INTRODUCTION

PART A: GEOGRAPHICAL AND GEOLOGICAL DISTRIBUTION

N.L. Anderson, Ohio University - Athens;

D.A. Cederwall, Poco Petroleums Ltd; and

L.V. Hills, University of Calgary.

Exploratory drilling for hydrocarbon potential of the Western Canada Sedimentary Basin has been the focus of the Canadian oil and gas industry for several decades. During this period, exploration activities have become increasingly dependent on the capabilities of the seismic interpreter and the continually improving seismic reflection method. This Atlas documents a selected group of pools which are discernable with the current capabilities of the seismic reflection method. With the continually improving technology there is a concommittant need for both the geophysicist and the geologist to access the accummulated experience of their predecessors. This volume is designed to not only introduce the novice to the techniques but also to allow practising geophysicists and geologists to quickly educate themselves in areas where they have not had experience.

The seismic signatures of some 70 oil and/or gas pools are illustrated by the suite of conventional seismic, 3D seismic and VSP data incorporated into this Geophysical Atlas of Western Canadian Hydrocarbon Pools. These examples span the Phanerozoic from Cambrian to Tertiary and encompasses the four western provinces from southern Manitoba to northeastern British Columbia (Fig. 1). These reservoirs are morphologically diverse and representative of the broad spectrum of Western Canadian hydrocarbon plays. Incorporated are bars, beaches, channel sandstones, deltas, reefs, banks, mounds, subcrops, faults, folds and salt dissolution features. Some of the larger pools are in excess of 100 km^2 in area and produce from thousands of wells. Some of the smaller reservoirs are single well pools. The example reefs typically tower more than 100 m above their platform facies and are associated with visually anomalous seismic signatures. The channel sandstones at Crystal Field, in contrast, are difficult to differentiate, on seismic data, from the encasing non-reservoir facies.

The example reservoirs are stratigraphically, geographically and morphologically diverse and yet are all significant from an economic perspective. Each and every one is an exploration success and indicative of the intuition and expertise of the Canadian explorationist. Each of these oil and/or gas pools contributes to the hydrocarbon reserves of Canada and reflects the imagination and technological expertise of our industry. This expertise is clearly illustrated by the descriptions and discussions of the seismic data incorporated into the 12 chapters.

Chapter 1: Basal Paleozoic clastic reservoirs
Chapter 2: Upper Elk Point reservoirs
Chapter 3: Beaverhill Lake reservoirs
Chapter 4: Woodbend reservoirs
Chapter 5: Winterburn/Wabamun reservoirs
Chapter 6: Mississippian reservoirs
Chapter 7: Jurassic/Triassic reservoirs
Chapter 8: Lower Cretaceous reservoirs
Chapter 9: Upper Cretaceous reservoirs
Chapter 10: Tertiary coals
Chapter 11: 3D Seismic case study
Chapter 12: VSP case study

With the exceptions of Chapters 11 and 12, which are based on 3D seismic and VSP data respectively, the reservoir and coal field examples are catalogued chronologically on the bases of stratigraphy. This classification system has proven optimal, for as discussed in the Geologic Overview (section II), the reservoir examples within each chapter are very typically similar with respect to geological history, depositional environments and facies. The Basal Paleozoic Clastics chapter, for example, is devoted entirely to reservoirs within the halo of clastics deposited about the Peace River Arch. Similarly the Upper Elk Point, Beaverhill Lake, Woodbend and Winterburn/Wabamun chapters incorporate reefal reservoirs for the most part. The Mississippian chapter is based on subcrop clastic and carbonate plays, whereas the Lower Cretaceous and Upper Cretaceous are devoted to fluvial, lacustrine and marine clastic reservoirs.

In chapter 10, several interpreted seismic lines across an example Tertiary coal field are presented. In contrast to the preceding example seismic data, these lines were acquired utilizing high resolution seismic recording techniques. These data are extremely significant in that they illustrate that seismic techniques can be applied to the mapping of shallow and thin coal beds. By analogy, the applicability of these techniques to hydrogeology, environmental geology and engineering site evaluations is inferred.

Chapter 11 is based on 3-D seismic case studies. The methodology and application are discussed from both a conceptual and applied perspective. Spatial aliasing, 3-D migration, cost-effectiveness, acquisition problems and a host of other questions are poised and discussed with a view to objectively evaluating this technique. In a similar manner, VSP case histories are presented in Chapter 12. Innovative acquisition, processing and interpretational techniques are described in an attempt to elucidate this innovative imaging methodology.

Each of Chapters 1 through 10 is prefaced by an Introduction to the stratigraphy and geological history of the relevant sedimentary section. Included are the criteria used in the selection of the example hydrocarbon pools as well as selected bibliographies. These brief overviews are followed by separate discussions of the example reservoir, each of which is accompanied by an illustrated geologic section and an interpreted seismic line. The intent is to document the seismic signatures of each of these selected hydrocarbon pools. Synthetic seismograms, suites of geologic maps and production data is used to elucidate the ideas presented.

As noted the incorporated reservoir examples are economically significant. Each contributes to the reserves of Western Canada, (Introduction Part B). The corresponding example seismic lines are also significant, not from an economic perspective, but because they represent an educational tool and the technological expertise of our industry. These data displays are state of the art, two-dimensional, cross-sectional images of the earth's subsurface. They are extremely useful from both an exploration and conceptual point of view. They are not only prerequisites for successful drilling but also for expanding our knowledge of subsurface depositional environments. On the bases of these data, morphological and stratigraphical relationships can be elucidated to an extent not possible with well log data alone. Seismic data has become the key stratigraphic tool as illustrated in the succeeding chapters. As an aid to interpreting the incorporated seismic data, an overview of seismic signatures is presented in Part C of this Introduction.

GEOLOGICAL OVERVIEW OF THE EXAMPLE RESERVOIRS

The approximate geographical locations of the example hydrocarbon reservoirs and the coal field are depicted in Figure 2, on the geological distributions map. These cross-sections A-A' through G-G' are reproduced as Figures 3 to 10, respectively. As illustrated in Figure 2, the reservoir examples trend northwesterly across the four western provinces, from southern Manitoba to northeastern British Columbia.

The incorporated reservoirs are not only geographically widespread, but are stratigraphically, sedimentologically and morphologically diverse as well. These examples span the entire Phanerozoic from Cambrian to Tertiary and include a representative suite of clastic and carbonate, stratigraphic and structural traps. These examples are correlated to appropriate geological sections (Figs. 3 to 10) in order to illustrate, on a regional scale, the geological relationships discussed in detail and referenced within each of the individual chapters. Below a brief overview of the stratigraphic relationships between these examples is presented. This overview is intended to provide perspective. McCrossan and Glaister (1964) provide an unequalled overview of the geology of the Western Canada Sedimentary Basin.

The basal beds of the Western Canada Sedimentary Basin rest upon rocks of Precambrian age which are generally referred to as "the basement". The Precambrian is comprised principally of igneous, volcanic, metamorphic and sedimentary rocks. As illustrated in Figures 3 to 10, the Precambrian surface was denuded by erosion, chiefly in early Paleozoic time.

Throughout most of the Western Canada Basin, the Precambrian is directly overlain by clastic facies of Cambrian, Ordivician, Silurian or Devonian age. For the most part these Basal Paleozoic Clastics were deposited in near-shore environments in a subsiding basin and grade basinward into marine shales, carbonates and/or evaporites facies. Across much of Western Canada these clastics are differentiated into separate formations on the basis of lithology and stratigraphic age. Where undivided these basal Paleozoic clastics are collectively referred to as "Granite Wash".

Four basal Paleozoic clastic reservoirs are described in Chapter 1. The approximate geographical locations of these pools is shown in Figure 1, while in Figure 5 these reservoirs are correlated to appropriate sites on the geological sections.

As noted, the nearshore clastic facies of Devonian age, generally grade basinward, into marine carbonates, evaporites and shales. The carbonates are the dominant reservoir facies, the encasing evaporites and shales are typically effective seals whereas the shales are a principal source rock. In the Atlas, these Devonian age carbonate reservoirs are discussed sequentially in four chronologically ordered chapters, each of which is based on specific stratigraphic group(s). These chapters are entitled Upper Elk Point carbonate reservoirs, Beaverhill Lake carbonate reservoirs, Woodbend reservoirs and Winterburn/Wabamun reservoirs, respectively.

The Upper Elk Point Group, described in Chapter 2, is mainly of Middle Devonian age and forms the base of the Devonian system in Western Canada. It consists of cyclical sequences of evaporitic, carbonate and clastic rocks up to 600 m thick in the plains area. Reef carbonates are well developed in the upper part of the section and form the principle reservoir facies. These carbonates consist predominantly of fringing reef complexes which developed about the periphery of the main Upper Elk Point Basin and minor sub-basins and isolated bioherms which developed therein. These reefal carbonates are stratigraphically sub-divided into the following four stratigraphic units, examples of each of which are incorporated into this volume: Rainbow Mbr, Upper Keg River Reef Mbr, Keg River Fm (Senex area) and Winnipegosis Fm. Specifically, in Chapter 2, the seismic signatures of several Upper Keg River Reef and Rainbow member bioherms from the northern and southern parts of the Black Creek sub-basin respectively, are described and discussed. Similarly, interpreted seismic data crossing the shelfal carbonates of the Keg River Fm in the general Senex area and the Winnipegosis Fm reefs within the main Upper Elk Point basin are presented and analyzed. Herein, the seismic signatures of these carbonate reservoirs are related to the height of the respective reefs, differential compaction and, where applicable, the dissolution of Upper Elk Point salts. The geographical distribution of the example Upper Elk Point Carbonate reservoirs is shown in Figure 1. The stratigraphic relationships between these reefal complexes and the encompassing sedimentary sections is depicted on the appropriate geological sections (Figures 3, 4, and 5).

The succeeding Upper Devonian marine transgression began with the deposition of the Beaverhill Lake Gp, a cyclical repetition of carbonates and shales in central Alberta which pass laterally to shales in northern Alberta and carbonates and evaporites in southern Alberta and Saskatchewan. In a manner analogous to the Upper Elk Point, the Beaverhill Lake reefal carbonates developed as fringing reef complexes about the periphery of the main basin and as isolated biotherms which grew therein. These carbonates, from the predominant Beaverhill Lake Gp reservoirs, and are stratigraphically classified as Slave Point Fm and Swan Hills Fm. Incorporated into Chapter 3, are seismic examples of fringing reef and biohernal reservoirs for both of these groups. The seismic signatures of these reservoirs are relatively subtle primarily due to the low height of these reefs. In Figure 1 the geographical locations of the example Beaverhill Lake Gp carbonate reservoirs are shown. In Figures 3, 4 and 5 these reservoirs are correlated to the appropriate geologic sections in order to place these pools in proper regional perspective.

Further marine transgression towards the south initiated deposition of the succeeding Woodbend Gp and equivalents. This sequence consists of two main facies: shale in northern and central Alberta and carbonates and evaporites in southern Alberta and Saskatchewan. Continued subsidence of central Alberta resulted in the progressive southward migration (backstepping) of the more-or-less continuous fringing reef complex. These shelf carbonates and the isolated bioherms within the interior of the Woodbend basin are denoted as Leduc Fm in the plains area and constitute the principal Woodbend Gp reservoirs. These reef complexes typically tower 200 m above their platform facies and are encased in a relatively low-velocity shale seal. As a result they generally exhibit relatively anomalous seismic signatures. The geographical distribution of the example Woodbend Gp reservoirs discussed in Chapter 4, are shown in Figure 2. On the geological sections (Figures 3 and 6) the stratigraphic relationships between these build-up and the adjacent sedimentary section are illustrated.

The succeeding Winterburn Gp similarly consists primarily of carbonates and clastics. The Nisku Fm (Winterburn Gp) which forms the principal reservoir facies developed as fringing shelf carbonates, isolated reefs and interreef clastics. Production from the Nisku Fm is generally from isolated reefs, closed structures on the shelf and along the Nisku subcrop edge (pre-Cretaceous unconformity). These reefs, (Chapter 5), constitute the principal reservoirs and generate a broad spectrum of seismic signatures ranging from very subtle to very anomalous, depending upon the height and extent of the build-up and the velocity contrast between these carbonates and the enveloping shale seal. The geographical distribution of the example Winterburn reservoirs is shown in Figure 2. Figure 6 illustrates their stratigraphic position.

The Winterburn Gp grades upwards into carbonates of the Wabamun Gp. The latter tongues out to shale in northeastern British Columbia but consists of limestone over most of Alberta. It passes through a transition of dolomite and dolomitic limestone in southcentral Alberta into evaporites and eventually evaporitic Red Beds further south. Wabamun Gp reservoirs typically form: 1) where these carbonates are draped over underlying features such as Leduc Fm reefs or remnant salts; 2) along the Wabamun subcrop (pre-Cretaceous unconformity); and 3) where porous, permeable facies grade laterally into an effective seal.

The overlying Mississippian strata, (Chapter 6), are dominantly shallow water marine sediments. Biogenic carbonates dominate in southern Alberta, whereas shale content increases to the north to become the major lithology. The original depositional extent of the Mississippian sediments was far greater than their present distribution. These strata were extensively eroded during the pre-Permian, pre-Triassic and pre-Cretaceous erosional intervals.

Reservoirs of Mississippian age in the plains area generally develop within closed structures along these erosional surfaces. Nearer to the foothills closure can be due to later stages of faulting. The seismic signature (Chapter 6) of the example Mississippian reservoirs is a function of the magnitude of the closure and the acoustic impedance contrast along the subcrop. The geographical distribution of the example Mississippian reservoir is shown in Figure 2. In Figures 3, 5, 6, 7 and 9 these pools are correlated to appropriate sites on the geologic sections in order to illustrate the relationships between these sediments and the adjacent section.

The Mississippian is stratigraphically overlain by the Permian, Triassic and Jurassic succession. The Permian in the plains area is restricted to the Belloy Group in the subsurface of the Peace River Area. The Belloy consists of carbonates and sandstones and is unconformably overlain by the Triassic. The Triassic as discussed in chapter 7, is subdivided into three intervals; A, B and C. Interval A consists of a transgressive sequence of dark shales and siltstones which grade eastwards in a continental direction into deltaic and bar, siltstones and sandstones and coquina banks. Interval B similarly consists of transgressive sandstones and siltstones which fine to the west and are capped by the regressive Halfway bar sandstones. Interval C is comprised of succession of evaporites, carbonates and sandstones and siltstones. These Triassic strata are succeeded by Jurassic sandstones and siltstones in Alberta. Within the Williston basin, in contrast, the Jurassic is comprised of carbonates, evaporites sandstones and shales. As is discussed in chapter 7, hydrocarbon production from the Halfway Fm is predominantly from sealed sand bodies and erosional structures along the subcrop edge. Generally such reservoirs are characterized by subtle seismic signatures which are a function of the thickness and areal extent and the associated acoustic impedance contrast along the reservoir facies/seal contact. In Figure 2 the locations of the incorporated Triassic reservoir examples are shown. Figures 3 and 5 present the stratigraphic position of these pools.

The Lower Cretaceous comprises continental through marine clastics and shales deposited on and above the pre-Cretaceous unconformity, a surface of extreme erosional relief in places. As is discussed in Chapter 8 a broad spectrum of clastic reservoirs are present within the plains area. Included are fluvial channel sandstones, paralic sheet sandstones, beaches, off-shore bars, deltas and dunes. Structural closure can be due to primary depositional patterns, compaction, faulting and/or the dissolution of Devonian salts. As anticipated the seismic signatures of the diverse reservoirs change as a function of the thickness and aerial extent, reservoir facies, acoustic impedance contrasts between the sandstones and shale seals, associated structural relief as well as numerous other factors. The geographical distribution of the selected Lower Cretaceous reservoir examples is shown in Figure 2. Figures 3, 5, 6 and 8 illustrate the stratigraphical position of these reservoirs.

The Lower Cretaceous is overlain by the Upper Cretaceous, a conformable sequence of marine and non-marine shales and sandstones deposited in and around a shallow inland sea. These strata are predominantly marine at the base and increasingly continental upwards. Examples of the two principle Upper Cretaceous reservoirs, the Cardium and Belly River formations are outlined in Chapter 9. These formations are generally productive where, as result of lateral facies charges, sandstones are sealed by shales. Typically, the reservoirs are characterized by lateral amplitude variations which are indicative of corresponding facies changes. The geographical locations of the incorporated examples are depicted in Figure 2. Their stratigraphical position is shown in Figure 6.

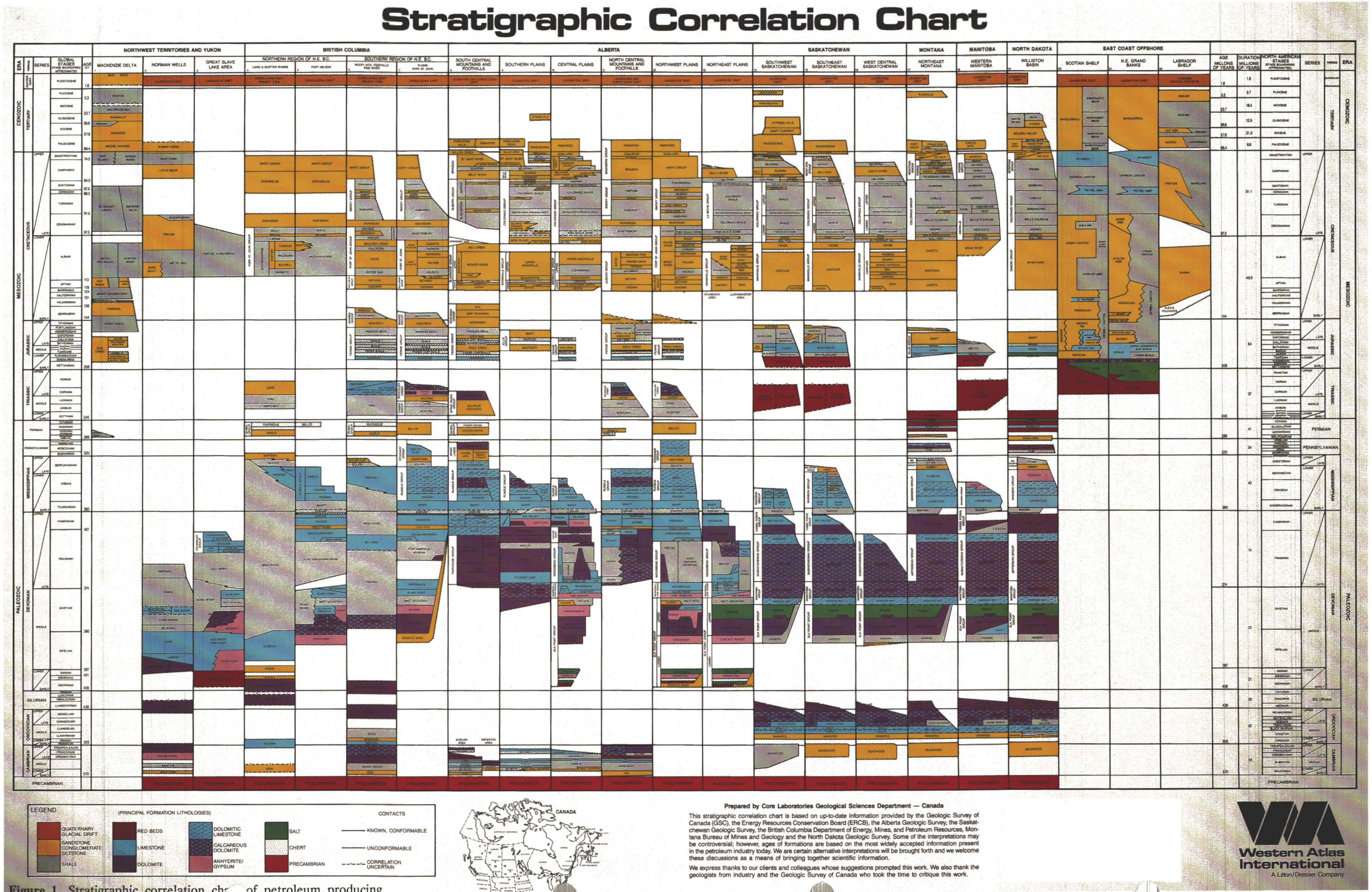


Figure 1. Stratigraphic correlation cha[illegible] of petroleum producing areas of Canada and the northern U.[illegible] Kohrs, B.M. and Norman, D.K. 1988. (courtesy of Western Atlas International).

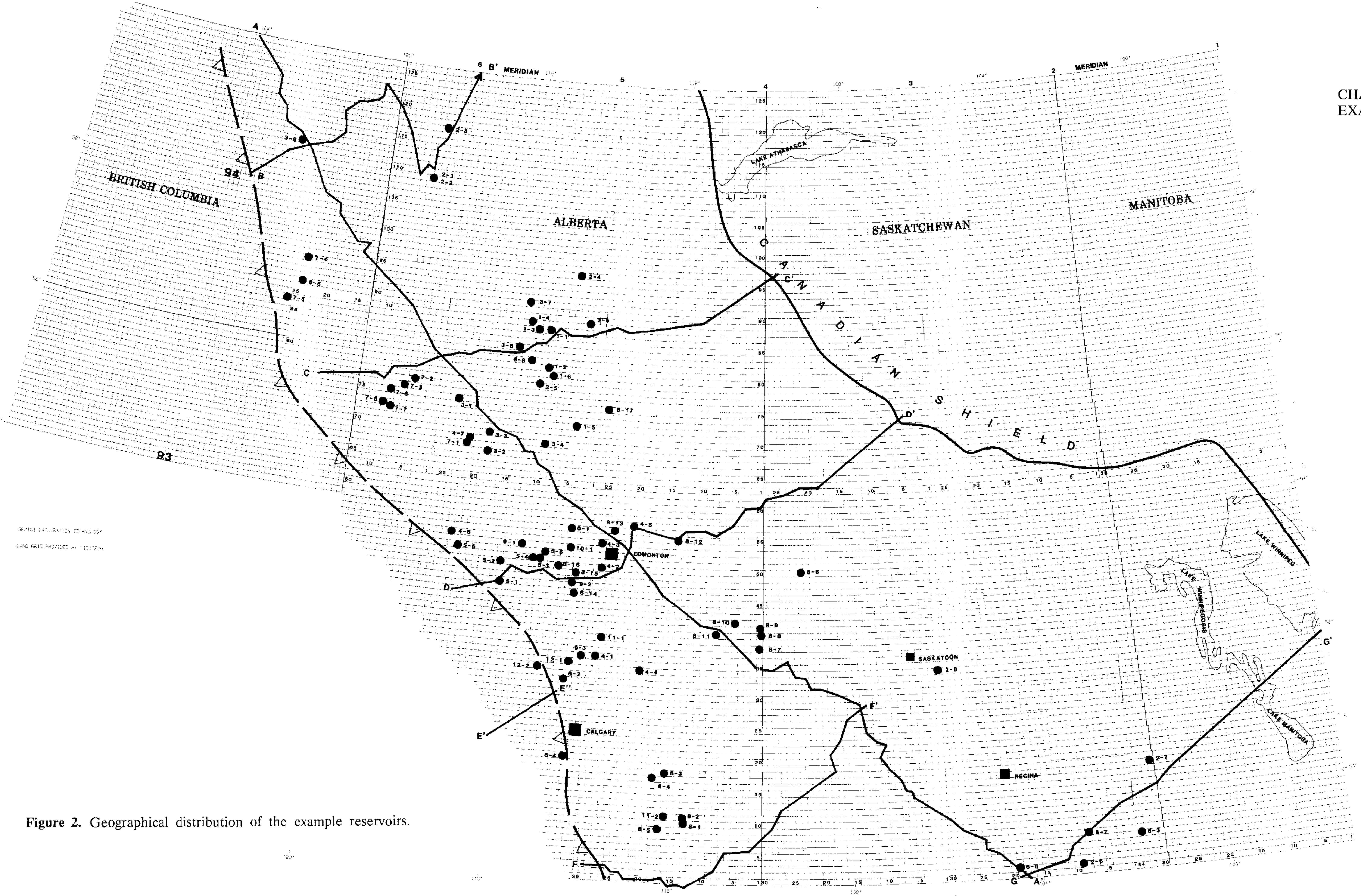
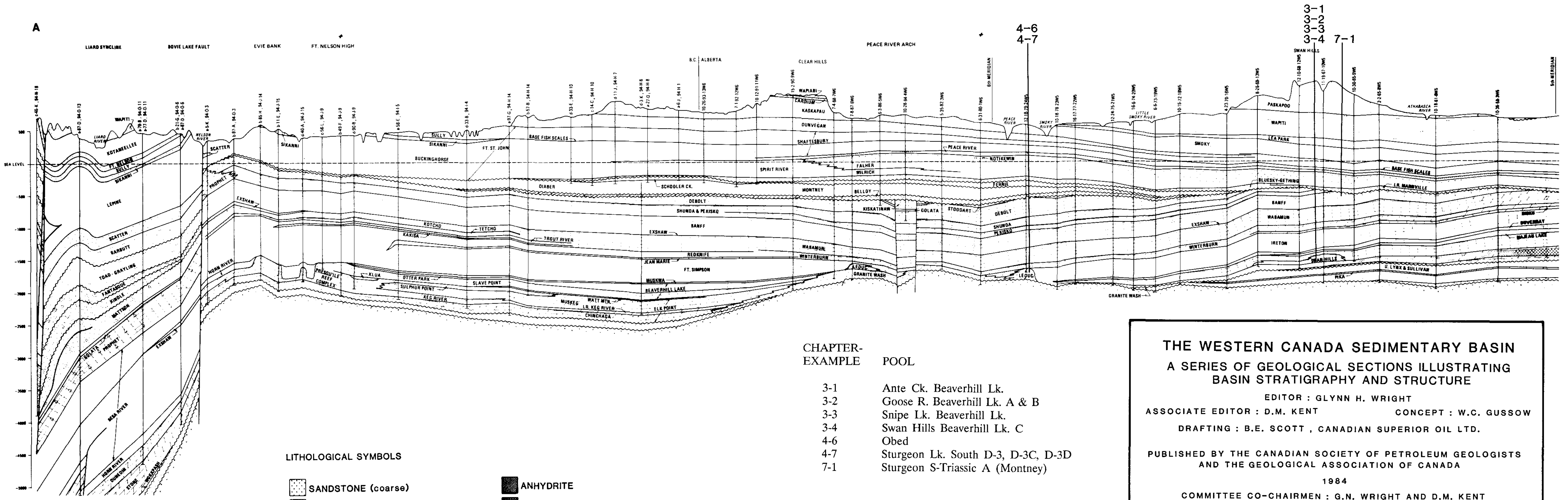


Figure 2. Geographical distribution of the example reservoirs.

CHAPTER EXAMPLE	POOL	CHAPTER EXAMPLE	POOL
1-1	Red Earth Granite Wash A	6-4	Turner Valley Rundle
1-2	Utikuma Keg R. A	6-5	Blueberry Debolt A/B
1-3	Evi Granite Wash P	6-6	Hummingbird Ratcliff/Bakken
1-4	Otter Granite Wash F & I	6-7	Viewfield Frobisher
1-5	Mitsue Gilwood A	6-8	Seal Pekisko
1-6	Nipisi Gilwood A		
		7-1	Sturgeon S Triassic A (Montney)
2-1	Rainbow Keg R. HH-NN-LL	7-2	Rycroft Charlie Lk. A.
2-2	Rainbow Keg R. PP	7-3	Spirit R. Halfway F
2-3	Zama Keg R.	7-4	Nig Ck. Baldonnel
2-4	Panny Keg R. D	7-5	Kobes Charlie Lk./Halfway
2-5	Trout Keg R.	7-6	Valhalla Halfway C
2-6	Tableland Winnipegosis	7-7	Wembley Halfway B
2-7	Rocanville Winnipegosis	7-8	Hythe Halfway A
2-8	Allan Winnipegosis		
		8-1	Bow Is. A Glauconite A
3-1	Ante Ck. Beaverhill Lk.	8-2	Grand Forks
3-2	Goose R. Beaverhill Lk. A & B	8-3	Countess Upper Mannville D
3-3	Snipe Lk. Beaverhill Lk.	8-4	Badger Upper Mannville B
3-4	Swan Hills Beaverhill Lk. C	8-5	Taber Mannville A
3-5	Gift Slave Pt.	8-6	Westhazel GP Sand
3-6	Slave Slave Pt.	8-7	Provost Upper Mannville BB
3-7	Sawn Lk. Slave Pt.	8-8	Hayter Dina B
3-8	Clarke Lk. Slave Pt.	8-9	Hayter Sparky B
		8-10	Wainwright Ridge
4-1	Penhold D-3A	8-11	Provost Basal Quartz C
4-2	Leduc Woodbend D-3A	8-12	Hairy Hills-Colony W
4-3	Morinville D-3	8-13	Peavey-Blairmore
4-4	Rich D-3A	8-14	Crystal-Viking A & H
4-5	Redwater D-3	8-15	Pembina-Ostracod E
4-6	Obed	8-16	Pembina Lobstick-Glauconite G
4-7	Sturgeon Lk. South D-3	8-17	Marten Hills
5-1	Brazeau Nisku K & S	9-1	Carrot Ck.-Cardium
5-2	Whitehorse Nisku	9-2	Pembina Keystone Belly R.
5-3	Bigoray Nisku D & E	9-3	Tindastoll-Belly R.
5-4	Pembina Nisku F		
5-5	Bigoray Nisku H & K	10-1	Whitewood-Paleocene Coal
5-6	Apetowun Nisku	11-1	Joffre D-3 3D
		11-2	Taber-Lwr. Cretaceous-3D
6-1	Alexis Banff A	12-1	Ricinus VSP
6-2	Harmatton Elkton	12-2	Lanaway VSP
6-3	Alida East Frobisher & Alida		



LITHOLOGICAL SYMBOLS

- SANDSTONE (coarse)
- SANDSTONE (medium and fine)
- SILTSTONE and SANDSTONE (very fine)
- SHALE
- LIMESTONE
- DOLOMITE
- ANHYDRITE
- HALITE and other EVAPORITES
- ARGILLACEOUS CHERTY STRATA
- COAL
- IGNEOUS and/or METAMORPHIC ROCKS
- MAJOR UNCONFORMITY

CHAPTER-EXAMPLE	POOL
3-1	Ante Ck. Beaverhill Lk.
3-2	Goose R. Beaverhill Lk. A & B
3-3	Snipe Lk. Beaverhill Lk.
3-4	Swan Hills Beaverhill Lk. C
4-6	Obed
4-7	Sturgeon Lk. South D-3, D-3C, D-3D
7-1	Sturgeon S-Triassic A (Montney)

Figure 3. Geological section A-A' (modified after Crabtree et al., 1984, In: Wright and Kent, 1984).

THE WESTERN CANADA SEDIMENTARY BASIN

A SERIES OF GEOLOGICAL SECTIONS ILLUSTRATING BASIN STRATIGRAPHY AND STRUCTURE

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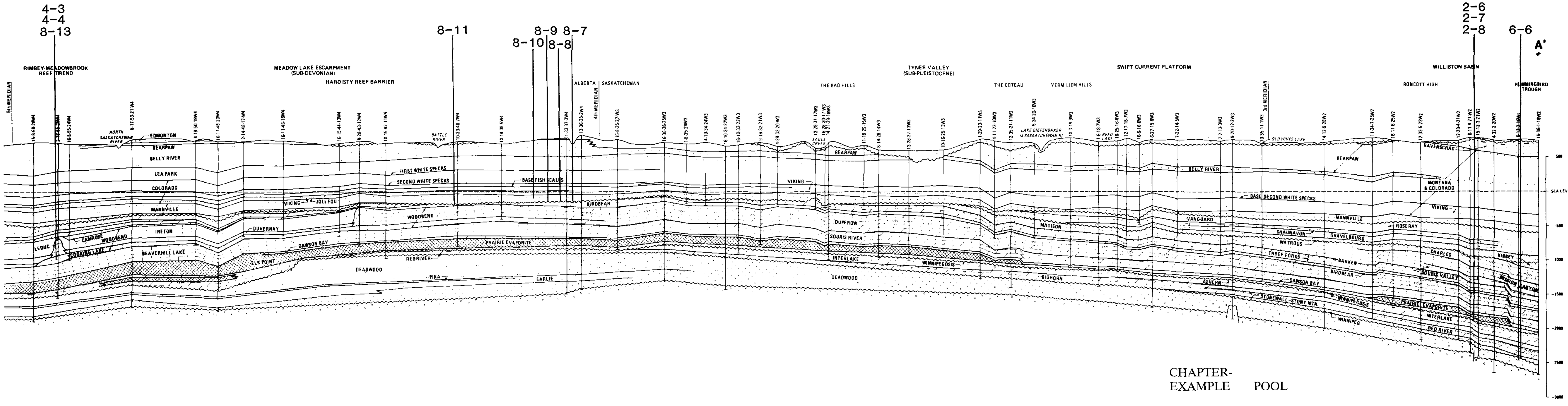

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Figure 4. Geological section A'-A" (modified after Crabtree et al., 1984, In: Wright and Kent, 1984).

CHAPTER-EXAMPLE	POOL
2-6	Tableland - Winnipegosis
2-7	Rocanville - Winnipegosis
2-8	Alan - Winnipegosis
4-3	Morinville D-3
4-4	Rich D-3A
6-6	Hummingbird-Ratcliff/Bakken
8-7	Provost-Upper Mannville BB
8-8	Hayter-Dina B
8-9	Hayter-Sparky B
8-10	Wainwright Ridge
8-11	Provost-Basl Quartz C
8-13	Peavey-Blairmore

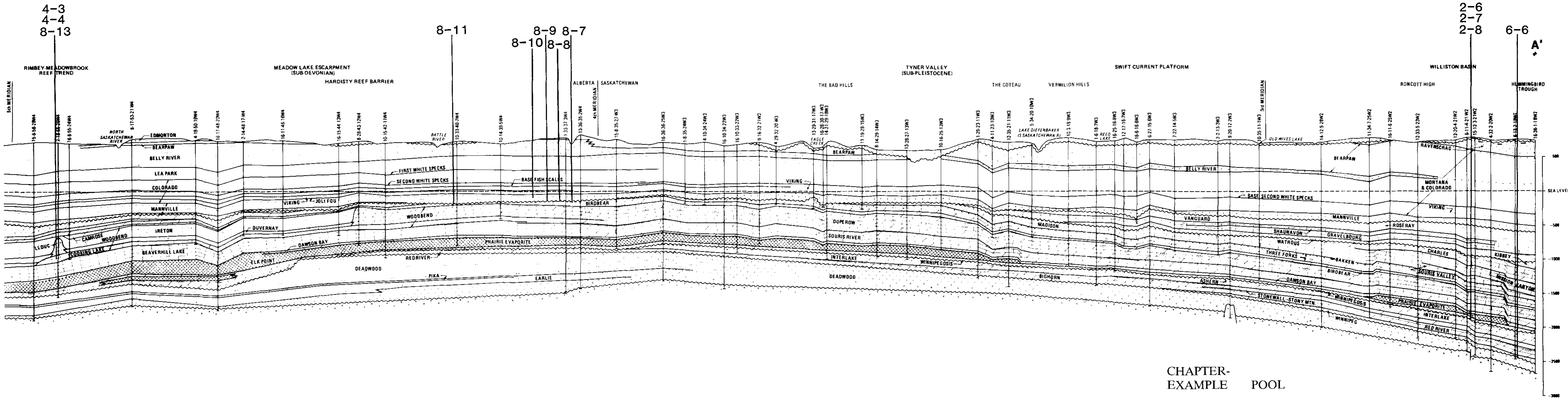

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Figure 4. Geological section A'-A" (modified after Crabtree et al., 1984, In: Wright and Kent, 1984).

CHAPTER-EXAMPLE	POOL
2-6	Tableland - Winnipegosis
2-7	Rocanville - Winnipegosis
2-8	Alan - Winnipegosis
4-3	Morinville D-3
4-4	Rich D-3A
6-6	Hummingbird-Ratcliff/Bakken
8-7	Provost-Upper Mannville BB
8-8	Hayter-Dina B
8-9	Hayter-Sparky B
8-10	Wainwright Ridge
8-11	Provost-Basl Quartz C
8-13	Peavey-Blairmore

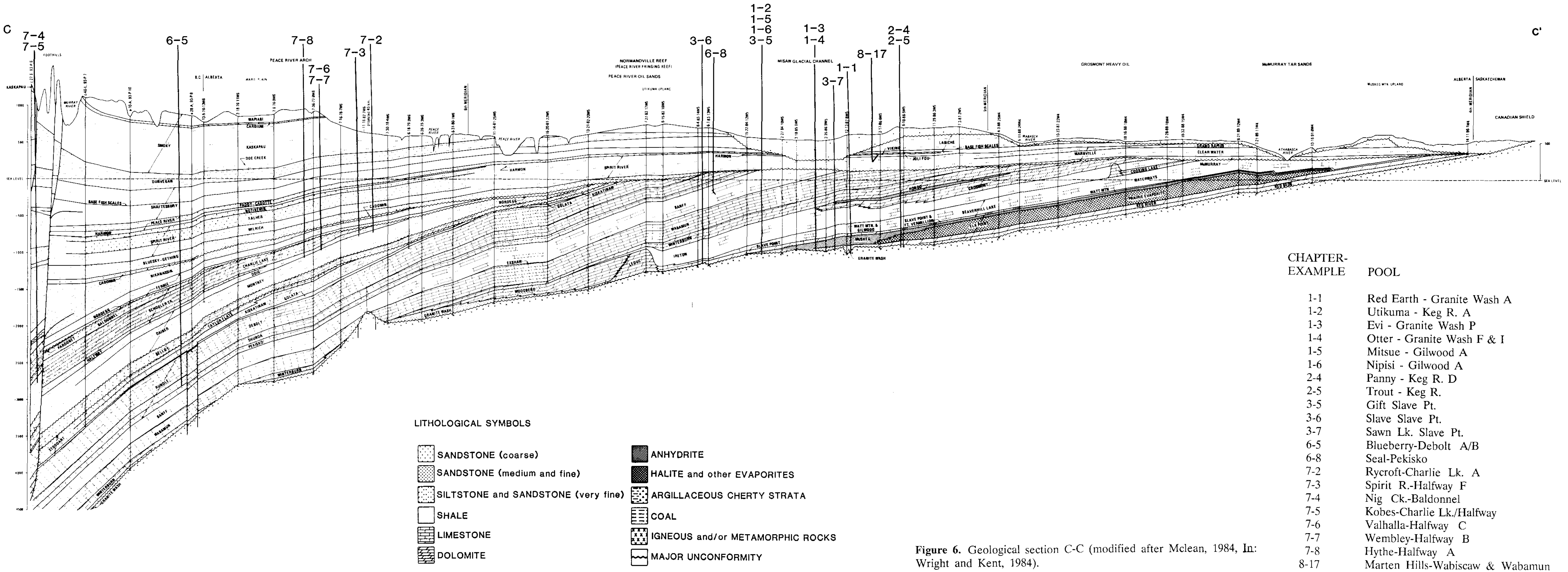
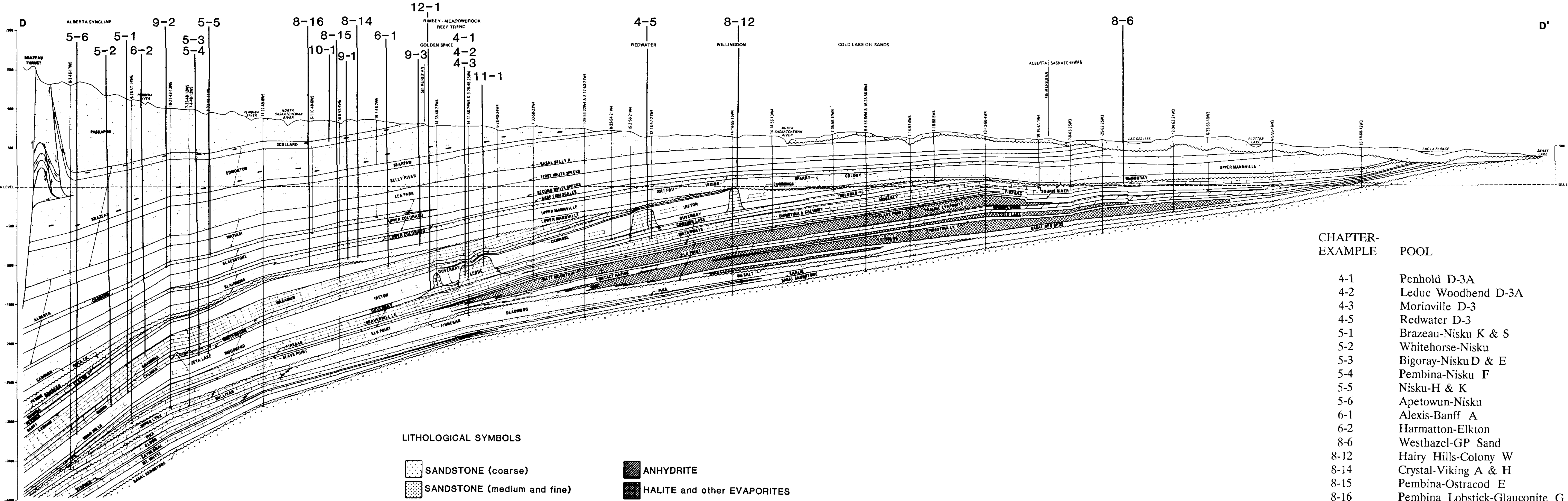


Figure 6. Geological section C-C (modified after Mclean, 1984, In: Wright and Kent, 1984).

CHAPTER-EXAMPLE	POOL
1-1	Red Earth - Granite Wash A
1-2	Utikuma - Keg R. A
1-3	Evi - Granite Wash P
1-4	Otter - Granite Wash F & I
1-5	Mitsue - Gilwood A
1-6	Nipisi - Gilwood A
2-4	Panny - Keg R. D
2-5	Trout - Keg R.
3-5	Gift Slave Pt.
3-6	Slave Slave Pt.
3-7	Sawn Lk. Slave Pt.
6-5	Blueberry-Debolt A/B
6-8	Seal-Pekisko
7-2	Rycroft-Charlie Lk. A
7-3	Spirit R.-Halfway F
7-4	Nig Ck.-Baldonnel
7-5	Kobes-Charlie Lk./Halfway
7-6	Valhalla-Halfway C
7-7	Wembley-Halfway B
7-8	Hythe-Halfway A
8-17	Marten Hills-Wabiscaw & Wabamun



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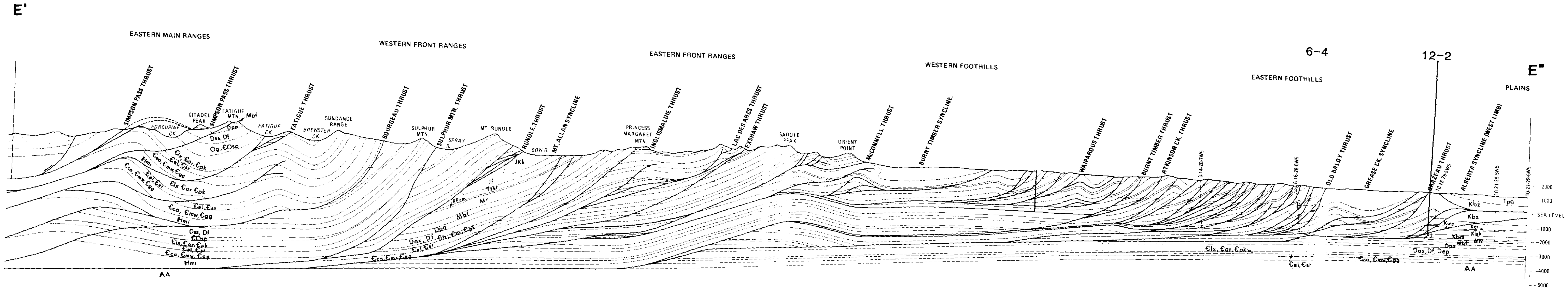
CHAPTER-EXAMPLE	POOL
4-1	Penhold D-3A
4-2	Leduc Woodbend D-3A
4-3	Morinville D-3
4-5	Redwater D-3
5-1	Brazeau-Nisku K & S
5-2	Whitehorse-Nisku
5-3	Bigoray-Nisku D & E
5-4	Pembina-Nisku F
5-5	Nisku-H & K
5-6	Apetowun-Nisku
6-1	Alexis-Banff A
6-2	Harmatton-Elkton
8-6	Westhazel-GP Sand
8-12	Hairy Hills-Colony W
8-14	Crystal-Viking A & H
8-15	Pembina-Ostracod E
8-16	Pembina Lobstick-Glauconite G
9-1	Pembina Keystone-Cardium, Belly R
9-2	Carrot Ck.-Cardium
9-3	Tindastoll-Belly R.
10-1	Whitewood-Paleocene Coal
11-1	Joffre D-3 3D
12-1	Ricinus VSP

Figure 8. Geological section E'-E" (modified after Fermor et al., 1984, In: Wright and Kent, 1984).



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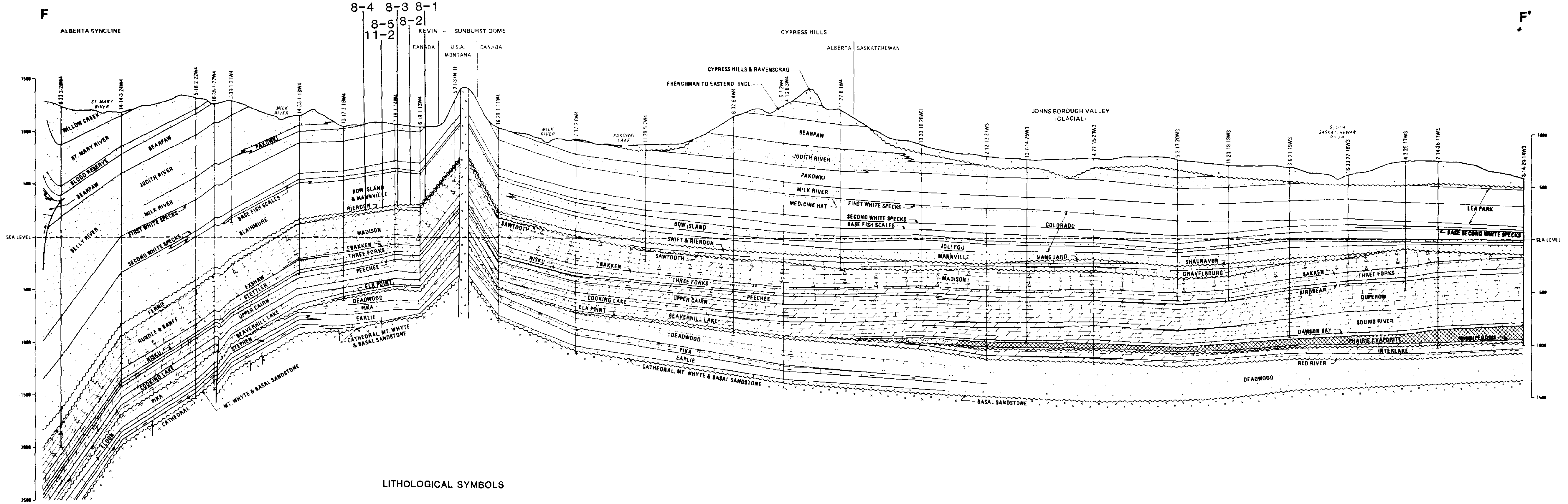
CHAPTER-EXAMPLE	POOL
6-4	Turner Valley Rundle
12-2	Lanaway VSP

Figure 9. Geological section F-F (modified after Doherty and Wright, 1984, In: Wright and Kent, 1984).

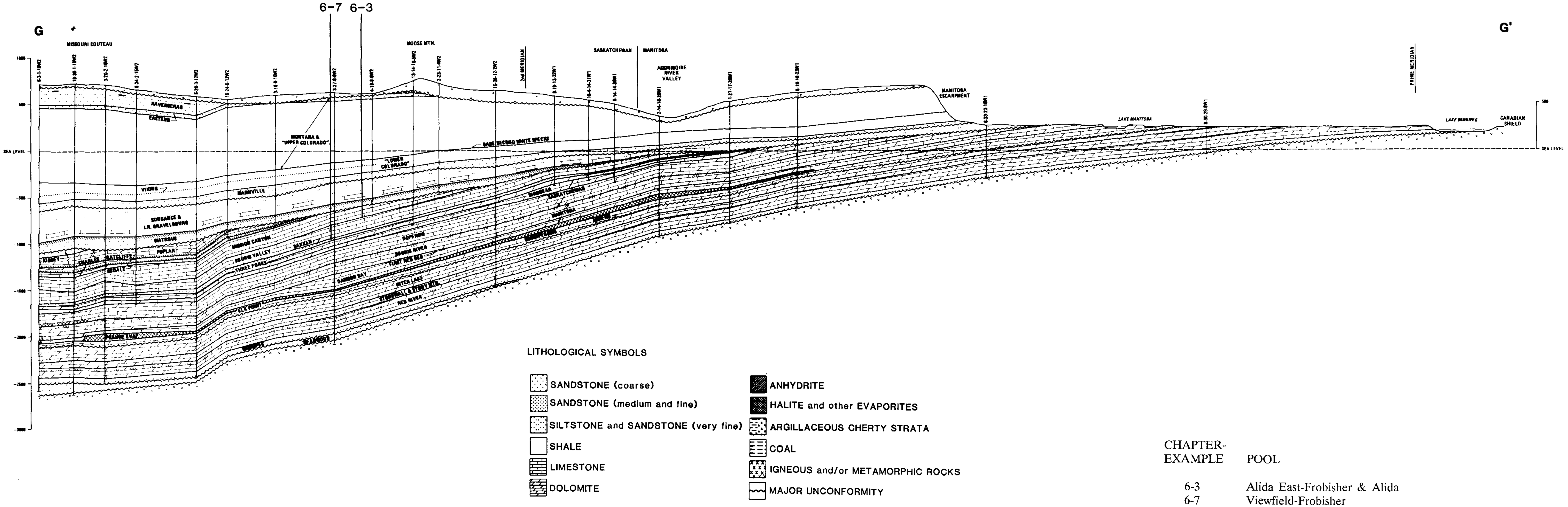


LITHOLOGICAL SYMBOLS

- SANDSTONE (coarse)
- SANDSTONE (medium and fine)
- SILTSTONE and SANDSTONE (very fine)
- SHALE
- LIMESTONE
- DOLOMITE
- ANHYDRITE
- HALITE and other EVAPORITES
- ARGILLACEOUS CHERTY STRATA
- COAL
- IGNEOUS and/or METAMORPHIC ROCKS
- MAJOR UNCONFORMITY

CHAPTER-EXAMPLE	POOL
8-1	Bow Is.-A Glauconite A
8-2	Grand Forks-Lwr. Mannville D (Sawtooth)
8-3	Countess-Upper Mannville D
8-4	Badger-Upper Mannville B
8-5	Taber-Mannville A
11-2	Taber-Lwr. Cretaceous-3D

Figure 10. Geological section G-G (modified after Argan and Hartling, 1984, In: Wright and Kent, 1984).



CHAPTER-EXAMPLE	POOL
6-3	Alida East-Frobisher & Alida
6-7	Viewfield-Frobisher

PART B: STRATIGRAPHIC DISTRIBUTION OF HYDROCARBON RESERVES AND PRODUCTIVITY IN ALBERTA

D. Cederwall. Poco Petroleums Ltd;

B. Fransden, Virtual Computing Services Ltd;

P. Howard, Logis Data Systems Ltd; and

G. Rehwald, Logis Data Systems Ltd.

INTRODUCTION

The reserves and productivity of the Western Canada Sedimentary Basin are well described in the literature of provincial, federal and industry agencies and no attempt is made in this overview to restate these values. These data however, are generally directed either towards an analysis of total reserves and productivity within a portion of the basin or towards the attributes of specific pools and little work exists on the regional significance of the nine stratigraphic subdivisions utilized in this Atlas.

In order to illustrate the relative significance of production from each of these nine stratigraphic subdivisions, Tables 1 and 2 were constructed. These summary tables address oil and gas respectively. They were derived from computerized data of the Alberta Energy Resources Conservation Board (ERCB) and processed by Virtual Computing Services Ltd. and Logis Data Systems Ltd. Note that this analysis is limited to Alberta. The reserves and productivity of the Alberta portion of the basin are analogous to many of the pools of Saskatchewan and British Columbia which are not discussed in this section. Reserves and productivities of these two provinces are documented in the reports: Saskatchewan Reservoir Annual (1987) and Hydrocarbon and By-product Reserves in British Columbia (1986).

Due to the averaging which has been applied to the pool parameters, many of the numeric values shown in Tables 1 and 2 have no direct application to prospect evaluation. These data represent an overview of each of the nine stratigraphic subdivisions presented in this volume and allows comparison of their respective reservoir characteristics, their contribution to production to date, and reserves. To a lesser extent these data document changes with time in the significance of these divisions.

Note also that these data may contain some apparent differences to the above referenced reports. These differences may be two fold and sourced from either: 1) the grouping or selection of the zone codes (formational grouping) which is unique to this report; and 2) the definition of gas, oil and condensate or the methods of their grouping which may vary within the report. Several of these differences are annotated within the text. Note, however, that misinterpretation is avoidable by utilizing these data in a relative, rather than an exact sense.

METHODOLOGY

In order to determine the relative significance of the nine stratigraphic subdivisions, two ERCB computer files, the reserves volume and the production volume were respectively sorted utilizing software of Virtual Computing Services and Logis Data Systems. To obtain the production segment, each of the 85,000 recorded well completions in Alberta were categorized by their associated zone code into one of the nine stratigraphic subdivisions, a tenth category was also recorded for the undefined (confidential) wells. These wells were summed over southern, central and northern Alberta, and by their major product components; oil, gas and water. These data were subsequently totaled and are displayed in Tables 1-4. In reviewing these data note that the well count is slightly misleading for two reasons: 1) any single well may be recorded more than once due to multiple zone completions; and 2) wells which were previously oil producers, but are now water injectors (in the same zone) do not show in the oil well count, but only appear in the water well count. Total oil production by zone is slightly misleading in that it does not recognize any mined oil production.

Note also that gas production recorded on the ERCB production file tape differs significantly from production recorded in the ERCB reserves data file. This difference is due to the inclusion of all fuel gas, inert gas, water vapour, injected gas and most condensate and natural gas liquids in the production file. These portions of the produced volumes are deleted from the "marketable gas production" recorded in the reserves data file.

The reserve figures were summed in two separate runs, one for gas reserves and one for oil reserves. Note that the reserves of bitumen, natural gas liquids, sulphur and solution gas are not addressed in this summation. The pool count made in this section may be misleading in that pools which contain both oil and gas are normally counted once as an oil pool, and once as a gas pool.

Each of the pools recorded on the reserves data tapes were assigned to one of the nine stratigraphic categories via their associated zone code, then summed and averaged by dividing by the number of recognized pools in each zone. Thus, these data can only be viewed as averages, in that they account for both small and large reservoirs and a wide distribution of reservoir types, ie. light, medium and heavy oil pools. Note also that a discrepancy occurs in the recorded produced volumes of oil between the production data file and the reserves data. Both data files were current to the second quarter of 1988, however, the production data were edited to a reference data of January 1st, 1988. Data for the tenth category (confidential wells and pools) are not displayed in the Tables.

OBSERVATIONS

To January 1st, 1988 some 84 567 zones have been completed for oil, gas and water recovery or injection in Alberta. Of these wells 47% or 39 668 are oil wells, 43% or 36 555 are gas wells, 1.5% or 1286 are classified as gas/oil wells and 8% or 7,058 are classified as water wells. As previously mentioned many of the wells which are now classified as water wells may have been previously oil wells but are now water source or injector wells and are not included in the oil well count. Commingled zones also show only once and are classified according to the shallowest of the commingled zones.

Of the 39 668 oil well completions in Alberta 22 279 (56%) contributed some production in December of 1987. Of the 39 585 gas well completions in the province some 25 691 wells (64%) contributed to production in December 1987. Note that some of the "shut in" wells may have produced in the 4th quarter of 1987 and may be a source of error in the presented tables. Of the total well count a disproportionate number of these completions occur in the Cretaceous system, ie. 24 391 oil and 32 278 gas (Table 3). Note that this disproportionate ratio of the well count does not apply to the same extent in the production volumes of either oil or gas. Cumulative oil production has historically been dominated by the Woodbend and Beaverhill Lake groups (28% and 19% respectively). Current quarterly oil production is dominated by the Lower Cretaceous interval (26% of the provincial total in the 4th quarter of 1987).

The largest oil reserves groups in Alberta have historically been the Leduc and Beaverhill Lake groups, but are now of lesser significance when production volumes are taken into account. The Lower and Upper Cretaceous contain some 13% and 25% respectively of the remaining recoverable reserves of the province. These factors are all indicative of a change with time in the relative significance of different stratigraphic zones. Production and reserve volumes of oil which previously were dominated by Devonian reef plays are being replaced by Cretaceous pools which, in general, are smaller, less productive, shallower and have poorer recovery factors.

In general the Cretaceous oil reservoirs are less attractive with respect to reserves and productivity, but are not as capital intensive due to their shallower depth. Furthermore, the increase in the significance of shallower production indicates that these zones are being successfully explored for on a more active basis.

Notable exceptions to this generalization are the increases in the productive significance of Wabamun - Winterburn, Elk Point and basal Paleozoic clastic subdivisions. All of these intervals show an increase in the relative contribution to total production in the last quarter of 1987 versus their contribution to total cumulative production to date. This change is due to the significant reserve and production additions to the Winterburn Gp in the West Pembina area in the late 1970's, and the ongoing reserve additions to the Elk Point Gp and basal Paleozoic clastic units in the Peace River Arch area of northern Alberta.

With regard to the pool average figures, some features are noteworthy. In general, the average recovery factor for the shallower clastic reservoirs are less than one half of the recovery for the Devonian carbonate plays. This is partially due to the occurrence of a large number of heavy oil pools in the Cretaceous, but is also attributable in part to porosity and permeability differences and distribution, reservoir geometry, drive mechanisms and recovery schemes. Note that where Devonian reservoirs once contained 57% of the total recoverable reserves of the province, they now contain 44% of the remaining recoverable reserves. By comparison the combination of Triassic, Jurassic and Cretaceous reservoirs which once contained 32% of initial reserves of recoverable oil in the province, now contain 44.7% of the remaining reserves. This shift in the reserve trends of the province suggests that production is becoming more dependent on recovery from shallower, poorer recovery and heavier gravity reservoirs. By comparison, the per barrel capital costs associated with the shallower oil are probably similar to the deeper reservoirs, however, a significant increase in operational costs because of lower rates of production can be expected.

To January 1st, 1988 there has been some 39 585 gas zone completions in Alberta. A disproportionate number of these wells, approximately 19000 occur in southeast Alberta and are attributable to the Upper Cretaceous production of that area. The most significant initial reserves of gas in Alberta are from the Mississippian and Lower Cretaceous intervals, which contained 27% and 31% of the total marketable gas production. Production, however, has depleted some 58% of recognized Mississippian reserves and 37% of the Lower Cretaceous gas. Of interest is the fact that some 11000 Lower Cretaceous gas wells have at one time produced in Alberta, although there are some 15 240 recognized Lower Cretaceous gas pools. This difference is attributable to the existence of many shut in single well Lower Cretaceous gas pools which have never produced.

Of note in the analysis of gas production is the wide variance in the productivity of the various horizons with the shallower horizons showing the highest well counts and the lowest per well productivity. In the last quarter of 1987 approximately 17 691 on stream Upper Cretaceous gas wells produced an average of 2 370 m^3/d per well, accounting for some 12.7% of the provincial production. In the same period approximately 135 Beaverhill Lake Gp gas wells produced some 2933 x $10^3 m^3$ of gas accounting for 9.8% of provincial gas production (note that these volumes include solution gas from oil wells).

These data, when coupled with the increase in the relative contribution of the shallow horizons show an ongoing change in gas production in the province. Although many of the deeper carbonate reservoirs are still strong gas producers there is a slow but continual increase in the proportion of production from shallow low productivity wells.

CONCLUSIONS

Reserves and production volumes of the Alberta portion of the Western Canada Sedimentary Basin have historically been dominated by carbonate plays which occur as subcrop and reefal traps. Although the Paleozoic reservoirs remain strong producers, their overall contribution to the productivity is being gradually replaced by more numerous but less productive Mesozoic reservoirs. This tendency reflects the maturity of the basin and also shows a tendency towards conservative investment strategies in moderate risk and moderate return type plays. Seismic studies including 3D will play an increasing role in the location and evaluation of these plays.

ALBERTA CUMULATIVE PRODUCTION PROVINCIAL SUMMARY

	OIL (M3)			GAS (E3M3)			WATER (M3)		CONDEN (M3)	
	4Q/87	CUM 12/87	# OIL PROD	4Q/87	CUM 12/87	#GAS PROD	4Q/87	CUM 12/87	4Q/87	CUM 12/87
UPPER CRETACEOUS	1,623,222	224,171,187	5,276	3,774,288	207,417,539	17,691	2,197,700	138,615,754	270	19,769
LOWER CRETACEOUS	4,271,699	172,090,507	9,136	10,189,667	530,088,641	6,004	11,241,474	270,535,059	15,670	714,077
JURASSIC/TRIASSIC	1,131,135	40,412,155	1,201	1,342,554	36,820,257	179	2,154,474	36,220,066	2,384	176,273
MISSISSIPIAN	551,842	66,578,560	967	5,687,140	545,508,349	842	916,759	34,081,867	4,214	2,445,585
WABAMUN/WINTERBURN	1,876,770	130,372,056	847	1,801,336	118,117,978	331	2,264,535	53,503,140	272	75,711
WOODBEND	1,970,915	449,077,179	1,528	2,859,582	305,266,907	216	15,952,481	602,480,034	293	1,261,227
BEAVERHILL LAKE	1,882,754	302,159,339	1,533	2,932,195	177,039,489	135	10,499,150	296,998,258	0	73,416
ELK POINT	1,370,632	112,895,648	790	434,274	21,553,804	5	1,112,704	28,652,971	55	26,086
BASAL PALEOZOIC CLASTICS	1,278,670	98,838,585	809	171,494	9,036,382	1	18,835,723	1,148,654,793	0	128
UNDEFINED	69,500	1,084,271	192	446,614	2,720,138	287	405,284	53,292,512	943	15,157
GRAND TOTAL	16,027,139	1,597,679,487	22,279	29,639,144	1,953,569,484	25,691	65,580,284	2,663,034,454	24,101	4,807,429

WELL COUNT

	WELL STATUS					
	OIL	GAS	GAS/ OIL	WATER	TOTAL WELLS	
UPPER CRETACEOUS	7,004	21,207	97	2,060	30,368	
LOWER CRETACEOUS	17,387	11,071	823	1,827	31,108	
JURASSIC/TRIASSIC	1,651	303	47	238	2,239	
MISSISSIPIAN	1,586	1,204	83	263	3,136	
WABAMUN/WINTERBURN	2,300	649	22	220	3,191	
WOODBEND	2,984	494	31	176	3,685	
BEAVERHILL LAKE	2,299	232	6	539	3,076	
ELK POINT	1,294	71	10	78	1,453	
BASAL PALEOZOIC CLASTICS	1,393	89	1	1,092	2,575	
UNDEFINED	1,770	1,235	166	565	3,736	
GRAND TOTAL	39,668	36,555	1,286	7,058	84,567	TOTAL WELLS
	47%	43%	1.5%	8%	99.5%	% of TOTAL WELLS

Table 3: Summary of productive wells by interval, in Alberta

RESERVES AND PRODUCTIVITY OF ALBERTA'S PROVEN AND PROBABLE LIGHT, MEDIUM AND HEAVY OIL POOLS

	TOTAL OIL IN PLACE ($10^6 m^3$)	TOTAL PRIMARY RECOVERABLE RESERVES ($10^3 m^3$)	TOTAL PRIMARY PLUS SECONDARY RECOVERABLE RESERVES ($10^3 m^3$)	TOTAL PRIMARY PLUS SECONDARY RECOVERABLE RESERVES AS A % OF PROVINCIAL TOTAL	REMAINING RECOVERABLE RESERVES ($10^3 m^3$)	% OF TOTAL OR REMAINING RESERVES	AVERAGES FOR ALL POOLS WITHIN EACH STRATIGRAPHIC SUBDIVISION: INITIAL OIL IN PLACE ($10^3 m^3$)	RECOVERY FACTOR (%)	PRIMARY RECOVERABLE RESERVES ($10^3 m^3$)	TOTAL PRIMARY PLUS SECONDARY RECOVERABLE RESERVES ($10^3 m^3$)	CUMULATIVE PRODUCTION ($10^3 m^3$)	REMAINING RESERVES ($10^3 m^3$)	AREA (ha)	THICKNESS (m)	POROSITY (%)	WATER SATURATION (%)
UPPER CRETACEOUS	2,085	222,046	380,357	17.3	153,392	25.0	4,307	8	459	786	469	318	951	4.93	14.0	30
LOWER CRETACEOUS	1,921	173,353	245,250	11.2	83,903	13.6	939	6	85	120	79	41	223	3.89	20.5	34
JURASSIC & TRIASSIC	318	46,598	77,505	3.5	37,379	6.1	1,028	11	151	251	30	121	277	4.95	15.8	31
MISSISSIPPIAN	590	75,612	85,700	3.9	18,487	3.0	2,252	8	289	327	257	71	384	8.33	10.5	31
WABAMUN & WINTERBURN	373	144,161	176,823	8.1	46,311	7.6	1,623	18	627	769	567	201	333	18.07	7.6	25
WOODBEND	810	454,814	489,846	22.3	47,561	7.8	5,399	26	3,032	3,266	2,949	317	600	15.88	8.4	18
BEAVERHILL LAKE	1,036	171,000	404,601	18.4	102,686	16.7	8,636	16	1,425	3,372	2,516	856	1,443	8.81	8.7	33
ELK POINT	487	145,083	187,131	8.5	74,757	12.2	627	17	187	241	145	96	55	35.76	7.1	19
BASAL PALEOZOIC CLASTICS	345	88,849	147,627	6.7	48,857	8	1,984	19	511	848	568	281	650	3.57	15.6	35

	DEPTH (m)	DENSITY (kg/m^3)	PRESSURE (kpa)	TEMPERATURE (°C)	TOTAL NUMBER OF POOLS	NUMBER OF LIGHT AND MEDIUM POOLS	NUMBER OF HEAVY POOLS	NUMBER OF POOLS UNDERGOING ENHANCED RECOVERY	TOTAL AREA (ha)	TOTAL NUMBER OF WELLS	TOTAL NUMBER OF PRODUCING WELLS	TOTAL NUMBER OF SHUT IN WELLS	TOTAL CUMULATIVE OIL PRODUCTION TO DATE ($10^6 m^3$)	TOTAL CUMULATIVE WATER PRODUCTION FROM GAS, OIL AND WATER SOURCE WELLS ($10^6 m^3$)	QUARTERLY CUMULATIVE OIL PRODUCTION ($10^3 m^3$)	QUARTERLY CUMULATIVE WATER PRODUCTION FROM GAS OIL AND WATER SOURCE WELLS ($10^3 m^3$)	AVERAGE DAILY OIL PRODUCTION ($10^3 m^3/D$)	CUMULATIVE OIL PRODUCTION BY ZONE AS A % OF TOTAL CUMULATIVE OIL PRODUCTION TO DATE FROM ALL ZONES	QUARTERLY CUMULATIVE OIL PRODUCTION BY ZONE AS A % OF TOTAL QUARTERLY OIL PRODUCTION FROM ALL ZONES
UPPER CRETACEOUS	1,696	815	14,263	55	484	482	2	39	460,103	7,004	5,276	1,728	224	138	1,623	2,197	3.4	14.4	10.1
LOWER CRETACEOUS	1,215	889	9,966	41	2,046	1,088	958	95	455,728	17,387	9,136	8,251	1,727	270	4,271	11,241	5.1	10.2	26.6
JURASSIC & TRIASSIC	1,673	843	14,637	58	309	239	70	24	85,678	1,651	1,201	450	40	36	1,131	2,154	6.2	2.5	7.0
MISSISSIPPIAN	1,655	872	13,334	53	262	195	67	13	100,615	1,586	967	619	66	34	551	916	6.2	4.3	3.4
WABAMUN & WINTERBURN	1,916	822	16,959	63	230	211	19	47	76,532	2,300	847	1,453	130	53	1,876	2,264	24.4	8.3	11.7
WOODBEND	1,882	853	15,142	65	150	145	5	8	89,966	2,984	1,528	1,456	449	602	1,970	15,952	14.3	28.0	12.2
BEAVERHILL LAKE	1,860	811	17,029	59	120	120	0	17	173,135	2,299	1,533	766	302	296	1,882	10,499	13.5	19.1	11.7
ELK POINT	1,564	842	14,629	71	776	776	0	80	42,794	1,294	790	504	112	28	1,370	1,112	19.2	7.1	8.5
BASAL PALEOZOIC CLASTICS	1,687	822	15,766	51	174	174	0	5	113,153	1,393	809	584	98	1,148	1,278	18,835	17.4	6.2	7.9

Table 1: Summary of oil reserves in Alberta

RESERVES AND PRODUCTIVITY OF ALBERTA'S PROVEN AND PROBABLE GAS POOLS

	TOTAL GAS IN PLACE ($10^9 m^3$)	TOTAL PRODUCIBLE GAS ($10^9 m^3$)	TOTAL INITIAL MARKET GAS ($10^9 m^3$)	TOTAL PRODUCTION (MARKET GAS) ($10^9 m^3$)	PRODUCTION BY INTERVAL AS A % OF TOTAL PRODUCTION	TOTAL REMAINING MARKET GAS ($10^9 m^3$)	TOTAL REMAINING MARKET GAS AS A % OF TOTAL INITIAL MARKET GAS	TOTAL AREA (10^3 ha)	NUMBER OF POOLS	TOTAL WELLS	TOTAL WELLS PRODUCING AS OF DECEMBER, 1987	TOTAL WELLS COMPLETED BUT NOT PRODUCING OR ABANDONED AS OF DECEMBER, 1987
UPPER CRETACEOUS	581	400	380	146	11.3	233	61	5,001	1,840	21,207	17,691	3,516
LOWER CRETACEOUS	1,662	1,153	1,135	409	31.4	726	63	8,440	15.240	11,071	6,004	5,067
JURASSIC & TRIASSIC	188	143	128	24	1.9	103	80	306	735	303	179	124
MISSISSIPPIAN	964	635	612	352	27.0	259	42	704	845	1204	842	362
WABAMUN & WINTERBURN	304	195	144	73	5.6	71	49	372	540	649	331	318
WOODBEND	397	288	213	132	10.2	81	38	375	212	494	216	278
BEAVERHILL LAKE	269	204	128	28	2.2	99	77	105	242	232	135	97
ELK POINT	26	20	17	5	0.3	12	70	22	499	71	5	66
BASAL PALEOZOIC CLASTICS	3	2.4	2.1	0.2	0	1.9	90	6	28	89	1	88

	AVERAGES FOR ALL POOLS WITHIN EACH STRATIGRAPHIC SUBDIVISION														RAW GAS PRODUCTION DURING THE FOURTH QUARTER OF 1987 ($10^6 m^3$)	CUMULATIVE RAW GAS PRODUCTION AS OF DECEMBER, 1987 ($10^9 m^3$)	AVERAGE DAILY GAS PRODUCTION PER WELL DURING THE FOURTH QUARTER OF 1987 ($10^9 m^3$. D)	PRODUCTION BY ZONE AS A % OF TOTAL PRODUCTION DURING THE FOURTH QUARTER OF 1987
	DEPTH (m)	AREA (ha)	THICKNESS (m)	POROSITY (%)	PRESSURE (mkpa)	TEMPERATURE (°K)	COMPRESSABILITY (Fraction)	GAS IN PLACE ($10^6 m^3$)	RECOVERY (Fraction)	GAS PRODUCTION ($10^6 m^3$)	SURFACE LOSS (Fraction)	INITIAL MARKET GAS ($10^6 m^3$)	PRODUCTION OF MARKET GAS ($10^6 m^3$)	REMAINING RESERVES ($10^6 m^3$)				
UPPER CRETACEOUS	797	2,718	3.3	22	5.5	300	.91	316	65	218	.06	207	80	127	3,774	207	2.73	12.9
LOWER CRETACEOUS	963	554	2.5	22	7.4	306	.88	109	70	76	.07	75	27	48	10,189	530	18.85	34.9
JURASSIC & TRIASSIC	1,929	417	4.2	13	16.5	340	.85	257	75	195	.10	175	34	141	1,342	36	83.30	4.6
MISSISSIPPIAN	1,923	834	7.4	11	16.1	332	.85	1,141	74	752	.11	724	417	307	5,687	545	75.04	19.5
WABAMUN & WINTERBURN	1,430	691	8.5	12	12.2	312	.87	563	69	361	.13	268	136	133	1,801	118	60.45	6.2
WOODBEND	1,812	1,773	15.2	10	15.7	327	.88	1,877	68	1,360	.16	1,009	625	384	2,859	305	147.06	9.8
BEAVERHILL LAKE	1,509	436	7.4	7	14.6	326	.83	1,114	76	844	.12	530	118	411	2,932	177	241.32	10.0
ELK POINT	1,485	44	14.6	7	13.9	326	.80	53	76	41	.15	35	9	45	432	21	96	1.4
BASAL PALEOZOIC CLASTICS	2,204	227	3.6	12	20.5	342	.85	11	76	86	.14	76	6	70	171	9	—	0.005

Table 2: Summary of gas reserves in Alberta

NOTES: 1. RAW GAS INCLUDES ALL MEASURED, PRODUCED GAS VOLUMES AT THE WELL HEAD, AND IS NOT EQUIVALENT TO MARKET GAS IN THAT IT CONTAINS H_2S, CO_2, WATER VAPOR, FUEL GAS SUPPLY AND REINJECTED GAS; WHEREAS MARKET GAS PERTAINS ONLY TO THE SALEABLE PORTION OF THE RAW GAS. IN MANY INSTANCES THIS INCLUDES THE ENERGY EQUIVALENTS OF CONDENSATES AND NATURAL GAS LIQUIDS (NGL'S).
2. PER POOL AVERAGES ARE DERIVED BY SUMMING FOR THE ZONE AND DIVIDING BY THE NUMBER OF POOLS.
3. PER WELL PRODUCTION AVERAGES ARE HIGH DUE TO THE INCLUSION OF SOLUTION GAS IN THE TOTAL RAW GAS PRODUCTION VOLUMES.

PART C: SEISMIC SIGNATURES

N. L. Anderson, Ohio University, Athens;
R. J. Brown, University of Calgary; and
E. Greenwood, Canada Northwest Energy.

The seismic signatures (or distinguishing seismo-geological features) of western Canadian hydrocarbon reservoirs are generally made up of two basic components: lateral character variations and time-structural relief (Fig. 10). Ideally both components are geophysical representations of geological features and are primarily functions of the morphology of the reservoir and the nature of the basin in which the reservoir facies were deposited: clastic or carbonate; shale or evaporite.

Lateral character variations can be classified either as phase and/or amplitude changes along seismic events or as changes in the pattern of a sequence of events originating from a stratigraphic unit or interval (this pattern is herein referred to as the seismic image). Such lateral character variations, or seismic representations of stratigraphic features, may include: variations in acoustic-impedance contrast (Fig.11) which may arise from gradational or abrupt facies changes; focusing and defocusing of reflections from curved or irregular surfaces (Fig. 12); diffractions; constructive or destructive interference as a function of varying interval thickness (Fig. 13), and amplitude variations which may be the result of differential attenuation. Following Sheriff (1973), attenuation is defined as any reduction in the amplitude of seismic waves, such as produced by spherical divergence, energy absorption, reflection and scattering. The term differential attenuation is here defined as any lateral change in the amplitude of a seismic event which is attributable to lateral variations in the attenuative properties of the relevant rock formations.

Character variations which are independent of the reservoir are not considered to be components of the seismic signature. In this regard, one should be cautious of apparent (i.e. spurious) character variations which can result from the application of, for example, inappropriate stacking velocities, or of erroneous static corrections. The latter could arise, for instance, in an area where fairly recent salt dissolution has created a collapse feature that extends a considerable way up the section. This feature could be interpreted as a residual static error on the seismic section and "corrected" out, creating a spurious "reef" or the like below the salt-bearing unit.

Time-structural relief is comprised of both velocity-generated relief and structural relief. Velocity-generated relief is primarily due to lateral variations in average velocity associated with facies changes (Fig. 14) and with local thickness variations (Fig. 15). Structural relief (Fig. 16) can be syndepositional or postdepositional in origin. Postdepositional relief results from geological phenomena such as erosion, faulting, salt dissolution and differential compaction. Time-structural relief which is independent of the particular reservoir is not considered to be a component of its seismic signature. Again, as a word of caution, it may be noted that spurious time-structural relief can result from erroneous statics corrections (Fig. 17) or from overzealous processing (Fig. 18).

There are many modelling studies in the literature which demonstrate the seismic effects of various stratigraphic features: Harms and Tackenberg (1972), Meckel and Nath (1977), Neidell and Poggiagliolmi (1977), Gelfand and Larner (1984), and Jain (1986), and Anderson et al. (1989) to mention just a few. Many of these ideas are incorporated into the seismic signature classification scheme used by Anderson and Brown (1987) and presented here (Fig. 1). In Figure 19, a geological model and a corresponding two-dimensional synthetic seismic section are presented in order to show some of the components of the seismic signatures associated with reefs. Table 4 illustrates one method of classification. Anderson and Brown (1987) suggest that modified versions of this classification scheme may be prepared and applied with advantage for any reservoir of interest, whether carbonate or clastic. Such tables may then be used as qualitative and quantitative benchmarks against which untested anomalies could be compared. In cases where untested anomalies deviate significantly from the classification norm, sound explanations, based on all available geological and geophysical information, should be developed to account for the observed deviations prior to drilling.

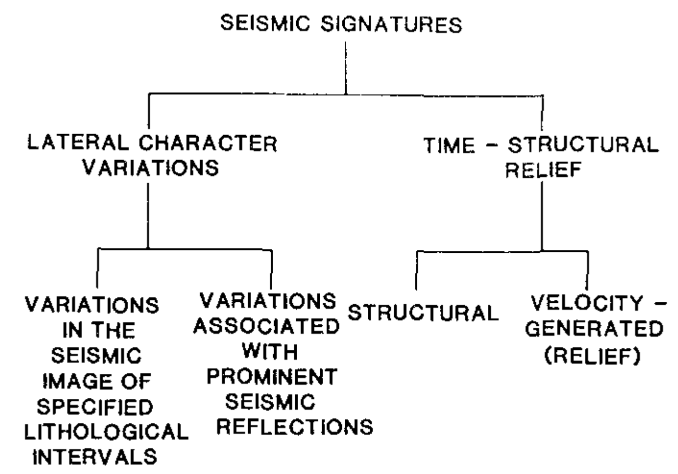


Figure 10. Seismic signatures (Anderson and Brown, 1987).

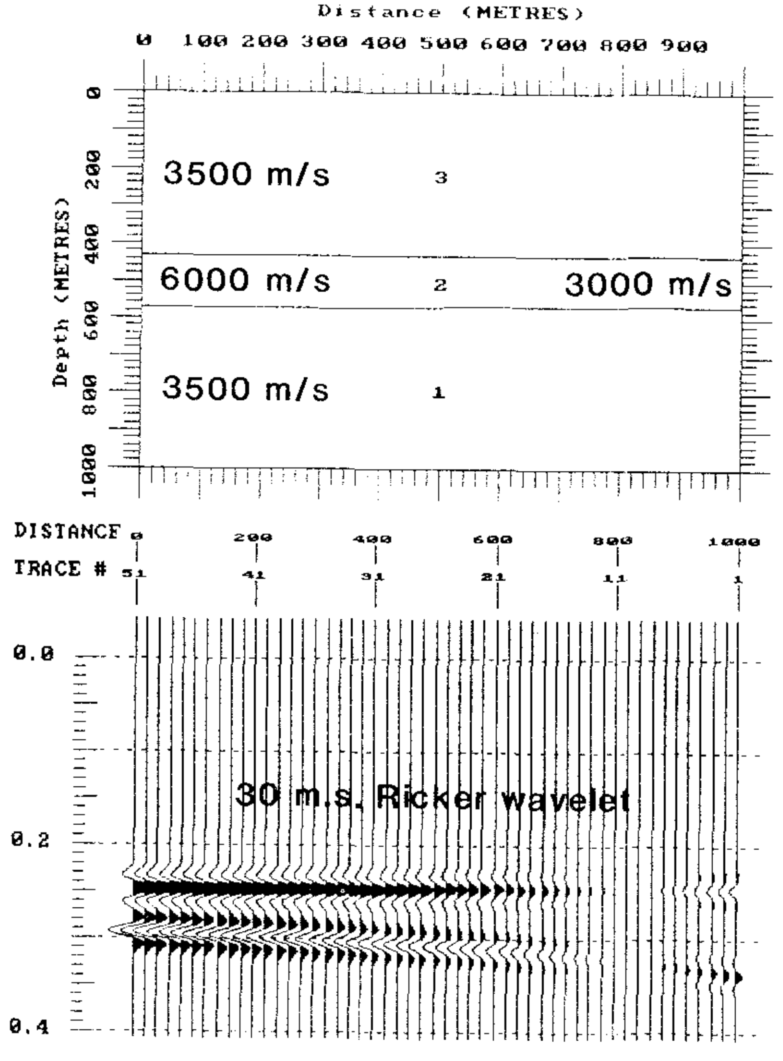


Figure 11. Phase and/or amplitude variations can result from lateral changes in acoustic impedance contrast.

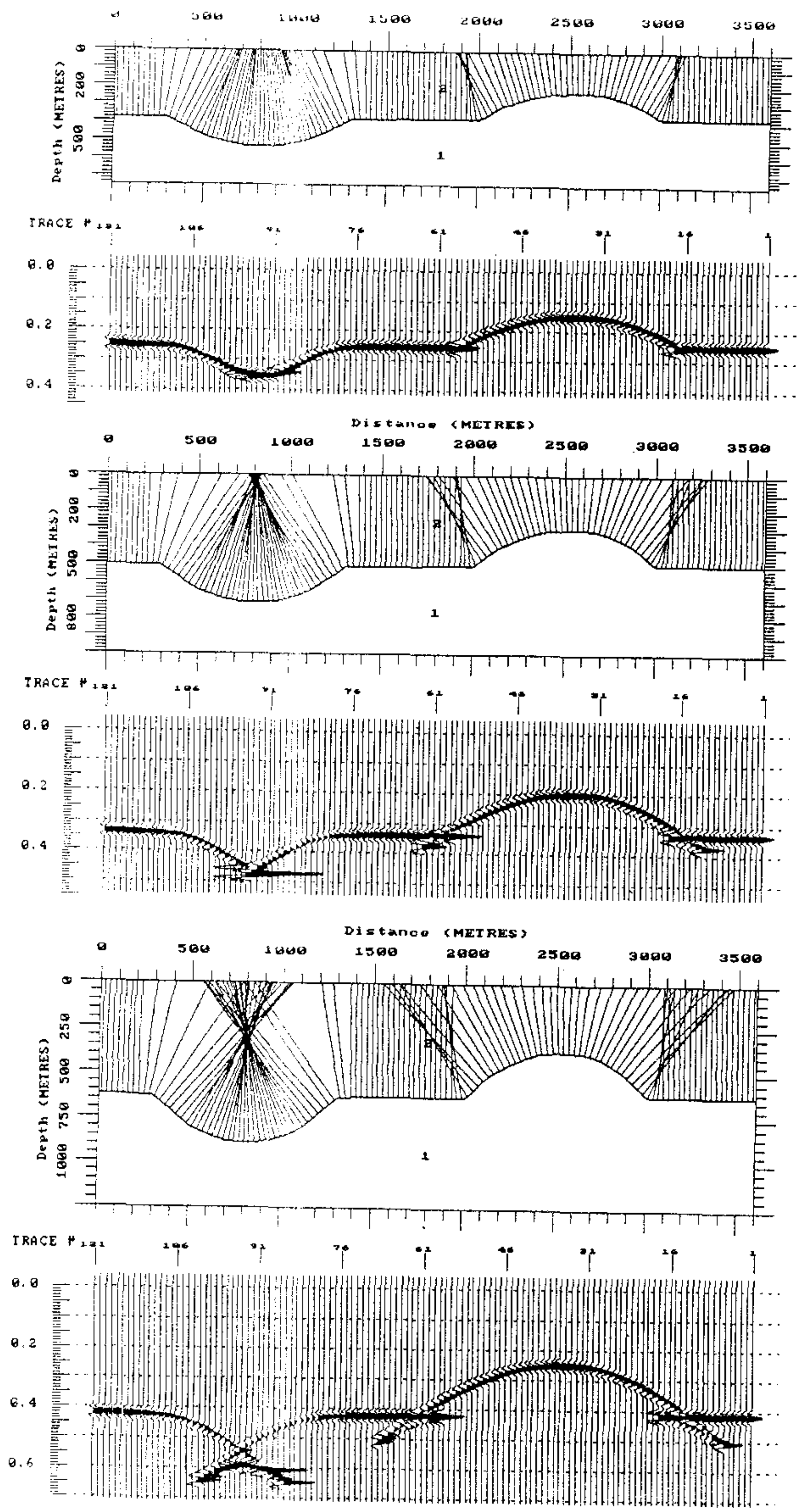


Figure 12. The focusing and defocusing effects of curved and irregular surfaces.

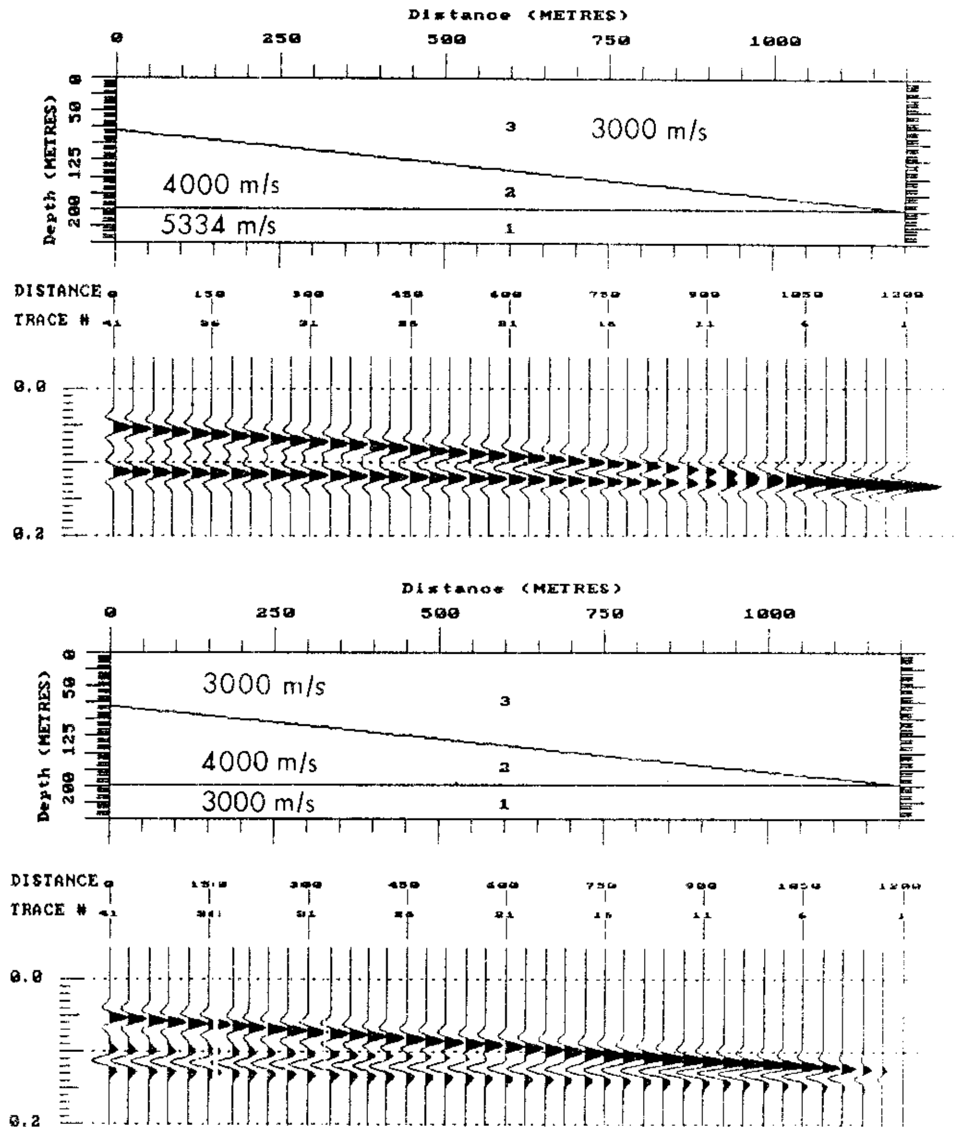


Figure 13. Constructive and destructive interference is a function of interval thickness and acoustic impedance contrast.

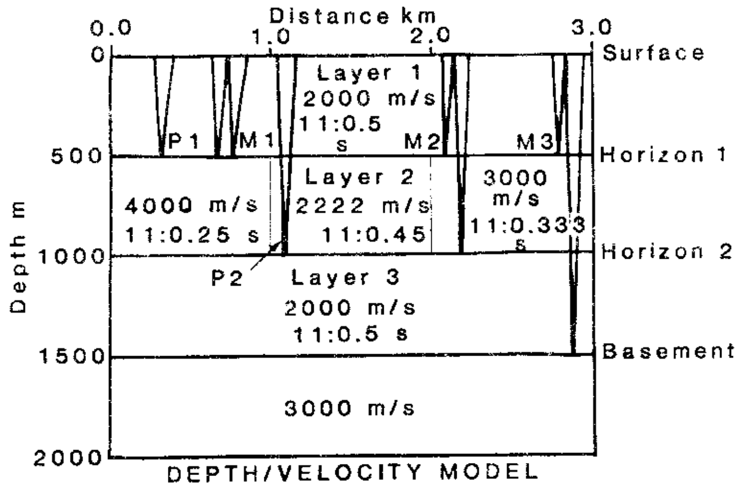


Figure 14.

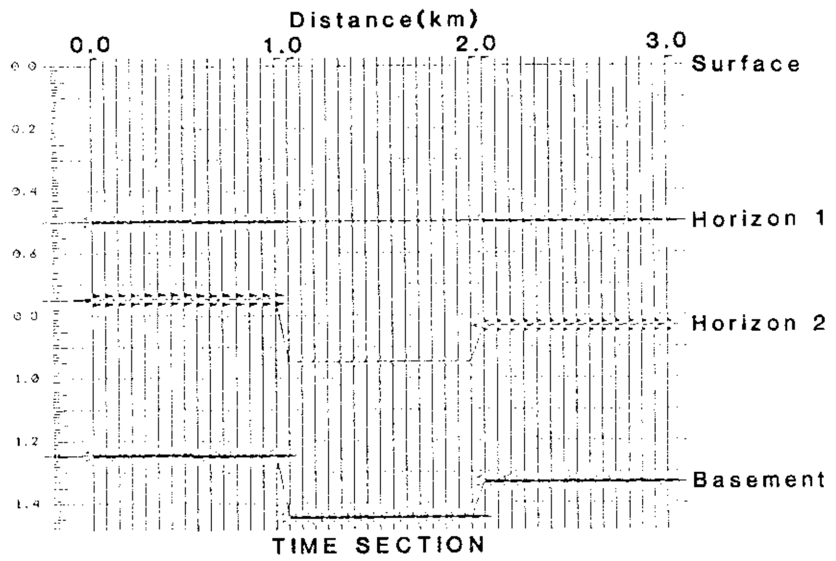


Figure 14. Velocity-generated time structural relief can be caused by lateral variations in the average velocity of the sedimentary section.

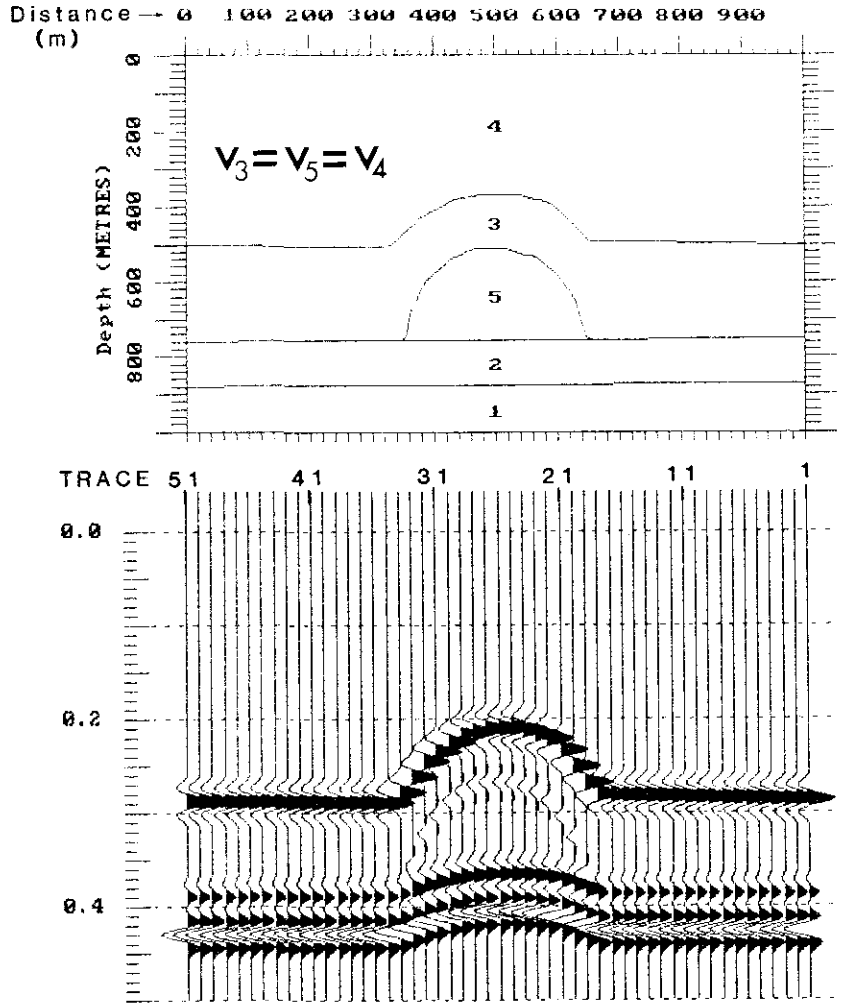


Figure 15. Velocity-generated time structural relief can be caused by lateral variations in the thicknesses of lithological units.

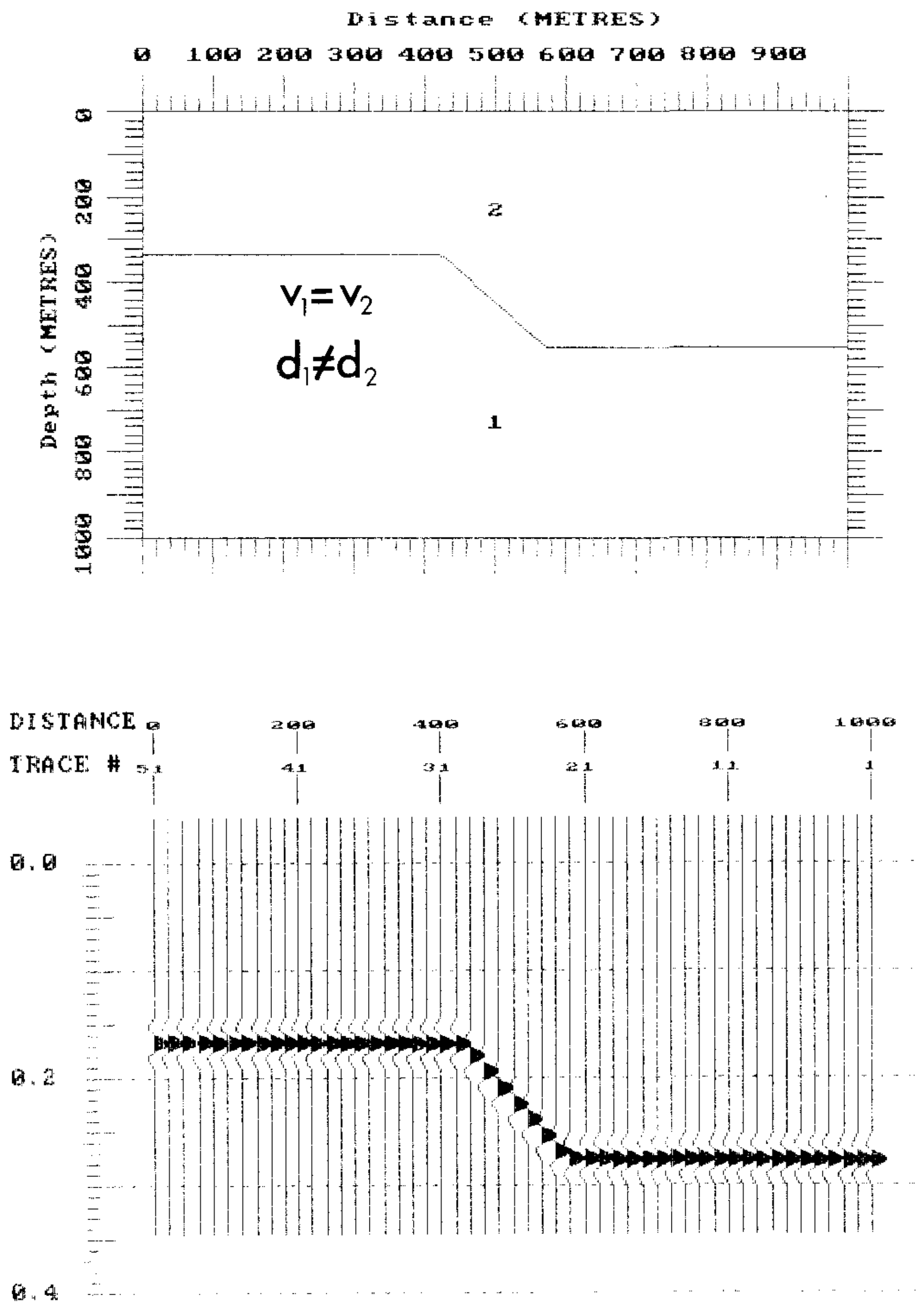


Figure 16. Time-structural relief can be caused by structural relief in the subsurface.

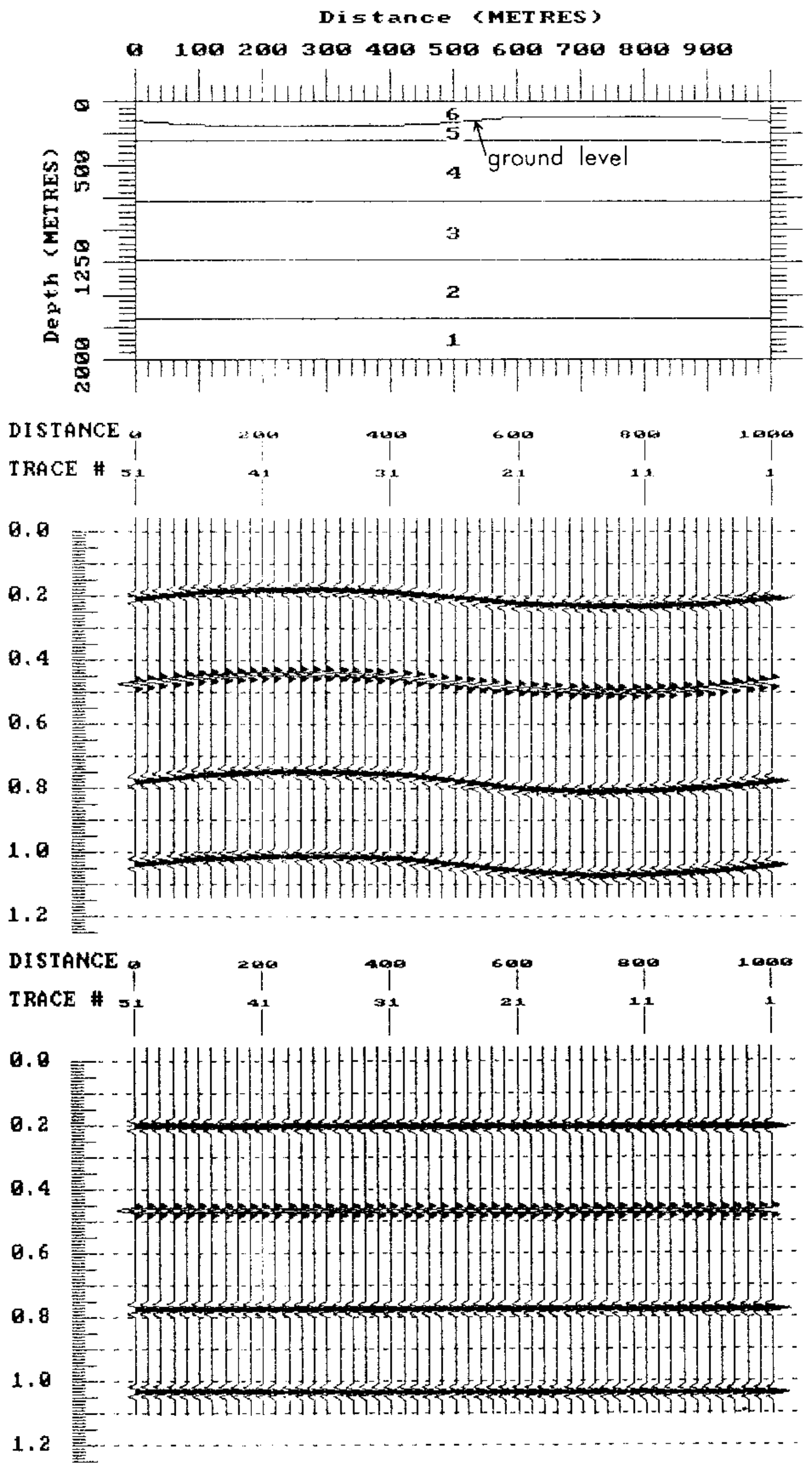


Figure 17. Apparent time-structural relief can be the result of either poor statics corrections or control.

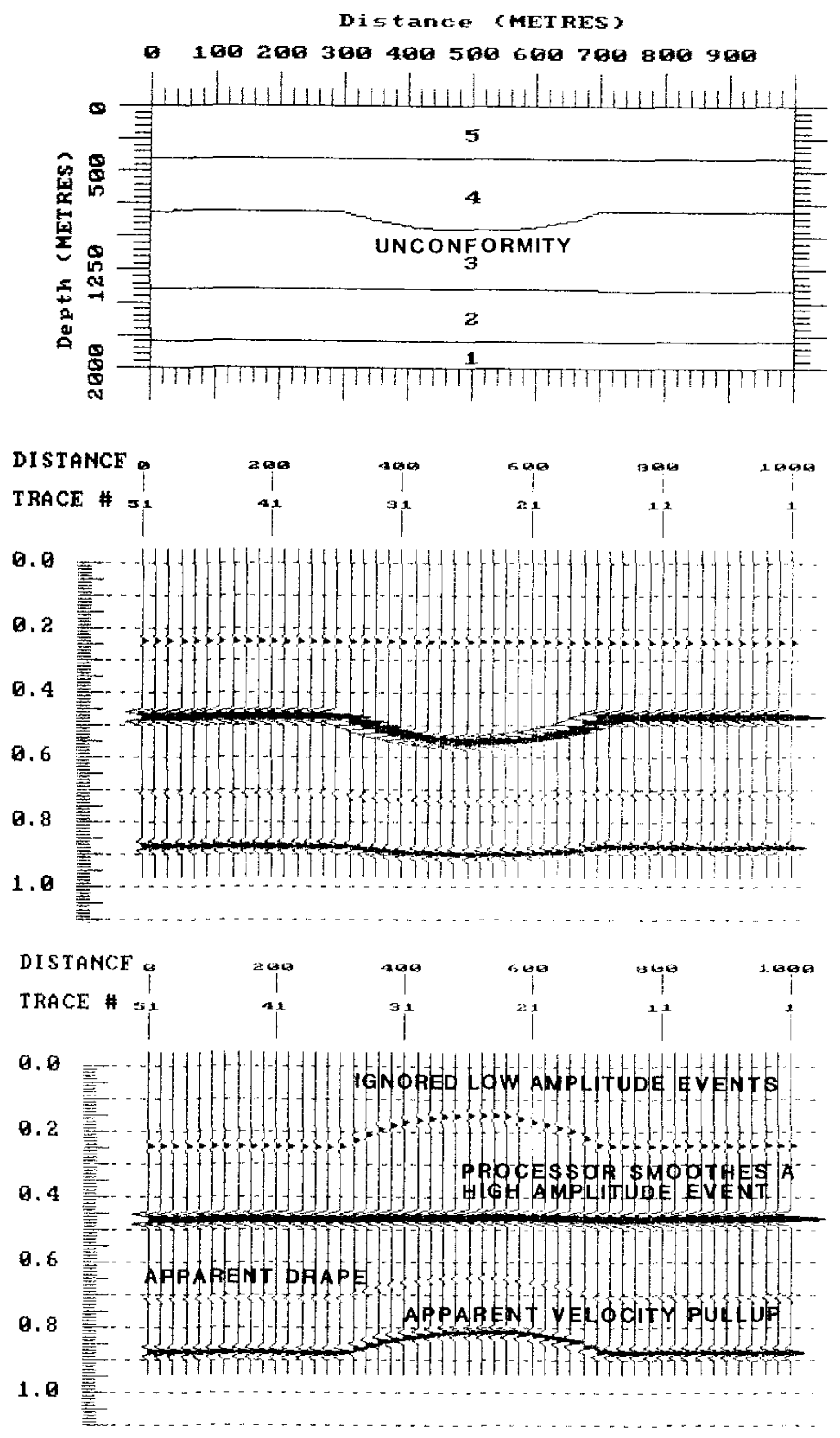


Figure 18. Aesthetic processing can transform the seismic signature of an erosional low into that of a carbonate reef.

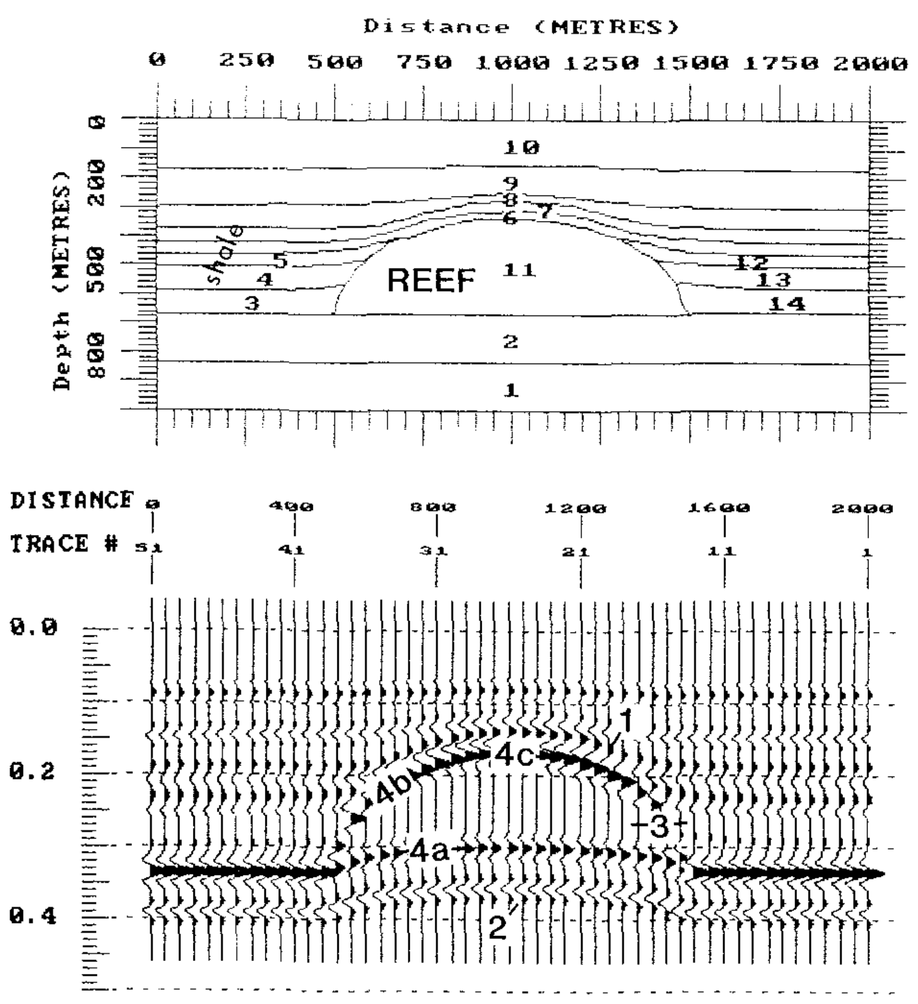


Figure 19. The seismic model illustrating some of the components of the seismic signature of a reef: 1) time-structural relief due to structure; 2) velocity-generated time-structural relief; 3) lateral variations in seismic image due to a change in facies; and 4) amplitude and/or phase variations due to: A) lateral changes in acoustic impedance; B) the focusing and/or defocusing effect of curved or irregular surfaces; and C) constructive and/or destructive interference.

REEF EXAMPLE: ____________________

SIGNIFICANT VELOCITY-GENERATED TIME-STRUCTURE	
REEF/OFF REEF VELOCITY RELATIONSHIPS	
EFFECT OF DRAPE	

SIGNIFICANT CHARACTER VARIATIONS ASSOCIATED WITH THE SEISMIC IMAGES OF THE REEF AND THE OFF-REEF FACIES	
REEF FACIES	
OFF-REEF FACIES	

SIGNIFICANT STRUCTURAL RELIEF	
PRE-PLATFORM HORIZONS	
REEF PLATFORM	
REEF	
POST-REEF (DEVONIAN)	
PRE-CRETACEOUS UNCONFORMITY	
CRETACEOUS HORIZON	

SIGNIFICANT CHARACTER VARIATIONS ASSOCIATED WITH PROMINENT SEISMIC REFLECTORS	
EVENTS ORIGINATING FROM PRE-PLATFORM REFLECTORS	
EVENTS ORIGINATING ALONG THE REEF PLATFORM	
EVENTS ORIGINATING FROM THE REEF/OFF REEF CONTACT	
EVENTS ORIGINATING ALONG POST-REEF REFLECTORS	

Table 4: Classification scheme for the seismic signature of a typical Devonian reef.

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