ABSTRACTS

Sequence Statigraphic Control of Source Rocks: Viking - Belly River System

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The post-Mannville sediments of the Western Canada Basin constitute a hydrocarbon system which is isolated hydraulically from the underlying sedimentary column. Thus, oils in Viking, Cardium and Belly River reservoirs are sourced exclusively from the Colorado Shales. The oils are high-quality, low sulphur crudes which, geochemically speaking, show very little variation other than that induced through source maturity differences.

The organic carbon content and the organic matter type of the Colorado Shale are controlled by the overall sedimentation rate. In the condensed sections of the First and Second White Speckled Shales and Fish Scales Zone, the organic matter is prolifically oil-prone. However, commercial oil has also been generated from leaner shales between the condensed intervals. Using geochemical data obtained from core samples, it can be shown that there is a threshold value of organic carbon content below which commercial oil sourcing ceases. Dilution of oil-prone marine organic matter with transported land-derived organics and inorganics controls effective source distribution.

Variable secondary migration pathways have been effective within the section. Mapping of oil, source rock and reservoir rock maturities, coupled with oil geochemical data, allow deductions to be made about migration distances within the post-Mannville hydrocarbon system. Maximum secondary migration distances are seen in the Viking where oil has travelled as far as the Eureka-Dodsland fields of Saskatchewan from mature sources close to the Disturbed Belt.

Stratigraphic and Facies Model of a Transgressing Estuarine Valley Fill in the Gironde Estuary (France)

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During the Holocene sea-level rise, the incised Gironde valley has filled with a fluvio-estuarine sediment wedge 55 m thick and 20 km wide at the estuary mouth. This wedge extends landward up to the present tide limit, 150 km from the inlet, where the high tide intersects the upward sloping fluvial profile. The junction between the fluvial profile and the estuarine deposits at base level forms the bayline which is characterized by a facies transition from conglomeratic fluvial point bars to tide-dominated sand-mud estuarine point bars.

The valley fill consists of a transgressive tract overlain by highstand regressive estuarine deposits. The transgressive tract comprises three facies associations: fluvial conglomerates at the base, overlain by transgressive estuarine sand and mud, capped by coastal marine sand. The conglomerates form a diachronous sheet-like deposit paving the upward sloping substrate, and are in updip continuity with the present fluvial conglomerates landward of the tide limit. The contact between the fluvial conglomerates and the overlying estuarine sediment is a flooding surface recording the fluvial-tidal bayline transition. The marine sands accumulated in the estuary inlet and indicate a period of maximum flooding of the estuary valley. These are overlain by prograding estuarine muds and tidal bars.

Cored borings have enabled the construction of a stratigraphic model for an estuarine valley fill. When rising base level inundated the incised valley at 10,000 ka, an aggrading fluvio-estuarine sediment wedge developed, which backstepped landward and onlapped the alluvial plain at the tide limit. Landward of this point, no fluvial aggradation occurred and the fluvial profile remained stationary. Since highstand (5,000 ka), the estuary has been filling with prograding estuarine deposits. As the estuary fills, its volume and cross-sections diminish, bringing about a seaward shift of the tide limit. This will result in a downstream migration of the fluvial conglomerates, as well as fluvial plain aggradation to maintain sufficient slope to ensure downstream continuity of fluvial discharge. This fluvial accumulation will develop the late highstand systems tract, as defined by Posamentier and Vail.

Fining-Upward Cycles: Problems and Prospects

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Fining-upward cycles are regarded as one of the more popular and powerful tools of environmental reconstruction. This simple feature, though it has led to an enormous increase in our understanding of ancient sediments, also has had many disastrous consequences in terms of interpretation and understanding. Several factors cumulatively led to the misunderstanding of the fining-upward model. There is a good deal of confusion in the usage of the terms 'sequence', 'cycle' and 'cyclothem'. The difference in the significance of 'pattern', 'repetition of the pattern' and the 'time taken' or 'thickness involved' for the pattern is occasionally not clearly spelt out. The classic fining-upward cyclothem of Allen (1965, 1970), which was regarded as a hallmark of the meandering stream deposit, has been challenged by Reading (1987). Questions which remain to be answered include: a) is lateral accretion the only mechanism for the deposition of the coarse grained member of

the fining-upward cyclothem? b) why the fine grained member, which was thought in Allen's model to be the result of deposition from suspension during overbank flooding, should uniformly fall in line with the grain size variation trend of the coarse grained member?

Fining-upward sequences, without strict adherence to cyclicity, and with or without systematic structural variation have been reported from a wide variety of environments, including alluvial fan, braided steam, distributary channel, tidal flat, tidal inlet, tidal creek, washover channel in a transgressive barrier system, and submarine fan-basin plain system. It would be unwise to put them all under a common umbrella 'fining-upward cycle', since (a) all may not be strictly cyclic, and (b) more than one process may be responsible for the observed textural variation. It is necessary to isolate strictly cyclic patterns from non-cyclic patterns and also to differentiate, in the case of cyclic patterns, short-term periodicities from long term periodicities. Superficially similar cycles or sequences may be differentiated on the basis of (a) associated variation in sedimentary structure, (b) careful facies and paleocurrent studies, (c) average thickness range, (d) rate of change of grain size with depth/thickness, and (e) number of beds versus thickness plot. For a better interpretation, beyond empirical deduction, it is necessary to establish the precise cause of grain size variation within a sequence and the periodicity of the cycles.

Facies Analysis of a Lignite Suite: the Sedimentary Competition Between Marine and Terrestrial Influences Near a Wave Dominated Coast (Open Cast Mine "Zukunft-W", Lower Rhine Basin, West Germany; Miocene - Pleistocene)

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In the Lower Rhine Basin, a block-faulted subsiding area since the early Tertiary, thick lignite seams developed in the setting of continuous competition between the terrestrial and marine realms. In the western part of the basin the ≈ 2.5 km long by ≈ 175 m deep lignite opencast mine "Zukunft-W" (Eschweiler, West Germany) was studied. The shifting exposures permitted a spatial facies analysis of the suite of siliciclastics accompanying and overlying the upper Miocene Main and Upper Seam groups (Hauptflöz und Oberflöz Gruppe). The roofing sediments are of Pliocene and Pleistocene age.

Field data were combined into a single detailed north-south section, 2 km long and 170 m high (Fig. 1). Special attention was given to the arrangement of lithofacies in vertical and lateral sequences of deposition. The following lithofacies (assemblages) were distinguished (in order of increasing terrestrial influence):

1. Transgressive marine sandsheet
2. Flood-tidal delta with inlet and spillover subfacies
3. Washover sand
4. Blowover (eolian) sand
5. Open lagoon
6. Backbarrier lagoon
7. Bayfloor
8. Bay margin
9. Swamp feeder channel
10. Minor distributary channel
11. Major distributary channel; fine grained, meandering
12. Crevasse splay
13. Major alluvial river; coarse grained, meandering
14. Braided river
15. Streamflood system.

These facies combine to represent six successive sedimentary episodes:

a. The marine onset
b. The lower deltaic plain
c. The marine onlap
d. The upper deltaic to alluvial plain
e. The marginal marine incursion
f. The final predominance of the alluvial plain.

The intercalated lignite layers have quite variable thickness, lateral continuity and levels of impurity. There appears to be a correlation between these characteristics of the seams and their environmental setting. Thick, continuous and relatively uncontaminated seams developed preferentially in the (back) barrier setting. The deltaic plain gave rise to rather irregular peat growth: layers tend to split up and unite, but are usually of small to intermediate thicknesses. The admixture of siliciclastics is also variable, but usually restricted to the fine grades. Lignite layers in the alluvial plain setting tend to be thin, discontinuous and often laterally replaced by silts and clays. Sedimentation responded to regional and local subsidence, compaction and eustatic changes in sea level. The effects of local, fault-controlled, higher subsidence rates and a eustatic rise in sea level are represented by streamflood and marine onlap units respectively.

Carbonates in Clastic Sequences: Mesozoic and Recent of Canada

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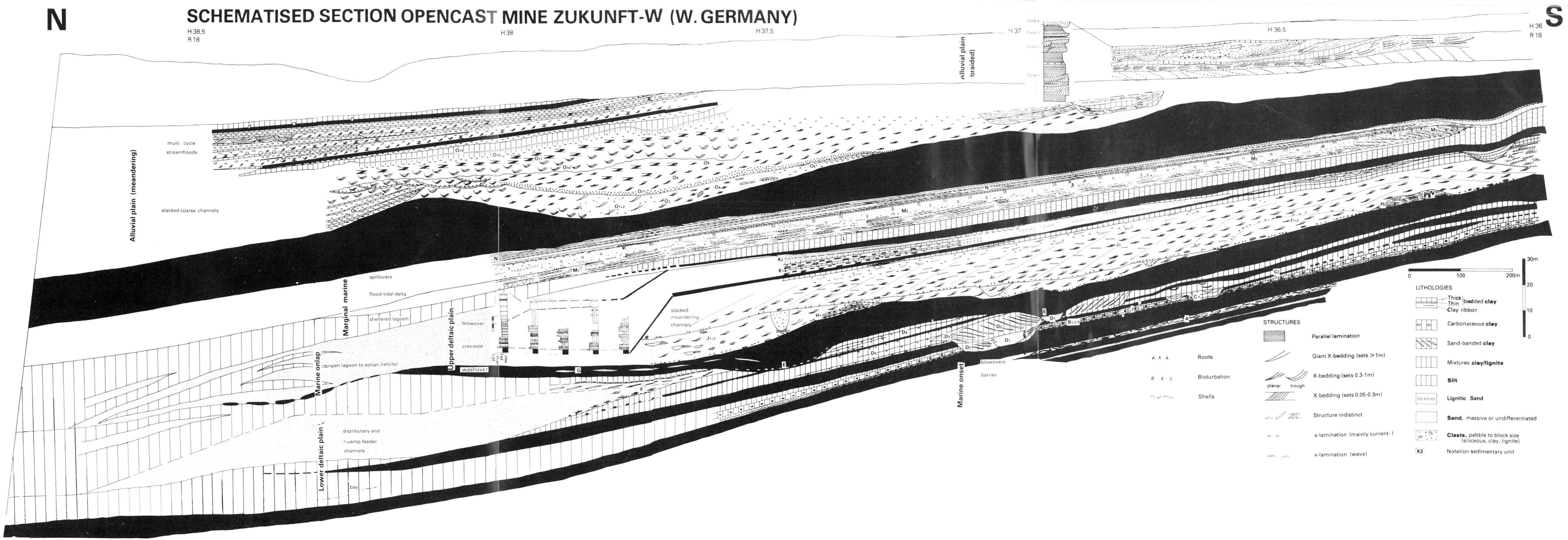
Siliciclastics dominate the Canadian Mesozoic and carbonates are rare. Recent Canadian carbonates are rarer yet, but they do exist. In a review for the Canadian Reef Inventory Project, significant reefal carbonates were recognized only in the Triassic of the Canadian Cordillera and


N
SCHEMATISED SECTION OPENCAST MINE ZUKUNFT-W (W. GERMANY)
S
H 38,5
R 18
H 38
H 37,5
H 37
H 36,5
H 36
R 18
Alluvial plain (braided)
Alluvial plain (meandering)
multi- cycle
streamfloods
stacked coarse channels
Marginal marine
spillovers
flood-tidal delta
sheltered lagoon
Upper deltaic plain
blowover
crevasse
washover
Marine onlap
open lagoon to eolian (relicts)
Lower deltaic plain
distributary and
swamp-feeder
channels
bay
stacked
meandering
channels
Marine onset
blowovers
barrier
0
100
200m
30m
20
10
0
STRUCTURES
Parallel lamination
Roots
Giant X-bedding (sets >1m)
Bioturbation
X-bedding (sets 0.3-1m)
planar
trough
Shells
X-bedding (sets 0.05-0.3m)
Structure indistinct
x-lamination (mainly current-)
x-lamination (wave)
LITHOLOGIES
Thick
Thin
bedded clay
Clay ribbon
Carbonaceous clay
Sand-banded clay
Mixtures clay/lignite
Silt
Lignitic Sand
Sand, massive or undifferentiated
Clasts, pebble to block size
(siliceous, clay, lignite)
K3
Notation sedimentary unit

in the Jurassic - earliest Cretaceous of offshore Nova Scotia. But what were termed 'atypical reefs' in the clastic-rich central cratonic area were found to be not so acceptable in the carbonate realm by many students of reefs. 'Atypical reefs' and carbonate accumulations included the following: tufas/travertines, lacustrine stromatolites and oncolites, marine peritidal stromatolites, oyster banks, shell bank/channel coquinas, sponge mounds, deep-water coral banks/thickets, and serpulid mounds. Other carbonates which were not considered are oolites, marls and chalks. Recent Canadian deposits that could serve as examples and analogues may include temperate climate carbonates of the "foramol" association consisting of foraminifera, bryozoans, barnacles and mollusks (especially bivalves); oyster banks; red coralline algal microbiostromes and rhodoliths; deep sponge mounds (under ice!); deep coral banks; hydrothermal vent or seep-associated tube worm-clam communities; and nonmarine groundwater-associated tufa deposits (including petrified beaver dam) and lacustrine stromatolites in both arid and humid climates.

Of what significance and interest to students of siliciclastics are these rare and typically thin carbonate deposits that might make them worthy of study? (1) Though rare, they are highly facies-specific for certain tidal or shelf settings, for example, estuarine or lagoonal oyster reefs. (2) They are indicative of slow or nondeposition and thus record low sediment supply and/or interdeltaic and/or bypass situations which in turn may indicate early structure such as might occur over a salt dome. (3) Alternatively, they may be indicative of sequence breaks in marine settings and associated (or subsequent) high sea-level stands with low sediment input. Tufas, like caliche carbonate soil profiles, indicate subaerial sequence breaks. (4) They, as coquinas, may provide evidence of temperate/cold or arid climates, both by resulting from low sediment supply and by not being leached subsequently. (5) Surprisingly, they may also be direct indicators of hydrocarbon accumulations. Methane in seeps forms the food base of certain Recent worm tube-clam communities and apparently was also the basis of a serpulid mound in the Cretaceous of the Canadian Arctic Islands.

In discussing these 'atypical reefs' and deposits at this conference, I wish to foster an appreciation for such carbonates in those who will be examining the surrounding sediments. Your help in reporting any examples of such deposits would be welcomed. Eventually we may all get a better understanding of these potentially highly useful and interesting but rare carbonates that occur in default of high or even moderate siliciclastic sedimentation.

The Origin of Third-Order Depositional Sequences: Eustacy, Tectonics, or Bolides

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Third-order depositional sequences characterize many stratigraphic successions, especially those consisting of paralic and shallow water lithologies. Each sequence is usually tens to hundreds of metres thick and spans a time interval of three to eight million years. Subaerial unconformities bound the sequences on the basin margins with submarine unconformities forming the boundaries in the central portion of the basin. In intermediate areas, sequence boundaries are commonly conformities which are difficult to pinpoint. Many sequences consist of a thin basal transgressive unit overlain by a thick regressive wedge of strata.

One hypothesis for the origin of third-order sequences is that eustatic sea-level change is the main forcing factor and that subsidence and sediment supply have background roles. This interpretation is favoured because many sequence boundaries appear to be synchronous over large areas of the globe. However, it must be mentioned that no physical mechanism that would produce eustatic cycles of three to eight million years duration is presently known.

In regards to tectonics there are a number of reasons for interpreting tectonism and associated changes in subsidence rate as the main factors in the origin of third-order sequences. These reasons include:

1. Many sequence boundaries are coeval with episodes of faulting and folding
2. Sediment source areas sometimes change markedly from one sequence to the next
3. Patterns of uplift and subsidence within a basin change dramatically across sequence boundaries
4. Sedimentary regimes in a basin are commonly very different from one sequence to another
5. Relative sea-level falls in rapidly subsiding basins are often greater than such changes in slowly subsiding areas
6. Some sequence boundaries have limited extent.

The one major barrier to accepting tectonics as the major cause of third-order cyclicity has been the great areal extent of many sequence boundaries. This hurdle has recently been overcome by the work of Cloetingh and others (1985, 1986, 1988) which has demonstrated that episodic variations in horizontal lithospheric stresses associated with major plate reorganizations are capable of producing relative sea-level changes of similar magnitude and extent to those recognized.

Finally, it is noted that the timing of most proposed bolide impacts, such as the Permian-Triassic boundary, the Triassic-Jurassic boundary, the Callovian-Oxfordian boundary and the Maestrichtian-Paleocene boundary, coincide with third-order sequence boundaries. Thus if one accepts the bolide hypothesis it would seem that plate reorganizations and associated tectonics, which result in sequence boundaries, are triggered by earth-shattering impacts which occur every 3 to 8 million years. At this time it would seem to be more reasonable to reject the bolide hypothesis and to look for more down-to-earth explanations for such phenomenon as the iridium anomalies which are sometimes present at sequence boundaries.

Marine Origin of the Bay Tree Conglomerate (Cardium Formation): Sedimentology at the Type Locality

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The Bay Tree Member of the Cardium Formation (Turonian) was originally defined as a thick conglomerate capping the Cardium in northwestern Alberta and adjacent British Columbia. Stott (1967) considered this member to be a coarse grained facies of the nonmarine Moosehound (= Musreau) Member, and there have been no published interpretations since.

The type locality is found on an escarpment to the south of Bay Tree Alberta (23-78-13W6). Here, up to 2 metres of swaley cross-stratified fine sandstone with thin pebble stringers are abruptly overlain by up to 12 metres of conglomerate with minor (<20%) laminated or crossbedded fine to very coarse sandstone. The top of the conglomerate is not exposed. The conglomerates consist mainly of chert and quartz pebbles, ranging from granules to over 1 centimetre, and are mostly clast-supported. They generally appear massive to crudely bedded, although in places several decimetre thick crossbeds and imbricated pebbles can be seen. The top of the section comprises 3 metres of pebbles interbedded with gently dipping laminated sandstones. These features strongly suggest a beach.

Pebble imbrications in beach strata indicate a northwest-southeast trending shoreline. The crossbedding in the sandstones lower in the section shows a dominant southeast transport direction in response to longshore currents. Pebble imbrication in the lower parts of the section developed in response to either the shore-normal wave approach or the shore-parallel longshore transport. No evidence of deposition in a fluvial environment can be seen here, or elsewhere in the region where the Bay Tree conglomerates are well developed. Wave-formed gravel ripples are present in many of these localities and provide evidence that deposition of these units took place in a shallow marine environment.

Siliciclastic Sequence Development in Foreland Basins — A Numerical Approach

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Seismic stratigraphy and its geological counterpart, sequence stratigraphy, have become important working tools in oil and gas exploration. The purpose of this paper is to clarify principles which govern the development of seismic sequences and their bounding surfaces in a foreland basin setting such as the Western Canadian Basin. To achieve this goal, a numerical model of progradational sedimentation was created which simulates large-scale basin filling processes. The model and its implications regarding depositional facies and sequence stratigraphic interpretation are discussed.

The strong asymmetry in subsidence rate across foreland basins has important consequences for sequence development. Relative sea level may be rising in axial basin settings at the same time that relative sea level is falling on structural arches and along the basin margins. These variations in relative sea-level change have profound effects on the stratal patterns, environmental facies, and the nature of the bounding surfaces of sequences forming in different parts of the basin.

Significance of Skeletal Concentrations for the Analysis of Unconformities and Condensed Intervals: Case Studies from Neogene Shallow Marine Sequences

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Despite conventional wisdom that fossil preservation requires rapid burial, stratigraphic and taphonomic analysis of Neogene mollusc-dominated shell beds indicates that most macroinvertebrate concentrations in shelf siliciclastics record conditions of *low* net sediment accumulation. These shell beds thus can mark stratigraphically significant surfaces and usually provide a condensed record of the depositional hiatus. Moreover, the dynamics of sediment accumulation can be reconstructed from single outcrops or cores on the relatively objective basis of shell bed contacts, which can be sharp or gradational. Hiatal shell concentrations can be: END-CYCLE, capped by an omissional (type I) or erosional surface (type II) and recording a deceleration in sediment accumulation (e.g., progressive starvation, or bypassing such as during toplap); BASE-OF-CYCLE, resting on an omissional (type III) or erosional surface (Type IV) and reflecting acceleration in siliciclastic accumulation (e.g., onlap, downlap, post-ravinement deposition); MID-CYCLE (composite I-III; slowdown then gradual resumption of sedimentation); or INTER-CYCLE (composite II-IV; slowdown, partial truncation, then resumption). These shell bed types are well represented in 3rd and 4th order sequences from passive (Maryland) and active continental margins (California), where they record hiatuses of (?)3 m.y. duration. Whether the model applies to hiatuses of greater duration is as yet unknown; the model may fail in Paleozoic sequences owing to very rapid post-mortem disintegration of brachiopod and trilobite hardparts.

Oil Possibilities, Offshore Nova Scotia

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In the offshore of Nova Scotia there are development projects which have been delayed due to the impact of lower international oil prices. One of these is the development of the Cohasset-Panuke oil trend. Although small by Canadian standards, these accumulations present an intriguing story and raise a number of questions. The oils at Cohasset come from zones dominated by organic matter of a terrestrial origin. Purcell (1979) indicated that these productive horizons lie within a marginally mature zone (vitrinite reflectance of 0.5% Ro). Investigations have been undertaken in an attempt to explain the presence of the oil.

The Cohasset experience provided some confidence for investigation of the Panuke structure, on trend to the southwest. The drilling of two wells established another oil accumulation. The delineation well was used to demonstrate the viability of a simple production technique which yielded the first oil produced from the east coast offshore.

Important questions have been raised by these discoveries. What is the source of the oil? Are the accumulations predictable? Finding the answers to these questions will provide a challenge and will likely evolve into a new exploration trend.

Late Quaternary Sand Body Formation on Sable Island Bank; Scotian Shelf

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The seismic stratigraphy of Sable Island Bank provides a model for sand body formation in an outer continental shelf setting. The outer Scotian Shelf consists of a series of topographically isolated banks which have been influenced by Pleistocene glaciations and glacio-eustatic sea-level fluctuations. Sable Island Bank is such an example. It has the largest and thickest sand accumulation on the Scotian Shelf which emerges at 44°N 60°W as Sable Island. Seismic profiles illustrate that the Sable Island sand body covers an area of 6500 km^2 and is up to 51 m thick. The sand body has a complex stratigraphy because it represents a series of individual sand bodies deposited during and since the Late Wisconsinan.

The last ice advance and retreat over Sable Island Bank provided sand-sized sediments in an ice-marginal and/or proglacial environment between 27-20 ka (thousands of years ago). Sediments were transported within subglacial channels up to 100 m deep and 3 km wide. The subglacial channels were conduits for sediment-laden meltwater, depositing a thick sand body, up to 40 m thick, on the southern half of Sable Island Bank. Termination positions of the subglacial channels suggests that the last Late Wisconsinan ice extended almost to the shelf break at latitude 44°05′N.

In the Northern Spur area, a local deltaic unit up to 22 m thick lies above this glacial sequence. The stratigraphic position of this unit and the orientation of depositional foresets to the south and southwest suggest that the sequence was deposited during an ice-recession phase within a proglacial delta complex.

The glacial deposition of sand on Sable Island Bank created a sediment reservoir for the subsequent development of coastal and marine sand bodies during and after the Holocene transgression. Sea level has risen around the bank in response to ice retreat for the past 11,000 years. Transgressive reworking of the underlying Pleistocene deposits further sorted the sediment into clean coarsening-upward sequences. During the Holocene, shoreface erosion, longshore transport and storm and tide-generated currents concentrated surficial sediments to the northeast and east over Sable Island Bank. Sable Island in response, has aggraded with a sea-level rise of 20 m since 7,600 BP.

The Sable Island sand body has accumulated since the last Late Wisconsinan ice advance on the outer Scotian Shelf. The core of the major sandbody complex consists, therefore, of a Late Wisconsinan glacial sequence. It is capped by submerged transgressive sand bodies, presumably of Holocene age, and the modern eolian and beach sands on Sable Island.

It was previously thought that the Sable Island sand body was Holocene in age and therefore a post-glacial feature. The seismic stratigraphic analysis here shows that the majority of the sand body is a result of Late Wisconsinan glacial advances to the outer Scotian Shelf. It also illustrates the importance of glacial sediment supply and sea-level fluctuations to large-scale sand body formation within a continental shelf setting.

The Upper Cretaceous Muskiki, Mistanusk and Bad Heart Formations: Relative Sea Level Control on Stratigraphy and Sedimentology

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The Muskiki and Mistanusk formations (Coniacian-Santonian) crop out in the deformed belt of the Foothills in northwestern Alberta and northeastern British Columbia. Nine outcrop sections were examined; five cores and 1100 well logs provide supplementary subsurface data. Outcrop sections consist of several coarsening-upward sequences (parasequences) within an overall upward coarsening, prograding clastic shoreline system. Para-

sequences may be capped by a pebble bed. Comparable parasequences are recognizable in logs. Subsurface correlation of these parasequences demonstrates that they can be traced basinward for many tens of kilometres.

The Bad Heart type section in the Plains consists of peloidal grainstones and oolitic sandstones. Detailed correlation of this unit into the subsurface demonstrates that it pinches out toward the west and lies stratigraphically *above* the 'Bad Heart Formation' of the Foothills. The latter, which pinches out toward the east, is therefore *genetically distinct* from the Bad Heart type section. Consequently, the Foothills units are informally renamed as the Mistanusk formation of the Smoky Group.

Detailed correlation of parasequences reveals four important aspects of Mistanusk history: 1) shelf sediments form a series of up to four coarsening-upward parasequences, each of which probably represents shelf aggradation following a minor relative sea-level rise, 2) shoreface sandstones prograded toward the east-northeast for at least 30 kilometres, 3) locally, shoreface sandstones rest on eroded muddy shelf sediments, and 4) the top of the Mistanusk has an erosional topography, with a relief of about 10 m.

These data suggest that: 1) the Muskiki and Mistanusk formations represent a major transgressive - regressive package, within which minor relative sea-level changes are recognized, 2) toward the end of Mistanusk deposition, relative sea-level fall promoted rapid shoreface progradation over, and local scouring into, a shallow, muddy shelf, 3) continued relative sea-level fall, and possible concurrent tectonic uplift, resulted in subaerial erosion to the west and seaward movement of the shoreline tens of kilometres into the basin, and 4) erosional shoreface retreat during subsequent transgression carved an erosional topography into the Mistanusk Formation, forming a regional unconformity. In outcrop, this unconformity is overlain by a pebble veneer. The stratigraphic position and lithology of the Bad Heart Formation suggest that it represents deposition on a relatively starved shelf during lowstand and the earliest phase of transgression. Parasequence thicknesses indicate that subsidence was greatest in the west near the thrust belt. From south to north, the Muskiki and Mistanusk thin from 75 to 45 m, before pinching out altogether. This suggests that the Peace River Arch may have been a positive tectonic element at this time.

The Development and Stratigraphy of the Late Holocene and Modern Mississippi River Delta Plains

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The current Mississippi River delta plain model depicts a single Holocene delta plain consisting of six delta complexes sequentially deposited over the last 7,000 years by the classic delta switching process. In order of increasing age, these complexes are the Atchafalaya, Balize, Lafourche, St. Bernard, Teche, and Maringouin. Between 1981 and 1986, the Louisiana Geological Survey has acquired more than 10,000 km of high-resolution seismic profiles, 248 offshore vibracores, 397 onshore vibracores, 234 soil borings, and 241 new radiocarbon dates throughout south Louisiana. Analysis of these data sets led to the development of a new, more precise stratigraphic model which depicts the Mississippi delta plain as actually two individual, imbricated shelf-phase delta plains deposited at different sea-level stillstands. Termed the Modern and Late Holocene, these two delta plains are separated by a ravinement surface several hundred kilometres in extent that can be traced updip to a relict-transgressive shoreline, termed the Teche Shoreline.

The Late Holocene delta plain (3,500-7,000 ka) consists of a set of delta complexes 15 to 20 m thick deposited during a sea-level stillstand 6 m below the present. This unit consists of the exposed Maringouin and Teche delta complexes offshore of south-central Louisiana and an eastern delta complex exposed offshore of the Chandeleur Islands in southeast Louisiana. A relative sea-level rise caused submergence of the Late Holocene delta plain, generating Trinity Shoal, Ship Shoal, and the Teche Shoreline, which represents the subsurface eastern extension of the Vermilion Bay shoreline. The 10 to 15 m thick Modern delta plain began building seaward of the Teche Shoreline about 2,800 ka. The St. Bernard and Lafourche delta complexes and associated transgressive shorelines represent the abandoned portions of the Modern delta plain, separated from the underlying Late Holocene delta plain by the regional Teche ravinement surface. The active portions of the Modern sequence consist of the artificially leveed, thick, deep-water Balize complex and the thin shelf-phase Atchafalaya delta complex building onto the transgressed Late Holocene delta plain.

This new model emphasizes the importance of sea level as a control on deltaic deposition. Additionally, in this interpretation, shallow-water shelf-phase deltas, which differ considerably from the traditional deep-water Mississippi delta model, are seen to be the primary depositional constituents of the Mississippi River delta plain.

Application of Sequence Stratigraphy Techniques for Interpretation of Clastic Depositional Systems

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Development of sequence stratigraphy techniques, as an outgrowth of the application of seismic stratigraphy principles to analysis of outcrop and subsurface geologic data, has provided a systematic, predictive approach for basin analysis. Cyclic depositional patterns can be divided into unconformity-bounded units comprised of depositional systems that record changes in relative sea level. Recognition of genetically significant physical surfaces, large-scale stratal patterns and depositional facies associations allows delineation of lowstand, transgressive and highstand systems tracts.

Deposits of the lowstand wedge systems tract rest directly on the sequence boundary and typically include regressive deposits basinward of the shelf edge and gradational valley-fill deposits landward. Depositional processes in the lowstand wedge vary from stacked turbidite lobes at the base of clinoform strata to deltaic or shelfal sedimentation in the toplapping portion of clinoforms. Nested channel deposits of the Brushy Canyon Formation, Guadalupe Mountains, typify proximal lowstand wedge facies. Fluvial, estuarine to tidal flat deposits of the J sandstone interval, Denver Basin, are characteristic of valley-fill deposition.

Upward-deepening retrogradational deposits of the transgressive systems tract rest upon a regional flooding surface at the top of the lowstand system. The transgressive surface is commonly sharp and erosional, often marked by a thin coarse grained lag deposit, as above the J incised valley deposits. Facies of the transgressive system vary from shelfal sandstones and shales to stacked shoreline deposits.

Dominantly regressive deposits of the highstand systems tract lie above the maximum flooding surface that caps the transgressive system. The shallowing-upward deltaic succession of the Denver Basin Skull Creek interval characterizes highstand clinoform strata. Oversteepening of the highstand progradational shelf edge may result in slope and basinal turbidite deposition.

Submarine Fans: Recognition and Occurrence Within a Sequence Stratigraphic Framework

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Submarine fans are fan- or cone-shaped turbiditic deposits formed at upper bathyal or deeper water depths. Within a sequence stratigraphic framework, these deposits are most likely to occur within the lowstand systems tract. The early part of this systems tract is characterized by an interval of relative sea-level fall, resulting in stream rejuvenation and depocenter shift from the coastal plain to the upper slope. This leads to retrogradational slope failure and canyon formation at the shelf-slope break. The sediment delivered here bypasses the canyon and continues down the slope as a succession of gravity flows and is deposited as fan-shaped turbiditic deposits on the basin floor (i.e., basin-floor fans). Seismic and outcrop evidence suggest that these sand-prone deposits are introduced abruptly into the basin and are typically characterized by subtle external mounding and internal bi-directionally downlapping seismic reflections. Deep water sediment deposited during this interval has no coeval shelf equivalent.

During the subsequent stillstand and slow relative sea-level rise, streams cease downcutting and valleys which have been freshly incised begin to fill. Because coarse sediment will be deposited preferentially within these incised valleys, the sand-to-mud ratio delivered to the upper slope will be decreased and, consequently, there is an inherent difference between submarine fans deposited at this time (i.e., slope fans) and those deposited during the time of relative sea-level fall. Deposits of these relatively sand-poor (slope) fans are characterized by slope-front fill or wedge-shaped "geometries" downlapping the earlier submarine (basin-floor) fan. They are typically composed of thinner bedded turbidites as well as the occasional leveed channel deposit. Seismically they often are characterized by a chaotic/contorted seismic facies resulting from mass movement processes active on the continental slope at the time.

Fluvial Deposition in a Sequence Stratigraphic Framework

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Fluvial deposition occurs in response to changes in relative sea level and can therefore be predicted within a sequence-stratigraphic context. In this presentation only fluvial deposition within the Type 1 sequence will be considered. Widespread fluvial deposition is believed to occur during the late highstand when the seaward shift of the shoreline or bayline results in a seaward shift of the point to which stream profiles are adjusted (i.e., the mouth of the stream). The initial response of the stream will be to straighten and deepen its channel to adapt to a lengthening of its stream profile. Ultimately the original stream pattern should re-establish itself, however, and result in a seaward shift of the steam profile. This seaward shift of the stream profile creates subaerial accommodation between the initial position of the equilibrium profile and the new shifted position of the profile.

During early lowstand systems tract time, which is characterized by relative sea-level fall, stream rejuvenation and downcutting occur. At this time fluvial deposition does not occur. Subsequently, when sea level stabilizes and starts to rise, fluvial deposition once more occurs. At this time, however, fluvial deposition is restricted to within incised valleys. Once again fluvial deposition is believed to occur in response to a seaward shift of stream equilibrium profiles. Fluvial deposition ceases with the onset of the transgressive systems tract. At this time incised valleys are flooded and the mouths of the streams are shifted landward. It is suggested that the streams respond by

maintaining a steady state condition of no net erosion or deposition.

Modern analogues are presented to illustrate the proposed fluvial response to changes of base level. These include examples of the effects on streams of changing water level within man-made reservoirs as well as examples of the hypothetical response of streams to changing base level.

Depositional Sequences in the Convergent Plate Margin Setting of the Southern Central American Island Arc

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Uppermost Cretaceous to Pleistocene deep and shallow water sediments were deposited in the fore arc area of Costa Rica and Nicaragua. Outcrop data show successions of depositional sequences bounded by unconformities. Strong structural activity and increased volcanic sediment supply overprint the effects of global sea-level changes. During long-term periods of subsidence sufficient space was available to store large amounts of shallow marine sands. Strong tectonic uplift reduced accommodation space and erosion of shelf deposits occurred.

Depositional sequences in the deep water sediments developed mainly as channel-lobe-systems and slope-apron-systems. The coarse grained, sand-rich channel-lobe-systems reflect a fast lowering of the sea level and strong removal of shelf sands. Canyons cut toward the shelf edge which formed point source feeding systems. Slope-apron-systems developed during slow lowering of the sea level. Depending on differential tectonic style a relative rise of the sea level caused either the development of coastal embayments or equilibrium coastlines. Strong tectonic uplift resulted in the initiation of fan deltas.

Stratigraphy and Lithofacies of Oligocene Lough Neagh Group in Northern Ireland, United Kingdom

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Late Oligocene sediments of the Lough Neagh group in Northern Ireland were deposited in and around a closed, shallow, perennial lake. There are four distinct lithological units present in this group. The lowermost unit is weathered basalt and clay-supported conglomerate, which forms a fining-upward sequence. This unit is overlain by an alternating sequence of clay and lignite units. The clays contain sand, silt and diagenetic ironstone laminae and in places contain fragments of basaltic, rhyolitic, micritic and schistose rocks. The sandstone and siltstone unit forms coarsening-upward and fining-upward sequences in clays above and below the main lignite bed respectively. The lignite occurs in woody and non-woody forms.

Five sedimentary facies are recognised in the Lough Neagh Group, representing 1) a fluvial environment, 2) a fluvio-lacustrine environment, 3) a marginal lacustrine-deltaic environment, 4) a lacustrine-nearshore and open lacustrine environment, and 5) a nearshore lacustrine and swampy environment.

Lacustrine nearshore and open lacustrine environments are dominant, whereas the fluvial and deltaic environments occur locally. The coarsening-upward sequence suggests deltaic deposition and contains the remains of leaves, fruits, rootlets and lizard's teeth. The fining-upward sequence containing plant and gastropod fossils suggests a fluvio-lacustrine environment. The thick sequence of structureless detrital clays were deposited under lacustrine conditions. The lignite horizons were formed in a swampy environment.

The vertical lithological repetition in the lacustrine and marginal lacustrine facies are attributed to lake-level fluctuations in response to climatic changes, rate of deposition, tectonic conditions of the basin and the source rocks.

Provenance of Oligocene Lough Neagh Group, Northern Ireland, United Kingdom

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The Oligocene Lough Neagh Group in Northern Ireland consists of three lithological units. The lowermost unit is weathered basalt and clay-rich conglomerate overlain by an alternating sequence of clays and lignite. The clays contain silt and sand laminae and in places contain fragments of basaltic, micritic, rhyolitic and schistose rocks. A detailed petrographic analysis of the heavy minerals in the Lough Neagh sediments and possible source rocks has been carried out to determine the provenance of the sediments.

The heavy minerals identified in this study indicate that the Lough Neagh sediments were derived from several sources. Five significant heavy mineral suites are evident which are interpreted as: 1) acid igneous, 2) basic and ultrabasic igneous, 3) pegmatitic, 4) high grade metamorphic, and 5) sedimentary sources. Three of these suites can be matched with heavy minerals in the Dalradian (Precambrian) metasediments, the Ordovician Tyrone Igneous Complex and Tertiary basaltic lavas.

In addition to the mineral suites, the presence/absence of zoning and inclusions in zircon grains, their shape, colour and chemical composition indicate particular mem-

bers of the Tyrone Igneous Complex as source rocks. Variation in the elemental composition of zircon and opaque minerals was used to help determine the provenance of sediments. For example, zircons from biotite-granodiorite contain a very high percentage of Ta_2O_5, while the zircons from Tyrone granite contain ThO_2, UO_2, Ta_2O_4, WO_3, and SrO_2 as minor oxides. Ilmenite grains from Tyrone granite contain various minor oxides such as BaO and Ta_2O_5 etc., whereas ilmenite grains from Tertiary basalts generally do not contain any minor oxides (except CuO).

It is also possible to divide the Lough Neagh Group into several stratigraphic horizons on the basis of lithology, heavy mineral suites, and chemical composition of zircons and opaque mineral grains.

Mesotidal Estuary Point Bar Deposits: A Comparative Sedimentology of Modern and Ancient Examples in Peels and Core

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Resin peels of vibracore taken from active mesotidally influenced estuary point bars in coastal Georgia State, U.S.A., are compared with drill core from the Athabasca Oil Sands, Lower Cretaceous, McMurray Formation, Alberta, Canada. In the vertical profiles the following ten sedimentological characteristics are similar in both peels and core: (1) inclined heterolithic stratification (IHS; same as epsilon cross-stratification) of sand and mud, (2) inclined strata and slope angles of point bar surfaces average 12 degrees, (3) bases of each sand unit are frequently in erosional contact with underlying mud, (4) tops of each sand are commonly gradational from sand to mud; gradation occurs as thin laminae, (5) sand beds normally contain ripple structures, (6) mud beds are usually thicker up-profile, (7) sand beds are usually thinner up-profile, (8) sand beds often contain mud balls, mud chips and mud blocks, interpreted as having been eroded from tidal marsh mud deposits, located at the top of the point bar deposits, (9) occurrence of bioturbation, organic litter beds and/or carbonaceous-rich (litter) mud increases up-profile, and (10) if preserved, a 2 to 4 m thick unit of marsh mud usually caps the point bar sequence (Fig. 1).

Other similar vertical sequences of modern estuary point bar deposits are present in the Willapa River estuary of southwest Washington State, U.S.A., and the Daule and Babahovo River estuaries of Ecuador, South America (Smith, 1988). Both sites have mesotidally influenced conditions. Analogous ancient deposits are present in the Upper Cretaceous Horseshoe Canyon Formation exposed in the Red Deer River Valley badlands at Willow Creek near Drumheller, Alberta, Canada (Rahmani, 1988).

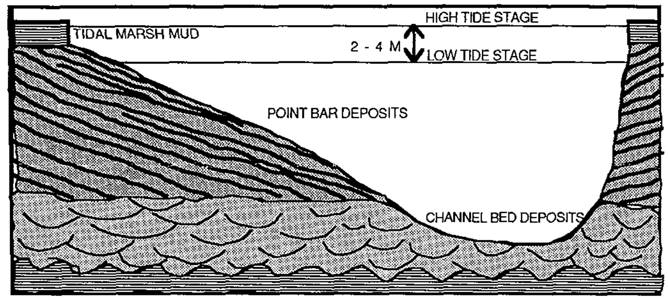

Fig. 1. Schematic diagram showing inclined heterolithic stratification (IHS) in a point bar of a mesotidally influenced estuary.

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Role of Stratigraphic Discontinuities in Development of Reservoir Quality, Muddy and Skull Creek Sandstones, Denver Basin

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Sandstone composition and related reservoir quality, and isotopic compositions of diagenetic minerals in sandstones and mudstones produced during the stratigraphic evolution of the Cretaceous Skull Creek, Muddy, and Mowry sediments vary in patterns that correspond to the following: (1) Skull Creek sandstones, consisting of transgressive highstand deposits, are litharenites that contain abundant kaolinite cement and local concentrations of quartz cement at a subaerial unconformity that separates the Skull Creek from the overlying Muddy Sandstone. The subaerial exposure in outcrops of Skull Creek deposits between Fort Collins and Turkey Creek, Colorado, is characterized by ^{18}O-enriched quartz overgrowths in a 10 to 15 m thick interval, indicating that the quartz cement in the Skull Creek sandstones formed during early meteoric water diagenesis beneath a subaerially exposed surface; (2) Overlying Muddy sandstones, consisting of incised valley-fill deposits, are porous quartzarenites and sublitharenites that contain abundant quartz cement formed from evolved, warmer subsurface fluids; and (3) Mowry shales with relatively high total organic content and siderite were deposited in a condensed interval during maximum flooding. The isotopic composition of diagenetic carbonate in both the Skull Creek and Muddy/Mowry stratigraphic sequences has variations in the $\delta^{13}O$ compositions that correspond to variations in total organic content. Co-varying patterns of regional stratal "geometry" and diagnetic modifications illustrate the strong impact of genetic stratigraphy on reservoir quality.

Palynological Biostratigraphy of the Skonun Formation, Queen Charlotte Basin

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The Neogene, marine to terrestrial Skonun Formation of the Queen Charlotte Islands (MacKenzie, 1916; Sutherland Brown, 1968) interfingers with the volcanic Masset Formation (Sutherland Brown, 1968; Hickson, 1988). The Skonun Formation consists of friable rocks and outcrop on the Queen Charlotte Islands is limited. However, Richfield *et al.*'s six wells on northeastern Graham Island have penetrated siltstones, shales and lignites. Shell wells in the Hecate Strait and Queen Charlotte Sound have penetrated up to 4750 m of predominantly sedimentary rocks,which are at least partly equivalent in age to the Skonun Formation outcrops (Shouldice, 1971). These Tertiary strata are important to petroleum exploration in the Queen Charlotte Basin.

Previous palynostratigraphic data for the Tertiary sediment are based on limited outcrop on Graham Island (Martin and Rouse, 1966), samples from the Cinola gold deposit on central Graham Island (Champigny *et al.*, 1981), cuttings from wells in the Queen Charlotte Sound (Hopkins, 1975, 1981), and sidewall cores from offshore wells (unpublished Shell paleontology reports). The present research more formally identified the palynostratigraphy by quantitative analysis of palynomorphs from core samples from the Tow Hill No. 1 well. This well, located on northeastern Graham Island, penetrates 1830 m of Skonun Formation. Middle Miocene to Late Pliocene ages have been indicated in previous work. While the number of samples available from core is limited, the problem of caving is eliminated. Closely spaced shale or lignite beds were examined separately in order to compare short-term and long-term changes in the palynological record. Short-term changes in vegetation, likely representing edaphic conditions, can be demonstrated and separated from long-term, stratigraphically useful changes. A stratigraphic break, of yet undetermined age, occurs at about 1100 m in the Tow Hill No. 1 well.

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An Application of Sequence Stratigraphy to Depth-Related Clastic Diagenesis, Cold Lake Oil Sands, East-Central Alberta

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Sequence stratigraphy is a method of investigating the origin of genetically related sedimentary packages deposited during sea-level fluctuations. A depositional sequence is a stratigraphic unit composed of a conformable succession of related strata bounded at its top and base by unconformities or their correlative conformities. The cyclic deposition of a sequence is controlled by the relative position of sea level at the time of deposition, the tectonism of the continental margin and local variations related to the environment of deposition. Depositional models based on sequence stratigraphy can be investigated by examining chemical, physical and ichnological variations within sediment at various depths from a pre-existing sediment/water interface.

Early diagenetic processes include those which occur during burial to depths of several hundred metres. Early diagenetic changes in clastic strata in marine environments are largely a function of sediment composition. Detrital solids are the major source of diagenetic reactants in clastic marine environments. Reactivity of mineral phases is a function of grain size and thermodynamic mineral stability. Diagenetic reactions can be quantified in terms of depth below a sediment/water interface. Three depth zones of early diagenesis can be identified, based on distinctive chemical reactions: oxidation, sulphate reduction and fermentation. Bacterial processes involving the degrada-

tion of organic matter dominate each zone. Various microbial reactions may result in the production of diagenetic pyrite, bicarbonate and methane. The presence of these products may be used to identify early diagenetic depth zones in ancient sedimentary strata provided numerous diagenetic episodes have not occurred.

Sequence stratigraphic concepts are used to interpret a depositional model for Clearwater sediment accumulation in the Cold Lake oil sands. Sequence boundaries between different depositional sequences are used as a reference plane for investigating early diagenetic alteration below a sediment/water interface, relating results to observed physical and ichnological characteristics present in the sedimentary record. This leads to a better understanding of diagenetic processes in the Clearwater Formation, perhaps leading to improvements in current production methods, and ultimately the future recognition and exploitation of new and analogous hydrocarbon reservoirs.