurate estimates of the probability of success in drilling ventures in frontier areas, such as the National Petroleum Reserve in Alaska (NPRA), are essential if these areas are to be developed rationally. Unfortunately, by definition, frontier areas have no extensive history of drilling and production on which to base estimates of their potential. Evaluations must be highly subjective, based upon intuitive appraisals, estimates of the volume of sedimentary rocks within the basin that might be productive, and qualitative comparisons with more thoroughly explored regions that appear geologically similar. These regional evaluations are highly uncertain and may be unduly influenced by the biases of those making the appraisals.

More accurate and reliable estimates of the probability of discovery within frontier plays may be obtained by systematic, quantitative comparisons with analogous regions. If no subsurface information is available in the frontier area, estimates of the probability of a discovery in a drilling venture must be based on geometric probabilities derived from statistics on field sizes in the analogue areas. However, if seismic information is available, the probability of success may be dramatically altered. The marginal increase in probability of success due to seismic coverage can also, with proper data, be estimated from analogue areas.

Constructing probability distributions in analogue areas may be arduous and frustrating, especially if proprietary seismic data must be considered. However, unpublished studies of the offshore U.S. Gulf Coast serve as an example of how such probabilities can be obtained, and indicate the improvement in probability estimates that result from detailed seismic information. Although the Gulf Coast is not an appropriate analogue for plays within the 95 800 km^2 (37 000 square miles) of the Petroleum Reserve in Alaska, the Gulf Coast study is relevant because it indicates the approximate effort that must be expended in an analogue study which involves seismic factors. NPR-A, as of August 1977, contains over 12 400 km (7 700 miles) of seismic lines and only 42 wells, so success probabilities for the area must be strongly conditional upon seismic results.

SALT REMOVAL AND OIL ENTRAPMENT

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Salt removal is one of the major, if not the most important hydrocarbon trapping mechanism in Western Canada. This phenomenon not only produces major trapping by creating simple structural reversal along the updip basin rim, but through contemporaneous salt removal at time of deposition of the reservoir and through multi-stage removal creates more complex structural stratigraphic trap conditions. Salt removal is the primary trapping mechanism for the trillion barrel belt of Lower Cretaceous heavy oil and oil sand deposits which stretches along the rim of the Western Canada Basin from the Cantaur-Success Field Area of Saskatchewan to the Athabasca Oil Sands Area of Alberta. The oil trapping has been brought about by removal of salt from the Middle Devonian Elk Point Group during Cretaceous and possibly early Tertiary time. Another major producing trend, the Nipisi-Mitsue Middle Devonian Gilwood Sand Trend, containing in excess of 79.4 x $10^6 m^3$ (500 million barrels), is stratigraphically trapped, with the trap being created by removal of salt from the Elk Point during Gilwood time. A multitude of other smaller trapping situations due to salt removal are evident in Western Canada, in the United States portion of the Williston Basin and in the Michigan Basin. In Western Canada removal of salt from the Upper Devonian Wabamun and Woodbend Groups, in addition to the Middle Devonian Elk Point Group, has produced oil and gas traps. Multiple stage differential salt removal has created complex traps such as the Hummingbird in Southeastern Saskatchewan. Inlier traps, such as the Westhope field in North Dakota, are a result of local late Mississippian salt removal preserving the producing beds from post-Mississippian erosion. Salt remnants of the Silurian Salina Group in the Michigan Basin have created structural drape traps in overlying beds.

Salt removal, besides creating trap conditions, significantly affects the mapability of underlying reef accumulations and in mapping of prospective trends. The Zama-Rainbow Middle Devonian Keg Reef Trend of Northern Alberta and the Silurian Niagaran Reef Trend of Michigan are examples of salt removal affecting the geological and geophysical mapping. Salt removal requires a much more prominent place in the world oil literature.

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The Peace River Arch is a major tectonic interruption of the Alberta-British Columbia sedimentary basin. The Arch, as a whole, has no surface expression and its existence wasn't suspected until uncovered by deep drilling for petroleum in the late 1940's.

The Arch, formed in post-Cambrian time, remained positive during much of the Paleozoic and was not completely buried until early Mississippian. During Upper Devonian time, a major fringing reef complex developed around the Precambrian high and is the site of some of the earliest discoveries. In Carboniferous time, the Arch literally collapsed and about 900 m (3 000 feet) of Carboniferous sediments were deposited over the former crestal area.

Regional tilting dominated throughout Mesozoic deposition, until the Laramide orogeny produced another period of structural deformation. The unique tectonic history of the Arch produced a complex series of structural and stratigraphic traps, many of which have been successfully mapped by seismic methods. The most common structural traps are drape structures over Precambrian highs, normal faults, and Laramide folds, which are also generally associated with the older faults.

Significant hydrocarbon reserves have been discovered in Middle Devonian, Upper Devonian, Mississippian, Permian, Triassic and Cretaceous reservoirs. Ultimate recoverable reserves at the end of 1976 were about 122 x $10^6 m^3$ (769 million barrels) of oil and 113 x $10^9 m^3$ (4 tcf) of marketable gas. In view of the dynamic structural history, the presence of multiple reservoirs and the broad distribution of oil and gas occurrences, the Arch area should have reserves significantly larger than those found to date. The largest gas pool is Dunvegan where about 26.8 x $10^9 m^3$ (950 bcf) of marketable gas is pooled in Mississippian Debolt carbonate reservoirs, separated by anhydrite interbeds. Pressure evidence and different gas water lines indicate the presence of separate reservoir compartments. An up-dip normal fault provides an effective barrier to fluid movement.

In recent years, improved seismic data gathering and processing techniques and the use of reflection amplitude, or direct hydrocarbon indicators, have resulted in the discovery of a number of new pools. Further significant discoveries can be anticipated.

HYDROCARBONS OF THE MESOZOIC BASINS OF WESTERN AUSTRALIA

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The tectonic events related to the rifting and drifting of Eastern Gondwanaland directly control the distribution of hydrocarbon source and reservoir rocks in the Mesozoic basins of the continental margin of Western Australia. Directly or indirectly, the tensional forces involved are responsible for most entrapment situations. Exploratory drilling has been carried out in the Perth, Carnarvon, Canning, Browse and Bonaparte Basins. Of these only the offshore Canning Basin has so far failed to yield hydrocarbons. Undrilled areas, which are indicated by seismic to have thick Mesozoic sections, are the Houtman Sub-Basin and the Exmouth Plateau. These are located in deep water west of the Carnarvon Basin. Initial rifting of the Gondwana continent began in late Permian. This was followed by a widespread marine transgression and shale deposition in Lower Triassic. From Middle Triassic to Middle Jurassic a regressive deltaic cycle prevailed. Major rifting in early Upper Jurassic produced a series of deep linear troughs in which thick marine shale sequences were deposited, except in the Perth Basin where continental arenaceous deposition occurred. This rifting phase preceded the drifting apart of the Gondwana continent. Concomitant with drifting the marine transgression extended and by early Upper Cretaceous all the positive areas were covered. From this period until late Tertiary, open marine deposition prevailed, interspersed by several hiatuses. Hydrocarbon source rock analyses indicate that sediments from Lower Triassic to Lower Cretaceous can yield oil as well as gas. The number of oil and gas discoveries is approximately equal. However, in magnitude of reserves, gas predominates. Chemical analyses show that two basic types of oil exist, believed to be derived from marine and terrestrial sources respectively. The latter type is the more frequently occurring. This could mean that oil generated from the great volume of marine sediments in the area remains largely undiscovered.

'FLYSCH-TYPE' ARENACEOUS FORAMINIFERAL ASSEMBLAGES IN UPPER CRETACEOUS-PALEOGENE SEDIMENTS OF THE EAST NEWFOUNDLAND BASIN, LABRADOR SEA AND NORTH SEA — PALEOGEOGRAPHICAL AND PALEOECOLOGICAL IMPLICATIONS

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This study explores the paleoecological significance of richly diversified, predominantly arenaceous foraminiferal assemblages in Upper Cretaceous-Paleogene fine-grained clastics from the East Newfoundland Basin, Labrador Sea and North Sea Basin. The faunas resemble those commonly associated with flysch deposits in various parts of the world. The paleoecological and paleobathymetrical significance of flysch-type faunas, and the depositional environment of flysch sediments, have been topics of an extensive literature and encompass a wide divergence of opinion. For example, flysch-type faunas have been interpreted as indicators of great (oceanic) depth, of shallow, nearshore realms, and are being essentially related to potential hydrocarbon source rock. A recent recovery of rather similar agglutinated faunas in Upper Cretaceous-Paleogene deep sea sediments located above oceanic basement, has provided an independent means of making paleobathymetric estimates using age vs. depth subsidence curves. The method indicates that such fossil faunas occur at water-depths of 2.5 - 3.5 km, which may serve as a lower depth limit. A recently published model emphasizes the importance of a number of inter-related physico-chemical factors at or near the sediment-water interface in accounting for faunal distribution. This model, which appears to be a function of somewhat restricted circulation, may provide an adequate explanation for the extensive bathymetric range and variety of biotopes these agglutinated foraminiferal faunas are capable of inhabiting. Application of this model to the East Newfoundland Basin, Labrador Sea and North Sea agrees well with the postulated tectonic evolution and paleogeography of these regions and illustrates the use of these faunas for basin analysis.

PROBABILISTIC RESERVES ESTIMATION, TAGLU GAS FIELD, CANADA

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Gas reserves were discovered in Tertiary age sands at Taglu in 1971. Difficult logistics, remoteness and delay in reaching potential markets precluded preinvestment in early and complete development drilling. Consequently the field has been delineated by a series of seismic surveys and six wells drilled over a span of seven years.

Estimates of the reserves are affected by variability in the seismic data used to interpret the structure of the field. Uncertainties also exist in each of several parameters used to calculate reservoir volume and hydrocarbon recovery. Imperial Oil Limited's reservoir engineers and geologists have coped with these uncertainties and with continual addition and improvement in data by using a computerized reserves calculation program. The program accommodates ranges and probabilities for the various reserves calculation factors. Reserves estimates are displayed as ranges of reserve sizes with probabilities attached to specific values in the ranges.

The approach encourages disciplined examination of all reservoir data, reveals significant uncertainties in reserves estimates and provides a means to communicate these uncertainties and relate them to development planning and investment decisions.

CLUSTER ANALYSIS INTERPRETATION OF RECENT AND SUBSURFACE BIOSTRATIGRAPHIC DATA

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Cluster analysis of published foraminifera and palynologic data from the recent Gulf Coast and Orinoco Delta, and company data from subsurface Mackenzie Delta and Canadian East Coast offshore, was undertaken in an effort to establish meaningful interpretation of subsurface biostratigraphic data. These data were integrated with sediment, hydrographic, well cuttings, core and well log data, in order to effect an integrated sedimentologic-biostratigraphic understanding of the results.

Interpretation of the above cluster analyses indicates the level of resolution applicable to subsurface data, and provide reasons for much of the difficulty of interpretation. Problems related to sampling density, and sample contamination are more readily recognized and can often be overcome. Abundance trends and species interrelationships which cannot be recognized otherwise, become quite meaningful when correlated with sediment or lithology. R-mode can be mapped indirectly. The results indicate such analysis is applicable to any part of the geologic record containing adequate paleontologic information. The data utilized can be expanded to include as many parameters as desired.

This study emphasizes the need to redefine philosophy and objectives in exploration biostratigraphy. Interpretation of core, logs and lithology is necessary to permit facies considerations. Advance planning to long-term projects having broad general applicability, but which are compatible concurrently with short-term exploration needs, must become standard procedure. Expansion of interpretation capability beyond the usual "tops" or "age" approach will improve credibility with other exploration disciplines. Breakdown of resistance to utilization of statistical approaches is necessary before their value can be fully appreciated. The technique works and provides very useful results. However, it requires learning experience, the willingness to maintain an open mind, and the recognition that it may not be justified for some studies.

NEW RESOLUTION IN SEISMIC

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Within the last seven years the geophysicist has teetered on being called a "doodle bug", that is a person whose exploration techniques are scientifically questionable. This dubious opinion of the seismic state-of-art was a natural consequence of the rapid development in seismic interpretational techniques for delineation of stratigraphic traps. Most of these new interpretational techniques were based on amplitude studies.

Seismic amplitude, however, was not the only parameter to be reinvestigated for detecting stratigraphic traps and predicting their shape and petrophysical properties. Efforts to improve the prediction accuracy (seismic resolution) also involve an interplay of the modern acquisition and processing techniques. As an example, the vertical and horizontal extent of small stratigraphic traps cannot be estimated independently from seismic data but must be investigated together using 3-D seismic data. This data would be easier to interpret if it were wavelet processed and if the data are not migrated a 3-D amplitude study must be conducted.

In an effort to quantify the state-of-art for seismic resolution, several rules of thumb have been developed which relate the seismic parameters (phase, amplitude, frequency content, reflection timing and velocity) to the principal stratigraphic parameters (porosity, lithology and body shape). These rules of thumb are applied to both real and model data.

APPLICATION OF PETROLEUM GEOCHEMISTRY IN THE NOVA SCOTIA SHELF AREA

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Shell Canada has obtained geochemical data on samples from 56 of the 67 wells drilled to January, 1978, on the Nova Scotia Shelf. This paper discusses the use of these data, combined with other data, in evaluation of the oil and gas potential of the shelf.

Interpretation includes source rock identification, regional maturity considerations, oil classifications, hydrocarbon shows, and migration aspects. For a source rock to be capable of expelling oil and gas, minimum values in three parameters are required, organic richness, organic type, and maturity. By this definition well-developed source rocks have not been penetrated. Only the very deep tests reach rocks of sufficient maturity for oil and gas expulsion. Potential source rocks are indicated by scattered occurrences of thin, organic-rich, lipid and humic laminae, the best of which are in the Verrill Canyon Formation of the Sable Basin, and the Iroquois Formation of the Abenaki Basin. Chemical analyses of 22 oils and condensates from seven wells characterize the oils into two typing groups, one from each basin, supporting the presence of only two source rocks or types of source rocks. Hydrocarbon shows determined from mud logs, oil staining fluorescence, as well as actual accumulations, are almost entirely confined to the two basins. This distribution of shows is interpreted to result from localized source rock development, and the existence of vertical communication from deep source rocks to shallow reservoirs, primarily by means of piercement-associated faulting.

Based on presently available geochemistry data, interpretation suggests that the best exploration potential for the Nova Scotia Shelf is in the Abenaki and Sable Basins, where accumulations have already been found.

THE ROLE OF COMPUTER SYSTEMS AND GEOMATHEMATICS IN PETROLEUM EXPLORATION

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Geological applications of computers and geomathematics to petroleum exploration and exploitation are described and evaluated under the following headings:

1) Data storage and retrieval;
2) Summarization of data;
3) Data analysis;
4) Search techniques;
5) Resource estimation.

Data storage and retrieval systems form the backbone of most exploration programs. These files have grown in content and sophistication from small, highly specialized collections of project-oriented data to enormous, generalized data bases containing a variety of subject matter. The impetus for development of storage/retrieval systems has been the tremendous expansion of available information and the need to make information quickly available to geologists. In general, the nature of the information stored has encouraged the continuation of traditional exploration methods. With the data bases of much larger scope now becoming available, applications not possible prior to their development became possible, that is, the data base itself generates new applications. Prime sources of information are commercial and government agencies augmented by in-company collection on special projects.

Summarization and presentation of data by computer means has evolved in direct proportion to hardware and software advances. Beginning with simple listings by line printers, systems have evolved to the

point where on-line video or hard copy displays are being produced directly by the working geologist. Sophisticated mapping routines, coupled with base-map programs, provide quick visual displays of data base information in the form of contour maps, facies maps, lithology logs, cross-sections and production statistics. Hardware and software advances are certain to increase the sophistication of techniques in this area of application.

Analysis of geological data by mathematical and statistical procedures does not appear to have gained as widespread usage in exploration activity as the variety of available methods would suggest. Most effort has gone into the development of mapping procedures which do receive routine usage. Trend-surface analysis, for example, is extensively used by many explorationists. But such methods as factor-analysis and pattern-recognition are rarely used outside research laboratories. Simulation of geological models, another technique of much academic promise, appears not to have caught on as an exploration tool. Simulation of reservoir performance is, of course, routinely used by engineers.

Interest in the development of probability based search models is on the increase. The exact nature and amount of routine use is, however, shrouded in secrecy. Several recent publications suggest that search model methods have received a great deal of research and have become fairly sophisticated. Although one of the first publicized geomathematical exploration methods (Dowd, 1961), early applications have not apparently proven successful enough to warrant widespread acceptance by working geologists.

Resource estimation of pools, basins and nations by means of mathematical models has developed into a major science in its own right. One such analysis by the Geological Survey of Canada has affected federal government energy policy. A variety of methods, ranging from rather simple probability models to extremely complex systems is used, but the final verdict as to their effectiveness has not been reached. A model specifically designed for petroleum and gas occurrence has not been developed as is the case with the mineral evaluation game.

DEEP BASIN GAS TRAP, WESTERN CANADA: THE CONTAINER FOR ELMWORTH

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Gas accumulations are distributed in a similar fashion to most other natural resources. The high grade deposits are comparatively small. In general, as the grade decreases the size increases.

Three of the largest sandstone gas fields in western North America are in low porosity - low permeability Cretaceous sands, in down-dip structural locations, with porous, water filled reservoir rock updip. Examination of the details of these fields sets the stage for recognizing an enormous tight sand gas trap in western Canada.

The Mesozoic rock section, only 300 m (1 000 ft) thick on the shelf in eastern Alberta, thickens westward to over 4 500 m (15 000 ft) in the deep basin in front of the Foothills overthrusts. Most of the developed sandstone gas fields are in updip porosity traps, or minor structural traps, on the shelf. The porous, generally water saturated sands of the shelf become less porous and permeable westward and downdip, passing from the water bearing area with local gas traps through a transition zone to a gas bearing area. This change is demonstrated by electrical resistivity logs and confirmed by drillstem tests.

Recent exploratory drilling in the deep basin has resulted in numerous discoveries in the area. Several hundred log analyses provide reliable data for measuring potential gas supplies in the range of 11.3 x $10^{12}m^3$ (400 tcf). Recoverable gas at \$2.00 per mcf net after royalty may reach 4.22 x $10^{12}m^3$ (150 tcf).

The quantities of gas apparently present would be a major addition to the North American energy supply.

OFFSHORE GEOLOGY AND HYDROCARBON POTENTIAL OF THE UNITED STATES

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In 1973 the U.S. Geological Survey initiated an oil and gas resource appraisal program having the following objectives:

1. To develop new methods for oil and gas resource appraisals that will permit the systematic collection and evaluation of basic geological and geophysical data from petroleum provinces throughout the United States and selected areas of the world;
2. to apply these methods to making detailed appraisals of the oil and gas resources, both offshore and onshore, of the United States and other specific areas of the world.

The procedures developed under this program facilitate the evaluation and use of all geological and geophysical data in reference to specific geologic provinces. As new and more detailed oil and gas data are compiled, particularly field and reservoir information on specific stratigraphic units and producing or prospective trends, the appraisal techniques become more sophisticated and their focus narrows from the total province to individual stratigraphic units. Finally, modified play-analysis techniques are employed for resource analysis, but still within the framework of each geologic province. A brief review is given of the resource appraisal procedures presently being used by the Resource Appraisal Group.

Interpretation of the geology of each potential petroleum province provides the basis for the resource appraisals discussed in this report. The geologic provinces of the offshore areas of the conterminous United States and Alaska are outlined and the basic geology is reviewed as known to date. The latest estimates of hydrocarbon potential for the offshore areas of the United States are reported in graphic form as probability distributions accompanied by updated maps and summary tables. Appraisals are made in all of the offshore areas to 200 m water depth. In areas which are thought to have greater petroleum potential, the appraisals are carried out to 2 500 m water depth.

A detailed report by Betty M. Miller and others, entitled "Geological Estimates of the Undiscovered Recoverable Oil and Gas Resources in the United States", was published in 1975 (U.S. Geological Survey Circular 725). The report included resource estimates for all offshore provinces of the United States to 200 m water depth. Since the publication of this report, more comprehensive studies have been completed for the Gulf of Mexico out to 2 500 m water depth. The comprehensive resource appraisals of the offshore provinces of the eastern United States and Alaska that are currently in progress will incorporate more detailed geological and geophysical data than were available in 1975.

GRAPHIC CORRELATION: A NEW CONCEPT FOR BIOSTRATIGRAPHY

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Traditional methods of paleontologic correlation based on assemblage zones are not capable of establishing the fine, detailed subdivisions of the rock column which are needed to accomplish accurate time-stratigraphic geology. These methods are based on the *local* stratigraphic range of fossils and use of relative geochronologic time scale with unequal units such as geologic periods and epochs as subdivisions. At best, correlation zones established by the traditional methods are broad and not necessarily time equivalent.

The graphic correlation method proposed by Shaw (1964) is a new method of paleontologic correlation which is practical and capable of establishing fine time zones with definite boundaries which can be traced over wide geographic areas. The technique involves a graphic plot on a simple two-axis graph — a "standard reference section" always plotted on the horizontal axis, and another section plotted on the vertical axis. The graphic plot is based on the *total* stratigraphic range of the fossils contained in both sections, and visibly displays the best time correlation between the two sections.

The graphic method of correlation uses a workable chronologic scale which differs from both an absolute and relative geochronologic time scale. This new scale can be quantified and used as an accurate measure to subdivide the rock column into fine time stratigraphic zones (Composite Standard Units) with definite boundaries for local and regional correlations.

The method of determining the total stratigraphic range of fossils and of establishing the chronologic scale is explained and illustrated. Biostratigraphic correlations of Upper Cretaceous rocks of Colorado and Wyoming based on graphic correlations are used as illustrations. Applications of the method useful to petroleum exploration are discussed and illustrated.

STRUCTURAL CONTROLS OF GIANT OIL ACCUMULATIONS

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The giant oil fields of the world contain 76% (125 x 10^9m^3, 787 billion barrels) of the total proved and prospective ultimate reserves and the giant gas fields contain 66% (54.5 x 10^9m^3, 343 billion barrels oil equivalent) of the total equivalent ultimate reserves. Although the combined oil and gas giants are shown to contain 73% of the total reserves of the world, inaccuracies in the data lead us to conclude that the giants contain 70-75% of the total.

The post-Lower Jurassic hydrocarbon "bloom" is thought to reflect mostly preservation from erosion, but also protection from seepage, biodegradation and thermal destruction. The most profound events affecting this preservation pattern may be the Hercynian (sub-Permian and sub-Triassic) orogenies that may have been accompanied and/or followed by major changes in the earth's heat flow and energy balance.

Studies show that fourteen well-known "tar" deposits, predominantly in rocks of post-Lower Jurassic age, are estimated to contain some 413 x 10^9m^3 (2 600 billion barrels) of hydrocarbons in place. These hydrocarbons, plus the reserves in the conventional post-Lower Jurassic rocks, make these the most prolific reservoirs by far. The change in order of reserves between Ghawar oil field and the Cold Lake, Olenek, Athabasca and Orinoco tar fields is probably meaningless because of the large estimation errors. But surely somewhere in the world there must be at least one producible "megasupergiant" (a field larger than the 13 x 10^9m^3 (83 billion barrels) at Ghawar). Also unknown is how many of these megasupergiants may have been removed by Plio-Pleistocene erosion alone, not to mention the rest of Phanerozoic time as evidenced by the fragmented nature of the stratigraphic section, both horizontally and vertically.

Future giant oil and gas discoveries will further enlarge the post-Lower Jurassic hydrocarbon bloom because the remaining unexplored areas are on the continental margins where the bulk of the sediment is almost entirely of Mesozoic and Tertiary age.

The structural setting of the giant oil and gas fields of the world is dominated by globally pervasive meridional and equatorial horizontal stress systems. This fact must form the backbone of any sound tectonic scheme that would explain both oceanic and continental wrench regmatic patterns.

ALBERTA ENERGY RESOURCES DATA — PAST, PRESENT AND FUTURE

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This paper provides a review of the methods of acquiring, processing and disseminating basic energy resource data within the Province of Alberta.

For many years, the Alberta Government, through the Energy Resources Conservation Board, has had a policy of encouraging dissemination of energy resources data. Data in this context is the non-

proprietary, non-confidential, and generally non-interpretive data required by engineers, geologists, accountants and administrators in both industry and government.

The traditional method of acquiring and disseminating the data was oriented towards visual records with manual transcription of data to summary reports. Since approximately 1966, both the Energy Resources Conservation Board and industry have developed computer assisted methods. Although these function reasonably well, the systems presently in operation are limited to the oil and gas area. They are not a practical source of data for the small to medium-size company and have limited usefulness to the larger companies. Additionally, data for coal and oil sands in computer processable form is not presently available.

With greatly increased interest in non-renewable energy resources, including oil and gas as well as coal and oil sands, the need to improve existing procedures has been recognized. The Energy Resources Data System has been proposed to develop a centralized computer assisted means of acquiring and disseminating basic energy resource data. The objectives and activities to date of ERDS are reviewed in some detail.

MILK RIVER GAS IN SOUTHERN ALBERTA: LARGE RESERVES IN AN UNUSUAL STRATIGRAPHIC TRAP

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Approximately 141.5 x $10^9 m^3$ (5 tcf) of recoverable gas is present in the shaly equivalents of the Upper Cretaceous Milk River Formation distributed in the sub-surface of southeastern Alberta over an area of 17 511 km^2 (4 328 090 acres).

The productive interval is stratigraphically equivalent to the Milk River (Eagle) Formation which outcrops further south. It represents a shallow-marine facies that is transitional between a beach barrier complex (the Milk River Formation) and a basinal shale facies (the Lea Park Formation). The reservoir is about 85 m (280 ft) thick and consists of thinly interbedded, bioturbated, montmorillonitic, silty shale and permeable, laminated, in places bioturbated, very fine-grained sandstone. The two lithologies form a sedimentological unit or composite bed-set and are similar to the "parallel-laminated to burrowed" sets commonly present in a marine sublittoral environment.

AN APPROACH TO ASSESSMENT OF POTENTIAL PETROLEUM SOURCE ROCKS, CANADIAN ARCTIC ISLANDS

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An investigation has been made of the hydrocarbon source rock potential of Mesozoic and Paleozoic sedimentary rocks of the Canadian Arctic Islands. Four facies of organic metamorphism have been recognized in the Sverdrup Basin, namely undermature, marginally mature, mature and overmature. Amorphous organic matter begins to generate hydrocarbons in the marginally mature facies and reaches a maximum in the mature facies. Significant hydrocarbon generation occurs in woody herbaceous organic matter only in the mature facies. Cracking of liquid hydrocarbons and kerogen to form gas occurs in the overmature zone. In the Sverdrup Basin the onset of the marginally mature zone occurs at approximately 1 500 m (5 000 ft) maximum burial depth, whereas the mature to overmature transition occurs in the vicinity of 4 300 m (14 000 ft) maximum burial depth. Hydrocarbon yields (mg of

hydrocarbons per gram of organic carbon) are used as a basis for assessment of source rock quality. Either due to lack of maturity or source organic matter type, the majority of the strata in the Sverdrup Basin are likely only to have yielded gas. The Schei Point Formation (Middle-Upper Triassic) consistently contains organic matter suitable for oil generation. However, the amounts of oil that may have been expelled are relatively small.

All the wells in the Franklinian Geosyncline commence in the mature or overmature facies. The fine-grained sediments of the Devonian clastic wedge and the Lower Paleozoic graptolitic shale facies can have excellent source potential for oil. The position of the mature to overmature transition is the governing factor in determining the hydrocarbon product (oil or gas). The Bird Fiord Formation consists of repetitive cycles of sandstone and shale and forms optimum conditions for drainage. However, the low organic carbon content of the shales means that the volume of migrateable oil is low.

QUANTITATIVE BASIN ANALYSIS AN IMPORTANT PART OF PETROLEUM EXPLORATION

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Estimating hydrocarbon resources and reserves may be divided into three phases:

1. future potential or undiscovered resources on an exploration play, basin or province scale;
2. undiscovered resources on a prospect scale; and
3. discovered reserves.

The basic parameters to be assessed are much the same in all three phases — expected productive area, pay thickness and recovery factors or hydrocarbon bearing reservoir volume and fluid saturations. The availability and accuracy of data required for parameter assessment tend to increase from the first through the third phase. In the first phase and in many cases in the second, the input data may be estimated within ranges as on a probability scale because they cannot be measured. After discovery, in the development phase, the parameters are generally known more accurately and input may be actual remote or direct measurements used as single values to develop more accurate estimates of hydrocarbon volumes than in the undiscovered resource phases.

The petroleum industry requires a complex array of data to explore for and develop hydrocarbon accumulations ranging from simple compilations of directly measured values to complex sets of seismic, remote sensing, electronic, radioactive, acoustic and other indirect measurements of physical properties. All data needed for estimating volumes of hydrocarbons are collected in the normal course of exploration and exploitation.

The great quantities of data required for detection, location and appraisal of petroleum resources together with the sophisticated, detailed processing required to render usable interpretations have promoted the extensive and intensive use of computer processing in all phases of resource and reserve estimates.

AN ANALYSIS OF PETROLEUM OCCURRENCE IN THE WYOMING-NORTHERN UTAH THRUST BELT

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Episodic, variable, large scale horizontal and vertical translation of source and reservoir rocks is a characteristic of thrust belts which complicates petroleum exploration. Understanding recent oil and gas finds in the Wyoming-Northern Idaho thrust belt requires a comprehensive analysis which includes

seismic, surface, aero-magnetic, gravity, petrographic and well data. These are integrated with the aid of empirical structural models developed earlier, primarily by workers in the Appalachian and Albertan thrust belts. Knowledge of times of trap formation relative to times of oil generation and migration is critical. This required palynological dating of clastic wedges and unconformities, as well as source rock identification, oil analyses, thermal alteration studies, and restored structural cross-sections and maps.

The Wyoming-N. Utah-E. Idaho thrust belt may be divided into four major thrust fault systems of different ages. They are, from west to east: Paris Willard (uppermost Jurassic), Meade-Crawford (Coniacian), Absaroka (Santonian-Maastrichtian), and Darby (Paleocene-L. Eocene). During the past three years sizeable new reserves have been found in folds in the hanging wall of the Absaroka Thrust at Pineview, Ryckman Creek, Painter Reservoir and Yellow Creek. Studies which consider time as well as temperature, show that the oil and gas in these fields probably originated in Cretaceous source beds in the footwall of the Absaroka thrust sheet. The oil migrated laterally and upwards into concurrently forming hanging wall fold traps in porous Triassic Nugget sandstone, and was preserved by bedded anhydrite and halite caprock. Studies of other parts of the thrust belt suggest that some structural traps are barren because they were formed after oil generation in nearby source rock. Ideally, trap formation should coincide with flush oil generation in laterally equivalent or thrust juxtaposed source beds. These concepts and techniques are applicable to exploration in all thrust belts.

OIL IN EGYPT

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Viewed in the light of the concept of plate tectonics, Egypt formed part of a converging continental margin up to the end of the Eocene, when its eastern part split to form a diverging margin in response to the initiation of the active spreading centre of the Red Sea. The early geologic history is intimately connected with the closing of the Tethys seaway and the column of sediments in northern Egypt is therefore made up of a thick, deformed Pre-Eocene section and a flat lying Tertiary cover. Oil occurrences in this province are associated with the northeast-southwest anticlinal folds that cut along northern Egypt. Source rocks are most likely the Cretaceous shale, while the producing horizons range from Paleozoic to Cretaceous. The Nile Delta is a post Upper-Miocene development, built up of thick clastic sediments with rapid facies changes, which provide opportunities for hydrocarbon generation and accumulation.

The Gulf of Suez-Red Sea province forms part of a spreading sea floor with high thermal gradients concurrent with shallow water deposition of sediment. This favours the generation of oil and the development of reservoirs and seals. Most, if not all, fields hitherto discovered in the Gulf of Suez are interpreted as fossil rifts with higher paleotemperatures. Production comes either from interbedded sandstones and evaporites of the Miocene which have been draped over tilted fault blocks, or from any porosity which these Miocene source rocks have met as oil moved out of the basin to the adjacent tilted blocks.

MODERN CONCEPTS IN SANDSTONE DIAGENESIS

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Established concepts in sandstone diagenesis are changing and new concepts are being developed as the result of new or improved methods of analysis and interpretation. Advanced methods are now routinely used in the visual analysis of sandstones and pore casts, and in the analysis of the crystallography and chemical or isotopic composition of sandstone constituents. Interpretive methods that originally were developed in the study of carbonate diagenesis proved to be extremely useful in the petrologic interpretation of sandstones. Changes of composition, fabric, porosity and pore geometry can commonly be assigned to the three major realms of sandstone diagenesis:

1. eodiagenesis (pre-burial);
2. mesodiagenesis (during burial); and
3. telodiagenesis (post-burial).

Significant improvements have also been achieved in the ability to differentiate between primary and secondary sandstone porosity, and in tracing the thermal history and the history of fluid migration and compaction in sandstones and their host sediments.

Mesodiagenesis is the most important realm for sandstone diagenesis in relation to the exploration and production of conventional hydrocarbons. Mesodiagenesis is not simply an irreversible path of mineral stabilization and porosity loss dependent mainly on the factors of time, temperature, overburden pressure, and the mineralogical maturity of sandstone constituents. The course of mesogenetic sandstone alteration is often strongly influenced by additional factors such as:

1. geopressures;
2. carbonate content;
3. the abundance, type, and degree of maturation of associated organic matter;
4. chemical composition of pore fluids;
5. flow rate and migration path of pore fluids;
6. transfer of dissolved matter between sandstones and intercalated host sediments;
7. sandstone fabric;
8. pore volume and pore geometry; and
9. presence of hydrocarbons as pore filling media.

Large volumes of mesogenetic porosity are frequently created in sandstone at depth. This significantly increases the depth range of reservoir-grade porosity in sandstones. Dissolution of carbonate constituents is prominent among the mesogenetic processes that create sandstone porosity. The chief cause for this decarbonatization appears to be the carbon dioxide that is generated during the maturation of organic matter.

Mesogenetic loss of sandstone porosity occurs mainly through:

1. mechanical compaction;
2. chemical compaction; and
3. authigenic cementation mainly by silica, carbonate, clay minerals and zeolites.

Zones of diagenetic textural maturity of sandstones can be defined on the basis of porosity loss and are mappable in the subsurface.

Chemical compaction is commonly but not invariably associated with reprecipitation of the dissolved constituents. In most sandstones the amount of mesogenetic pore-cement exceeds the amount of constituents that were dissolved during chemical compaction. This indicates a net addition of mineral matter in sandstones.

Minerals that are unstable under prevailing physicochemical conditions may be eliminated by dissolution, replacement or crystallographic reorganization. All common sandstone constituents, including quartz, can become unstable during mesodiagenesis and may be replaced by another mineral, or be dissolved.

Physico-chemical conditions in the subsurface vary greatly through time in individual sandstone units. This is reflected in the complex and variable history of mesogenetic sandstone diagenesis. The reservoir quality of sandstones can only be predicted if the status of diagenetic alteration itself can be foretold. Accurate prediction of the effects of mesodiagenesis in sandstones is still virtually impossible. However, the success ratio of qualitative predictions of the diagenetic status of sandstone reservoirs has been significantly increased through the application of modern petrologic concepts.

NATURE AND POTENTIAL OF BELLY RIVER GAS SAND TRAPS AND RESERVOIRS

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Although oil production is limited to a relatively small area, gas production from sands of the Belly River Formation occurs throughout the southwestern half of Alberta and in southwestern Saskatchewan. .

Within this large region there are many changing factors which affect the reservoir qualities in these sand traps. Serious producing problems are caused in part by a lack of study and understanding of these factors.

Several representative pools are compared. Reserves and recovery problems are discussed.

THE RAINBOW-BASSET-BLUESKY GAS RESERVOIR: A SECOND GENERATION EXPLORATION & DEVELOPMENT PROJECT

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In early 1973, prompted by rising natural gas prices and a shallow basal Cretaceous Bluesky gas discovery by Universal Gas Co. Ltd. near Keg River, Alberta, a regional study of the Bluesky-Gething Formations of northern Alberta was begun by Canadian Hunter.

The consistent presence of the Bluesky sand over large areas, numerous gas drillstem tests, similar pressures and scarcity of water recoveries all pointed to the existence of a very large regional gas trap. The sand was deposited as part of a beach-delta-offshore bar sequence in a shallow, regressing Early Cretaceous sea. Gas productivity relates directly to sand permeability which is a function of three products of the environment of deposition — grain size, sorting and matrix.

Following the regional study, an aggressive policy of land acquisition through farm-in and Crown sales was begun in January 1974 by Canadian Hunter Exploration Limited.

The Basset well, Canhunter et al. Haig 10-34-104-3 W6M (1974) and the Rainbow well, Canhunter Haig 11-27-107-6 W6M (1975) both discovered major Bluesky gas accumulations.

Follow-up drilling in 1976 generally delineated the reservoirs at both Rainbow and Basset. The reservoirs occur at a depth less than 460 m (1 500 ft), consequently the pressures average only 2 480 kPa (360 psi.) With porosity of 22%, connate water saturation of 45% and dry sweet gas, the recoverable gas is 2 800 m^3 (100 Mcf) per acre-foot. The Rainbow pool contains approximately 3.66 x $10^9 m^3$ (130 bcf) and the Basset pool approximately 1.4 x $10^9 m^3$ (50 bcf), underlying the lands developed by Canadian Hunter and its partner, Canadian Occidental Petroleum. Extensive muskeg throughout the area restricts drilling to the winter period of January through March. That, plus the remoteness of the area, makes the logistics of developing a field complicated and the costs high. In 1976 a gas purchase contract was negotiated and plans made to commence production in 1977. In the Rainbow area initial reservoir data made unitization on a hydrocarbon pore-volume basis impossible in time to commence production in 1977, consequently several companies entered into a unique pooling arrangement based on acreage ownership.

During the winter season of 1977 an intense development program enabled the operators to drill and complete additional deliverability wells, install pipeline gathering systems and construct compression and dehydration stations in both the Basset and Rainbow areas so that initial deliveries could commence in April 1977.

In spite of the remoteness of the area and the high cost involved, the work required to define the prospect, acquire land, drill, develop and connect the reserves was accomplished in less than four years.

THE ROLE OF PALEONTOLOGY IN HYDROCARBON EXPLORATION

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Micropaleontology was first introduced to the oil industry during the early 1930's for age dating and correlation in the Tertiary clastic sequences of the Gulf Coast U.S.A. and California. The absence of distinctive lithologic markers precludes reliable correlations and the ranges of foraminifera were used to define stratigraphic horizons. Even today, these horizons bear the name of the marker microfossil. Once the biostratigraphic framework had been established, foraminifera were used to provide environmental data to aid in the exploration of facies most favourable for the accumulation of oil and gas.

The development of palynology as an exploration tool in the oil industry is a post World War II phenomenon. Palynology extended the use of fossils into rocks of ages and lithologies previously regarded as barren. As well as being used for age dating and facies analysis, palynology has the additional capability of providing source-bed data and is now widely used to determine the degree of thermal maturation and types of hydrocarbons which can be generated.

To illustrate the application of paleontology in the search for hydrocarbons, specific examples from North America and Europe will be discussed.

THE PRACTICAL RELEVANCE OF THE CHOICE BETWEEN A STATIONARY AND A NONSTATIONARY GEOSTATISTICAL MODEL

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In order to assess the uncertainty or variability of geostatistical estimates based on incomplete data, it is now usual to adopt a probabilistic model of a spatially correlated random field. The fact that geographically close measurements resemble one another on the average, more than widely separated measurements, may be modelled in at least two different ways. In the first model we suppose that the greater resemblance of nearby measurements is due mainly to the greater resemblance of their mean values. The emphasis in this approach is usually on obtaining an estimate of the mean function (drift, trend surface) in a class of simply described, e.g., polynomial, mean functions. The secondary emphasis is placed on estimation of the statistical behavior of the residuals from the mean function. In the second model we suppose *a priori* that the mean is constant and that the greater resemblance of nearby measurements is due mainly to the strong correlation of their residuals. The practical consequences of choosing between these two basic approaches will be examined in the context of geographic interpolation between observations.

FACTORS CONTROLLING THE ACCUMULATION OF HYDROCARBONS IN THE CANADIAN ARCTIC ISLANDS

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Exploration in the Canadian Arctic Islands had, to the end of 1977, resulted in the discovery of 360 x $10^9 m^3$ (12.8 tcf) of marketable gas in seven fields, and one significant oil discovery. Two of the gas fields, Drake Point and Hecla, contain 152 and 104 x $10^9 m^3$ (5.4 and 3.7 tcf) of marketable gas, respectively, and are amongst the largest in Canada. Most of the exploration in the Arctic Islands has been carried out by Panarctic Oils Limited, a company established in 1966 by a consortium of mainly Canadian oil and mining companies and the Canadian Government.

The Franklinian (Pre-Cambrian — Late Devonian) and Sverdrup (Mississippian-Recent) basins, which underlie the Arctic Islands, are similar in many respects. They are both miogeosynclines which

appear to have had a eugeosyncline to the north, separated by a geanticlinal ridge. Both basins contain a thick mega-cyclic sequence of sediments which is trangressive in its lower part (ranging upward from continental sands at the base through carbonates and evaporites to deep water open marine shales) and regressive in its upper part (basin-filling deltaic sands, silts and shales). During the transgressive phase, "reefing" occurred on the geanticlinal ridge along the northern edge of each basin. Excellent source and reservoir beds were deposited in both basins and there is ample evidence that large amounts of hydrocarbons have been generated and trapped. As in most basins, however, not all original accumulations have been preserved, and this paper attempts to illustrate how the geological development of the basins and three major, plus several minor, orogenies, affected original entrapment and the subsequent preservation, re-migration, alteration, or loss of these accumulations.

PREDICTING STRATIGRAPHIC TRAPS

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Exploration for stratigraphic traps during the past 30 years has emphasized prediction of areas where porous and permeable reservoir rocks change into impermeable strata in a favorable structural position for petroleum entrapment. Efforts have been directed to areas where production is known from structural or other traps. Use of the depositional environment as a paleogeomorphic indicator has permitted determination of the geometry of reservoir rock, and has aided in predicting porosity trends. Regional stratigraphic analyses of ancient basins have been especially helpful in locating and predicting high-energy shoreline deposits and associated porosity trends, but less useful in predicting porosity trends associated with other depositional environments.

The question of why one area of good reservoir rock is productive of petroleum, while other similar areas are not, has long been an enigma in stratigraphic-trap exploration. New scientific advances hold promise of an answer to this question for many prospective basins. Organic geochemists now can more accurately evaluate source rocks, finger-print crude oil to trace migration paths, and determine time of migration by paleotemperature studies. Sedimentary petrologists can more effectively analyze the diagenetic history of a reservoir rock, and trace the evolution of both primary and secondary porosity and permeability, especially in relation to the time of migration and development of the trap. Mechanical log suites now give the geologist and geophysicist more accurate tools and methods for analyzing porosity, fluid content and other physical properties of reservoir and non-reservoir rocks. Further, bore-hole data, and advances in seismic data acquisition and processing, have opened the field of stratigraphic-trap exploration to seismologists. Finally, combining recent advances in the fields of paleontology, sedimentation, petrology and plate tectonics, the stratigrapher can now predict more accurately the influence of intra-basin tectonics on the deposition and distribution of reservoir strata, and describe changes in the structural configuration of a stratigraphic trap through geologic time.

Future success in predicting the subtle stratigraphic trap clearly lies in the explorer's ability to integrate all essential data from many scientific disciplines into a coherent geologic history of the origin, migration and entrapment of petroleum.

OIL AND GAS IN THE AQUITAINE BASIN (SOUTH WEST FRANCE)

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The first discovery of hydrocarbons in the Aquitaine Basin occurred in 1939 at the Saint Marcet Gas Field in the Pyrennees Foothills. Twenty years later the shallow Lacq Oil Field was discovered. Deepening of the third Lacq well led to a blow-out of gas and the ensuing Deep Lacq gas pool discovery. At the time, this gas field was one of the world's first giants. The latest giant discovery of gas was made in 1965 with the Pau Meillon Gas Field. Total recoverable gas in the area is estimated to be 253 x $10^9 m^3$ (9 tcf).

At the same time gas was discovered in the sub-Pyrenean part of the basin. Significant oil fields were found in the Parentis Basin close to the Atlantic shores.

The main habitat of oil and gas in Aquitaine is the Mesozoic carbonates.

The Jurassic-Cretaceous unconformity is of prime importance for the localisation of the traps. This is because:

1. Jurassic rocks are the main source and
2. Most of the reservoir rocks are located close to the top of the Jurassic formations or at the base of the Lower Cretaceous.

The structural setting and the classification of the reservoirs are more readily appreciated if the paleogeography is understood. The Aquitaine Basin is a marginal type and is strongly influenced by the proximity of the Pyrenean Geosyncline and the Atlantic Margin. The structure of the Basin, based on numerous wells and a profusion of seismic lines sheds new light on some problems related to the birth of the Bay of Biscay and the complex influences of successive Tethys and Atlantic openings.

OIL AND GAS OCCURRENCE IN SOUTHEAST ASIA

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The region discussed includes Burma, the peninsulas of Indo-China and Malaysia, the island of Taiwan, the archipelagos of Indonesia and the Philippines, and all contiguous marine areas. In area, this region is roughly as large as all of Canada, including the Arctic Islands. Excluding a narrow strip of mainland China and the city/state of Singapore, the area comprises nine sovereign states and five of these have established oil and/or gas production.

All production to date has been from beds of Oligocene, Miocene or Pliocene age in both clastic and carbonate rocks. Although 46 Tertiary basins have been identified, oil and gas occurrence has been proven in only a few.