CHAPTER 3 — BEAVERHILL LAKE GROUP CARBONATE RESERVOIRS

INTRODUCTION

Reservoirs of the Beaverhill Lake Group comprise Swan Hills Fm and Slave Point Fm carbonates. The geographic locations of reservoirs discussed in this chapter are illustrated in Figure 3.1.

Hydrocarbon potential of the Beaverhill Lake Group was first explored in 1957, with the discovery of the Virginia Hills reef complex in the Swan Hills area of westcentral Alberta. Fong (1959) introduced the term Swan Hills Member for the reefal carbonates ascribed to the Beaverhill Lake Fm. Nearly ten years later, after the Swan Hills play evolved into twelve major oil and two gas fields, Leavitt and Fischbuch (1968) described the carbonates as Swan Hills Fm and raised the Beaverhill Lake Group to group status. Concurrently, the Swan Hills play coincided with the influx of terrigenous material of the Waterways Fm, associated with continued subsidence of the basin. Slave Point sediments were deposited during regressive or oscillatory conditions prevailing before the main transgressive phase of late-middle Devonian. Limestones of the Slave Point and Swan Hills formations represent the organic sedimentation phase of the widespread Beaverhill Lake transgression. Condensation of carbonate production coincided with the influx of terrigenous material of the Waterways Fm, associated with continued subsidence of the basis. Slave Point sediments were deposited during a diachronous event, the product of shallow water deposition of an advancing marine environment. Stratigraphically, the Slave Point Fm is correlative with the Swan Hills and Waterways formations (Fig. 3.3). On a more regional scale, Griffin (1965) established the correlation between the Slave Point Fm in northeastern British Columbia and a substantial part of the Waterways Fm in Alberta (Fig. 3.43) modified after Griffin, 1965.

Swan Hills Fm reefs developed in an embayment south of the Peace River Arch, as illustrated in Figure 3.1. Reservoirs of the Beaverhill Lake Group developed within Swan Hills Fm fringing-reef, isolated bioherms and reef-reef carbonate banks; Slave Point Fm barrier-reef, platform reefs, shoals and carbonate banks. The limestone framework of Swan Hills carbonates is preserved, whereas some Slave Point reservoirs are enhanced by dolomitization (e.g. Clarke Lake, Slave). Porous carbonates are sealed by the enveloping argillaceous sediments of the Waterways Fm (Horn River and Muskwa formations in British Columbia). Beaverhill Lake Group hydrocarbon traps often exhibit both stratigraphic and structural components. Regional dip influences the distribution of hydrocarbons within stratigraphic traps such as carbonate banks (e.g. Anne Creek), shelf edges (e.g. Swan Lake) and some isolated reefs (e.g. Snipe Lake, Virginia Hills). Hydrocarbons are contained by the up-dip edge of these back-reefs. Relief of the reservoir may be afforded by Precambrian topography, imposing a structural constraint on some stratigraphic traps (e.g. Gift) due to compaction-induced drape. Paleotopographic influence on the carbonate facies distribution exemplifies the mutual involvement of structure and stratigraphy (e.g. Slave, Gift).

The eight Beaverhill Lake fields discussed in this chapter (Fig. 3.1) include reservoirs within the Swan Hills reef-reef carbonate bank (Anne Creek), isolated bioherms (Goose River, Snipe Lake), platform fringe-reef (Horse Mountain), Slave Point platform (Gift, Slave), carbonate shelf and platform accretion (Sawn Lake) and barrier-reef complex (Clarke Lake). The aforementioned

Figure 3.1 Regional setting of the Beaverhill Lake Group fields discussed in this chapter.
Calculations held within the Fission Track Laboratory generate consistent results, suggesting the term is used generically and the term "bioherm" is not necessarily stratigraphically correct.

RESERVOIRS
The reservoirs are stratigraphically diverse, due to the time transgressive nature of the carbonate facies (Figs. 3.2 and 3.3).

This chapter provides an integrated geological-geophysical approach to the interpretation of an exemplary cross-section through each field. Each morphologically distinct reservoir generates a characteristic seismic signature for which an integrated analysis is presented. Reservoir characterization, facies morphology, facies, porosity and compaction-induced drape are correlated with the seismic image. The lateral facies change between reservoir and encompassing sedimentary section is stratigraphically defined, together with the influence of tectonic activity. Geologically significant components of the seismic response include isochron changes, amplitude (reflectivity) anomalies, amplitude and frequency modulation (waveform interference effects), time-structured collapse, and velocity generated pull-up. These criteria are discussed in detail within the individual seismic interpretation sections of the chapter. Stratigraphic seismic models, accompanying each example (except Clarke Lake), integrate the geological cross-sections and present the seismic image, thus corroborating the interpretation. The Clarke Lake example is uncompensated, instead, by the seismic correlation of three synthetic seismic traces, representing distinct geological faces along the line of study.

Figure 3.2 Stratigraphy of the Beaverhill Lake Group, Peace River Arch and Swan Hills regions.

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Introduction
Ante Creek Field is located approximately 280 km northwest of Edmonton in Township 65, Ranges 23-24 W5M (Fig. 3.1). Hydrocarbon production is from the Swan Hills Fm of the Beaverhill Lake Group, at 3435 m average depth. The discovery well, Atlantic Ante Creek 4-76-20SW5, was completed November 1962 with initial potential flow of 58 m/day of 43°API gravity.

Stratigraphy of the Beaverhill Lake Group in the vicinity of Ante Creek is consistent with Figure 3.3, excepting the Fort Vermilion Fm which is poorly defined. Corneil (1969) referred to the 3 m of saline rocks, underlying the Elk Point chert, as basal Beaverhill Lake rather than Fort Vermilion Fm. The Swan Hills Fm comprises a lower 30 m of Dark Brown platform member overlain by up to 90 m of the Eight Brown shoestring unit, Anlagatch limestones and shales of the Watersway Fm envelop the Swan Hills reef complex.

The Swan Hills Fm of Ante Creek is part of a massive reef-fringed carbonate bank which includes Kapsib South and Canos Creek (Fig. 3.4). The reservoir comprises porous limestone, surrounding the carbonate bank complex. Production is confined in the up-dip edge of the fringing-reef. In this study, the term "reef" or "bioherm" will be used when referring to the fringing-reef associated with the carbonate bank complex. Ante Creek Field is an elongate feature, approximately 12 km in length, isolated from Ante Creek Northwest by a surge channel (Fig. 3.4). The reef complex is separated from the Kapsib - Goose River - Snipe Lake reef chain by a deep embayment, filled with basal sediments of the Watersways Fm. Ante Creek and Ante Creek Northwest are the most westerly situated Swan Hills reefs and

Figure 3.2 Stratigraphy of the Beaverhill Lake Group, Peace River Arch and Swan Hills regions.

Figure 3.3 Stratigraphic nomenclature for the Beaverhill Lake Group, Swan Hills area.

Figure 3.4 Distribution of Swan Hills Fm reefs in westcentral Alberta.

Figure 3.5 Schematic diagram of Ante Creek Field, bearing the seismic and geological cross-sections.
provide the only oil production from the reef-fringed carbonate bank.

Ante Creek is the deepest Swan Hills field at over 3400 m and the basinward extent of the main reef edge, is inferred from the seismic manifestation of the Ante Creek reef complex. The other fields bearing gas.

The acoustic impedance contrast between low velocity Woodbend shales and the argillaceous limestone of the Waterways Fm generates a strong, coherent Beaverhill Lake reflection. Lateral variations in amplitude of this event are attributed to the interference phenomena described above.

Absestion of structural dips on the Beaverhill Lake and younger horizons across the reef edge is apparent. The lack of differential compaction associated with the biohermal rim of the carbonate bank (4-7) is inferred from the seismic interpretation.

Figure 3.8 Correlation of seismic data (left) with a synthetic seismogram derived from the 1920 sonic log shown in Figure 3.7, facilitates the interpretation. The Swan Hills amplitude response is weak compared with the Muskeg (below) and Beaverhill Lake reflectivity (above), compounded by the effects of destructive interference with the dominant Beaverhill Lake event. Proximal through the Ante Creek is the Muskeg Fm, represented by a decrease in the Beaverhill Lake to Swan Hills time interval. Oscillations through the Woodbend Group. Depth zone seismic stratigraphy is illustrated by the seismic reflection in the vicinity of the Muskeg (below). The Ante Creek reef is manifested by an abrupt increase in amplitude at the base of the Swan Hills field event over the Swan Hills build-up (seismic traces 180 to 281).

Reflected energy from the Swan Hills Fm surface is resolved in the offshore, platform environment. Correlation with the synthetic seismogram generated from the 1920 sonic log, shown in Figure 3.8, facilitates the interpretation. The Swan Hills amplitude response is weak compared with the Muskeg (below) and Beaverhill Lake reflectivity (above), compounded by the effects of destructive interference with the dominant Beaverhill Lake event. Proximal through the Ante Creek is the Muskeg Fm, represented by a decrease in the Beaverhill Lake to Swan Hills time interval. Oscillations through the Woodbend Group. Depth zone seismic stratigraphy is illustrated by the seismic reflection in the vicinity of the Muskeg (below). The Ante Creek reef is manifested by an abrupt increase in amplitude at the base of the Swan Hills field event over the Swan Hills build-up (seismic traces 180 to 281).

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Figure 3.6 Ante Creek field geological cross-section, incorporating the seismic interpretation (facing page)
Figure 3.7 Seismic expression across Ante Creek field.

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The calcareous Brenton member and top of the Wabamun, Beaufort and Debert formations are identified on the interpreted section. Relief observed on these events is attributed to regional tilting of the sedimentary section.

To assist and corroborate the seismic interpretation a synthetic seismic section was generated using sonic logs from the three wells in the geological cross-section. The stratigraphic seismic model (Fig. 3.9) consists of zero-offset, primary reflection coefficients convolved with a 25 ms, zero-phase Ricker wavelet. The seismic model includes a 3.9 km thick sedimentary section.

The synthetic seismic section was generated using sonic logs from the three wells in the southwest region of the complex (Smink and Letnikoff, 1980).

Production from the porous bioclastic limestone reservoir is outlined to the north-eastern half of the reef, encompassing an area of approximately 36 km². The most porous reservoir is found in the higher energy reef rim environment. Porosity and net average pay for the field are 8.2% and 12 m, respectively. Estimated original volume of oil in place is 2,040,000 m³, with 3480 m³ (primary) and 5424 m³ (secondary) recoverable reserves.

The Geological section from Ireton to Elk Point; Ireton marker, the Swan Hills Fm is subdivided and comprises 30 m of carbonate sediments to the west separate this reef chain from the Swan Hills Group.

The calcareous Ireton marker and tops of Wabamun, Banff and Deer Lodge formations are identified on the interpreted section. Relief of 10-18 before constructive interference generates the anomalous amplitude of the Beaverhill Lake event over the main reef mass.

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SNIPE LAKE FIELD

The deepest seismic reflection annotated is interpreted as the Marking event, below the Waterways Fm (Fig. 3.14). Variability of porosity and lithology from wells to the confluence of the two principal members of the Sneepey Lake field of west central Alberta is located approximately 1.6 miles south of the Sneepey Lake field of west central Alberta. Variations of porosity and lithology from wells to the confluence of the two principal members of the Sneepey Lake field are indicated by the presence of well-developed faulting and fractures in the seismic data. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident. The acoustic impedance contrast between low velocity Woodbend Group shales and the igneous formations of the Waterways Fm is evident.

Recapturing the seismic image of the Goose River reef complex is extremely weak, due to the excellent porosity development along the reef margin. The abrupt Sneepey Lake isopach increase across the reef edge is associated with the porosity effect. Absence of significant reflectivity from the main reef source causes the contrary time-structure reversal observed on the Beverhead Lake event. The calcareous breton marker and tops of Wabamun, Banff and Ireton member. Argillaceous shales and the argillaceous limestone of the Waterways Fm facies are seismically unresolved. The calcareous Ireton marker and tops of Wabamun, Banff and Ireton marker, Beverhead Lake, Swan Hills and Watt Mountain events are identified.

The synthetic seismic section reinforces the interpretation of the seismic signature observed across the Goose River reef. Proximal thinning of the Beverhead Lake to Swan Hills cycle is apparent, accompanied by a decrease in the amplitude of the Swan Hills reflections. Continuity, with subtle frequency modulation characterizes the Swan Hills event across the reef edge, between 4-22 and 10-16. Seismic imaging of the top of the reef is subdued as a consequence of the porosity development in 10-16. Amplitude of the porosity event diminishes towards the predominantly tight, back-reef facies in 10-8.

SNIPE LAKE INTRODUCTION

Sneepey Lake field of west central Alberta is located approximately 28 miles northwest of Edmonton in Townships 70-71, Ranges 18-19, W5M (Fig. 3.15). Production is from the Swan Hills Fm of the Beverhead Lake Group at 2000 ft average depth.

The Beverhead Lake Group in the vicinity of Sneepey Lake comprises Fort Vermilion, Swan Hills and Waterways formations (Fig. 3.3). In the study area, approximately 9 mi of arctic-boreal Fort Vermilion Fm overlie 4-14 Point Group dolomites. The Swan Hills Fm is subdivided and includes 50 mi of carbonate platform (Dolus Bower member) and more of bioturbated limestones (Light Brown member). Agglutinated foraminifera and shales of the Waterways Fm basal facies envelope the reef complex.

Sneepey Lake is an isolated syncline which developed on a protrusion of the Swan Hills carbonate platform into the deeper Waterways basin (Fig. 3.4). Separated from the Goose River complex, to the south, by a single channel, Sneepey Lake is the most northerly situated Swan Hills reef. A deep embayment in the west

Figure 3.14 Stratigraphic seismic model of Goose River field, filtered with a 25 ms rho-phase Ricker wavelet.

Time-structural relief along these events is attributed to regional tilting of the sedimentary section.

To assist and corroborate the seismic interpretation a synthetic seismic section was generated using sonic logs from four of the wells in the geological cross-section. The stratigraphic seismic model (Fig. 3.14) comprises zero-offset, primary reflection coefficients convolved with a 25 ms, zero-phase Ricker wavelet. The stratigraphic seismic model includes the geological section from Ireton to Elk Point; Ireton marker, Beaverhead Lake, Swan Hills and Watt Mountain events are identified.

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Figure 3.11 Goose River field geological cross-section, incorporating the seismic interpretation (facing page)
Figure 3.12 Seismic expression across Goose River field.
Figure 3.16 Snipe Lake field geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.17 Seismic expression across Snipe Lake field.
separates the Snipe Lake complex from the Swan Hills carbonate bank at Arite Creek (Fig. 3.4). Snipe Lake is the largest discrete reef complexes of the Beaverhill Lake Group with an areal extent of approximately 100 km².

Production from the limestone reservoir is confined by regional dip to the northeast edge of the reef. The productive area of the field is approximately 73 km², with the most porous reservoirs found in the higher energy, reef margin environment. The discovery well S.O.B.C. 96-15-71-18 W5M, drilled in October 1962, penetrated back-reef sediments and produced only 231.9 m³ of oil. The S.O.B.C. Snipe Lake 10-21-70-18 W5M, drilled in October 1962, encountered at 10-21; further suppression of amplitude of the Swan Hills event, due to destructive interference phenomenon (between traces 208 and 212). The absence of structural drape on the Beaverhill Lake and Watt Mountain isopachs. Although a 3 ms interface generates a strong seismic event. Any velocity generated pull-up effect is tentatively inferred by the increase in amplitude of the Swan Hills event near seismic trace 156. A distinct seiche feature of the cross-section. The deepest reflection identified, is interpreted as the top of the Muskeg Fm at the base of Watt Mountain Fm clastics. The Muskeg horizon is not penetrated by any of the wells but the acoustic interface generates a strong seismic event. Any velocity generated pull-up effect is tentatively inferred by the increase in amplitude of the Swan Hills event near seismic trace 156. The synthetic seismic trace derived from the 6-21 sonic log is shown in Figure 3.18.

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The synthetic seismic section verifies the interpretation of the seismic image across Snipe Lake reef. Proximal thinning of the Beaverhill Lake to Swan Hills isochron is apparent accompanied by suppression in amplitude of the Swan Hills event. Resolution of a discrete Swan Hills reflection is delayed as the Watersways Fm thins over the reef at 2100 m. however, seismic waveform interference causes frequency modulation of the Beaverhill Lake reflection over the uppermost reef plateaus.

**INTRODUCTION**

The Swan Hills “C” pool of western Alberta is located approximately 200 km northwest of Edmonton in Townships 46-70, Ranges 8-11 W5M (Fig. 3.1). Hydrocarbon production is from the House Mountain reef complex discovered in 1958. The “C” pool is the shallowest Swan Hills production at 2100 m approximate depth.

**CONTOUR AND AGE TIME-CROSS-SECTION**

The Brookline Mountain reef complex comprises approximately 10 m of interbedded anhydrite and dolomitic shale overlying Elk Point carbonates. The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1). Hydrocarbon production is from the House Mountain reef complex discovered in 1958. The “C” pool is the shallowest Swan Hills production at 2100 m approximate depth.

The acoustic impedance contrast between low velocity Woodbend Group shales and the argillaceous limestone of the Watersways Fm generates a strong, coherent Beaverhill Lake reflection. Lateral amplitude variations of this event are attributed to the interference phenomenon described above.

The calcareous facies marker and tops of Wabamun, Banff and Dohi formations are identified on the interpreted section. Regional dip is the primary structural feature of these horizons.

Absence of structural slope over the reef is apparent. Instead, the Beaverhill Lake event exhibits the contrary time-structure across the main reef edge (between traces 274 and 280) conforming with a low relief time-structure on the deeper Muskeg Ranges 8-11 W5M (Fig. 3.1). Hydrocarbon production is from the House Mountain reef complex discovered in 1958. The “C” pool is the shallowest Swan Hills production at 2100 m approximate depth.

Stratigraphy of the Beaverhill Lake Group in the vicinity of House Mountain includes Fort Vermilion, Swan Hills and Watersways formaftions (Fig. 3.3). The Fort Vermilion Fm comprises approximately 25 m of the lower Dark Brown Ranges 8-11 W5M (Fig. 3.1). The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1). The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1). The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1).

The Brookline Mountain reef complex comprises approximately 10 m of interbedded anhydrite and dolomitic shale overlying Elk Point carbonates. The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1). The overlying Swan Hills Fm is represented by approximately 25 m of the Lower Dark Brown Ranges 8-11 W5M (Fig. 3.1).

**RESERVOIR DIMENSIONS**

The productive area of the pool, identified by the areal extent of oil on regional dip contours, is approximately 258 km². Porosity and net pay averages for the reservoir are 6.2% and 9.3%, respectively. Estimated original volume of oil in place is 68,710 x 10⁶ m³ with a 42° API gravity oil.

**RESERVOIR PHYSICAL AND PETROPHYSICAL CHARACTERISTICS**

The Archie rock type analysis on the composite core demonstrates that the 4.35 and 10-23 wells, where platform thickness increases from 12 m to 23 m, respectively, have the most mature reservoir. Well log results demonstrate the presence of an aesthetic boundary between the argillaceous Fort Vermilion Fm and Swan Hills carbonates.

**SUMMARY**

The Seafood Platform in the proximal wells and the Fort Vermilion Fm in the offshore environment. The abrupt lateral facies change between carbonate platform and the argillaceous, open-marine sediments forms the stratigraphic trap. For the purpose of this study, the Watersways Fm is subdivided into three informal units corresponding to divisions IV, V and VI of Sheasby (1971). Unit IV was the first to transgress the House Mountain reef complex (Fig. 3.20) and in the 4.35 and 10-23 wells this unit directly overlies the Swan Hills platform. Argillaceous limestone is overlain by the platform carbonate is distinguished by its lack of S.P. development, due to state content. Unit V is predominantly shale, becoming more...
Figure 3.21 House Mountain – Swan Hills "C" pool geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.22 Seismic expression across the House Mountain – Swan Hills "C" pool.
The approximate location of the seismic template line is shown in Figure 3.23. These 120% CDP Vibroseis data were acquired in 1983 using 8 x 12 second sweeps, 70-12 Hz, at 134-m source intervals. Data were recorded by 96 channels, over a 2 x 1075-m split spread, with 33.3-m group intervals. The Vibroseis technique was used in 1983 using a conventional processing sequence, including spiking deconvolution and a final bandpass filter of 12/16 - 60/70 Hz. 120% CDP coverage is preserved at the extremities of the line.

Prominent geological horizons are identified on the structural stack (Fig. 3.22), with the Swan Hills zone of interest occurring at approximately 1.35 seconds 2-way time. A 3.2 km gap in the data exists along the northern portion of line, as indicated on the schematic of Figure 3.20. The discontinuity does not affect the seismic delineation of the Swan Hills platform edge. Swan Hills platform carbonate is enveloped by the argillaceous limestone unit IV, of the Waterways Fm. Comparison of sonic log response of the Swan Hills and off-reef-equivalents (Fig. 3.21) connotes an extremely subtle seismic response for the platform edge.

The deepest, continuous seismic event identified originates from the top of unit IV of the Waterways Fm. The seismic interface between shales of unit V and the underlying carbonate of unit IV, generates the strong, coherent seismic event. Time-structural relief of this reflector is relatively thin, incongruous with regional slope exhibited by the younger Beaverhill Lake Group and Ireton marker events. Consequently, the Ireton marker to Waterways unit IV isochron thin by 12 m, in a proximal segment, between the 11-22 and 10-23 well locations.

Figure 3.24 Stratigraphic seismic model of House Mountain – Swan Hills “C” pool, filtered with a 20 ms zero-phase Ricker wavelet. The seismic model includes the geological section overlying the Swan Hills platform, generating the seismic waveform doublet observed in the vicinity of the 4-35 and 10-23 wells. Correlation with the synthetic seismogram generated from 10-23 sonic log, shown in Figure 3.23, expedites the interpretation. The reflection from unit IV decreases in amplitude over the reef and the second lobe of the doublet represents Swan Hills platform. Amplitude modulation of unit IV is attributed to destructive interference with the Ireton marker. A deeper reflector is formed due to the bedded nature of the seismic data.

Since seismic reflections depict chrontomeric horizons, unit IV of the Waterways Fm is, intrinsically, a time unit. It follows that sediments of the Waterways Fm must be significantly younger than the Swan Hills reef-platform complex. The corollary of the seismic interpretation is consistent with the conclusions of Sheasby’s (1971) geological study.

The seismic event from the top of the Beaverhill Lake is poorly defined, due to destructive interference effects of the interbedded carbonates and shales of the uppermost Waterways units (VI-VIII). The calcareous Ireton marker and tops of Ireton, Wabamun and Banff formations are annotated on the interpreted seismic section. Time-structural relief along these events is attributed to regional sedimentation.

A seismic model was generated, to support the interpretation, using a synthetic model from the three wells in the geological cross-section. The stratigraphic synthetic section (Fig. 3.24) comprises zero-offset, primary reflection coefficients associated with a 20 ms, zero-phase Ricker wavelet. The seismic model includes the geological section from lower Ireton to Elk Point; Ireton marker, Beaverhill Lake, Waterways unit IV and Swan Hills events are identified.

The synthetic seismic sections realign the geological significance of the seismic image observed across the House Mountain reef-platform complex. Encountering Swan Hills platform, the reduced amplitude of the Waterways unit IV event is apparent, together with the associated appearance of a wavelet doublet. The second lobe of the doublet is the seismic manifestation of the Swan Hills platform. Proximal thinning of the Ireton marker to Waterways unit IV isochron is also evident.
In the area of study, the Beaverhill Lake Group comprises Fort Vermilion, Slave Point, and Waterways formations. (3.25). The stratigraphic chart illustrates the time transgressive nature of the Slave Point Fm as sediments of the Beaverhill Lake Group transgress the Peace River Arch. Slave Point sediments at Gift field in stratigraphically equivalent to the Firebag Mbr of the Waterways Fm (Fig. 3.25). A relatively thin (8 m), evaporitic Fort Vermilion Fm is overlain by 25 m of Slave Point Fm limestone platform. The comparative time sequence of argillaceous limestone and slates of the Waterways Fm completes the Beaverhill Lake stratigraphy. The Waterways Fm is subdivided into the Firebag (shale), Calumet (carbonate), Christina (shale), Mohey (carbonate) and Mildred (interbedded shale-carbonate) members.

In the Gift area, shallow water carbonates of the Slave Point Fm were deposited as the Waterways Fm transgressed the eastern flank of the Peace River Arch. Precambrian basement topography appears to have influenced the Slave Point facies distribution with carbonate reef reservoir developing in the vicinity of a major basement structure. A facies change from fore-reef to distal fore-reef (Tooth, 1984, 1987, stratigraphic seal for the reservoir, Slave Point Fm lithofacies in the Gift field area are described in detail by Tooth and Davies (1987). Hydrocarbon distribution is controlled by Slave Point structure in an area of approximately 20 km². Pore space and net pay averages for the reservoir are 84% and 8.5 m, respectively. Estimated original volume of oil in place is 1.560 x 10^3 m^3, with 1.04 x 10^3 m^3 (primary) and 995 x 10^3 m^3 (secondary) recoverable reserves. Cumulative production to the end of December 1987 is 340 x 10^3 m^3 of 35° API gravity oil from the Slave Point pools. Calumet and Green Point pools augment the above reserves and production figures.

The seismic template line, oriented northwest-southeast, straddles the southwestern boundary of Gift field (Fig. 3.26). The line of study crosses a small, isolated, basement feature before encountering the main Precambrian structure controlling the field. Seismic time-structure images the erratic topography of the Precambrian basement. The steep slopes of a basement depression are apparent, bounding Gift field in the southwest. Compaction-induced drape on the Slave Point carbonate reservoir is manifested as time-structure on the Slave Point event. This event is relatively weak because Slave Point porosity, ubiquitous along the line of study, decreased the acoustic impedance contrast between the overlying shales and Slave Point carbonates. Although the seismic example does not transect the up-dip facies change (Fig. 3.26), a geological cross-section at the Gift field event is constructed.

Approximate location of the seismic template line is shown schematically in Figure 3.28. These 1200 CDP seismic data were acquired in 1984 using a 1 kg Ricker source, 120 recording channels over a 2 x 1500-m split spread, 125-m source intervals and 25-m group intervals. The line was reprocessed in 1987 following a conventional processing sequence, including spiking deconvolution and a final bandpass filter of 12/16 - 70/80-Hz. Full, 1200% COP coverage is maintained at the extremities of the line.

The acoustic and Precambrian basements are coincident, due to the presence of low velocity. Granite Wash sediments overlie the Precambrian surface. Thickness of Granite Wash over basement structure is manifested by a decrease in amplitude of the Precambrian reflection. Erratic time-structure on the basement event images diagenetic processes occurring on the overlying Precambrian cross-section. The southwest flank of the structure encountered at 7-36 has a relatively gradual slope of 80 m (8%)

The Elk Point Group is represented by an evaporitic Muskeg Fm overlain by Gilwood clastics. Gift field straddles the depositional edge of the Muskeg Fm and the northeast end of geological cross-section approaches the Muskeg Fm zero edge. Associated regional thinning of the Muskeg Fm is apparent. Platform development in the upper 16 m of Slave Point limestone is ubiquitous along the line of study, but an up-dip facies change with an increased number of wells is apparent to the northeast (Fig. 3.26). The stratigraphic boundary is not transected by the seismic example and, therefore, not included in the geological cross-section.

Cumulative production since 1984, from the Slave Point reservoir at 2-5 and 1-6 is 12,380 x 10^3 m^3 from 11 net pay and 10.1 x 10^3 m^3 from 9 net pay. 959 x 10^3 m^3 (secondary) reservoir.

The Elk Point Group is represented by an evaporitic Muskeg Fm overlain by Gilwood clastics. Gift field straddles the depositional edge of the Muskeg Fm and the northeast edge of geological cross-section approaches the Muskeg Fm zero edge. Associated regional thinning of the Muskeg Fm is apparent. Platform development in the upper 16 m of Slave Point limestone is ubiquitous along the line of study, but an up-dip facies change with an increased number of wells is apparent to the northeast (Fig. 3.26). The stratigraphic boundary is not transected by the seismic example and, therefore, not included in the geological cross-section.

Cumulative production since 1984, from the Slave Point reservoir at 2-5 and 1-6 is 12,380 x 10^3 m^3 from 11 net pay and 10.1 x 10^3 m^3 from 9 net pay. Both wells are dual zone producers augmenting the total production.

**SEISMIC SECTION**

Approximate location of the seismic template line is shown schematically in Figure 3.28. These 1200 CDP seismic data were acquired in 1984 using a 1 kg Ricker source, 120 recording channels over a 2 x 1500-m split spread, 125-m source intervals and 25-m group intervals. The line was reprocessed in 1987 following a conventional processing sequence, including spiking deconvolution and a final bandpass filter of 12/16 - 70/80-Hz. Full, 1200% COP coverage is maintained at the extremities of the line.

Major geological horizons are annotated on the interpreted data (Fig. 3.28), with the Slave Point zone of interest occurring at approximately 1.10 seconds 2-way time. Correlation with the synthetic seismogram generated from the 6-36 sonic log is shown in Figure 3.29.
Figure 3.27 Gift field geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.28 Seismic expression across Gift field.
The effects of regional dip, minus the local field, compaction-induced structures and regional tilting of the younger horizons. Hydrocarbon distribution is influenced by sedimentary section are superimposed on the deeper seismic events. Structural drape on the Slave Point reservoir. Gift field is confined in basement depressions. Induced the topographic relief on the topography. Compaction of thick Granite Wash sediment, deposited peak diminishes towards the northeast extremity of the line. Seismic events from the top of the Beaverhill Lake Group, Ireton and Wabamun formations are also annotated on the structural section. Slave Point event would be anticipated as the tight carbonate is encountered. One cycle (18 ms) above the Slave Point reflection, the event. Although the seismic example does not transect the updip Slave Point facies change (Fig. 3.6), an increase in amplitude of the Slave Point event would be anticipated in carbonate is encountered. One cycle (18 ms) above the Slave Point reflection, the Calenget Mbr of the Watersay Fm is resolved. Coherence of the peak diminishes towards the northeast extremity of the line. Seismic events from the top of the Beaverhill Lake Group, Ireton and Wabamun formations are also annotated on the structural section.

Time structure on the Slave Point event and younger Beaverhill Lake Group markers reflect the underlying Precambrian topography. Compaction of thick Granite Wash sediment, deposited in basement depressions, induced the topographic relief on the younger horizons. Hydrocarbon distribution is influenced by structural drape on the Slave Point reservoir. Gift field is confined to an area of high relief and drape on the Slave Point event, between the 6-2 and 13-31 wells, delineates the southwest boundary of the field. Compaction-induced structures and regional tilting of the sedimentary section are superimposed on the deeper seismic events. The effects of regional dip, minus the local structures, can be observed on the Ireton and Wabamun events.

To assist and corroborate the interpretation, a seismic model was generated using seismic logs from four wells in the geological cross-section: 12-5, 16-36, 7-36 and 8-36. The wells represent the major structural features along the line of study. The synthetic seismic section (Fig. 3.30) comprises zero, offset, primary reflection coefficients convolved with a doublet waveform. The model incorporates the stratigraphy from lower Ireton to Precambrian basement; Ireton marker, Beaverhill Lake, Calumet, Slave Point and Precambrian events are identified.

Although vertical incidence modeling results in a crude image of the steeper slopes, structural features of the seismic model are consistent with the previously described interpretation. The amplitude decrease towards the northeast extremity of the line, consistent with the previously described interpretation. The seismic example does not transect the updip Slave Point facies change, an increase in amplitude of the Slave Point event would be anticipated as the tight carbonate is encountered. One cycle (18 ms) above the Slave Point reflection, the Calenget Mbr of the Watersay Fm is resolved. Coherence of the peak diminishes towards the northeast extremity of the line. Seismic events from the top of the Beaverhill Lake Group, Ireton and Wabamun formations are also annotated on the structural section.

Slave field of northcentral Alberta is situated on the east flank of the Peace River Arch, approximately 340 km northwest of Edmonton and 1 km south of Range 14 WSM (Fig. 3.1). Hydrocarbon production is from the Slave Point Fm of the Beaverhill Lake Group, at 1750 m average depth. The discovery well, CDCOG Union Slave 16-15-84-14 W5M, was completed in December 1980 with 8 m of Slave Point Fm carbonate overlying the granitic basement. Sonic-gamma ray log suites are displayed for each well in the section.

Porosity of the carbonate reservoir, enhanced by dolomitization, averages 8.5%, with an average net pay of 8.3 m. Trapping is structurally controlled and the productive area of the field is approximately 9 km². Estimated original volume of oil in place is 12,268,3 x 10⁶ m³, with 3498.1 x 10⁶ m³ of primary recoverable reserves. Cumulative production to the end of December 1987 is 895.8 x 10⁶ m³ of 35° API gravity oil from the Slave Point pools.

The seismic template line, oriented east-west, crosses the northern part of the basement structure controlling Slave field (Fig. 3.32). A weak reflection from the Precambrian surface is restricted to areas of low relief, where thick Granite Wash carbonates exist. The Precambrian basement produces acoustic basement over the granite knoll. The field boundary is manifested by time-structural relief of the Slave Point and Beaverhill Lake reflections. These events form a doublet waveform over the highest part of the basement knoll, due to thinning of the Watersay Fm beyond the resolution limit of the seismic bandwidth.

GEOLOGICAL CROSS-SECTION
Orientation of the geological cross-section (Fig. 3.35) approximately parallels the seismic example, as shown in Figure 3.32. The cross-section extends east to west, from shallow marine environment (3-24), across the northeast flank of the structure (8-21) and onto the basement knoll (6-25). Sonic-gamma ray log suites are displayed for each well in the section.

Precambrian basement rocks, penetrated by each well, exhibit 68 m of structural relief between the 6-23 and 3-24 well locations. Basement relief at the extremities of the cross-section is inferred from the seismic interpretation. Precambrian topographically influenced deposition of the Granite Wash clastic sediments, encountered in the 3-24 well (10 m) and 8-23 location (5 m). The Precambrian knoll also affected the shallow water carbonate sedimentation during the subsequent Beaverhill Lake transgression. The 6-27 well, drilled of Granite Wash, encountered 8 m of Slave Point Fm carbonate overlying the granite basement. Thickness of the dolomitized carbonate facies increases to 20 m in the 8-23 flank location and 30 m in the more distal environment of 3-24.
A significant acoustic boundary between the Granite Wash clastics and Precambrian basement is apparent from the sonic log response of 3-24. In this location, the geologic and acoustic boundaries are coincident. However, absence of this sonic interface in the other wells alludes to the Slave Point horizon as representing acoustic basement.

The overlying calcareous shales of the Waterways Fm represent the final inundation of the basement knoll and surrounding carbonate bank. Waterways Fm sediments increase in thickness from 25 m over the structural high at 6-23, to 37 m in the other wells. The thicker Waterways Fm west of the well control is inferred from the seismic interpretation. Thinning of the shale facies over the granite hill is attributed to the progressive onlap of the time transgressive carbonate facies of the Beaverhill Lake Group. The upper part of the Slave Point Fm in the 8-23 and 3-24 wells is stratigraphically equivalent to the Moherly Mbr of the Waterways Fm (Fig. 3.25), whereas, Slave Point carbonate on the basement knoll, at 6-23, comprises the Maitland Mbr.

The Beaverhill Lake Group is overlain by shales of the Duvernay and Ireton formations which are superposed by the more calcareous sediments of the Winterburn Group and Wabamun Fm. The structural upwarp mechanism of Slave field is apparent with the Slave Point horizons exhibiting 36 m of structure removal along the cross-section. Existence of steep slopes on the Slave Point and Beaverhill Lake horizons, concurrent with an underlining basement scarp, is inferred from the seismic interpretation. Beaverhill Lake topographic relief is attributed to post-Beaverhill Lake tectonics and differential compaction across the basement scarp. Structural drape, of lesser degree, is apparent on the shallower Ireton Mbr. Porosity of the Slave Point carbonate facies at Slave field is enhanced by dolomitization. Cumulative oil production and net pay thickness for the 6-23 and 8-23 wells are 36.48 x 10^3 m^3 (8 m) and 31.20 x 10^3 m^3 (6 m), respectively.

Seismic Section

The approximate location of the seismic template line is shown schematically in Figure 3.32. These 12000 CDP seismic data were acquired in 1984 using a 1 kg dynamite source, 96 recording channels over 2 x 1608 m split spread, 134 m source intervals and 33.5 m 25 ms Ricker wavelet.

Seismic interpretation of the Slave field section from 400 m off-line, with a 25 ms zero-phase Ricker wavelet. The model incorporates the stratigraphy and frequency content of the data are such that the Precambrian surface underlying Slave field is not seismically resolved, characteristics of the acoustic basement event suggest the highest part of the Precambrian knob exists between the 8-23 and 6-23 projected locations. West of the structure, a thicker section of Waterways Fm shales is inferred from the broader time cycle from Beaverhill Lake to Slave Point, occurring between traces 172 and 211. To the east of 8-23, a basement scarp is inferred by the abrupt termination of the Precambrian reflections and accompanying steep slopes on the overlying Slave Point and Beaverhill Lake events. The opposite flank of the structure is similarly steep. Reflections from the top of the Ireton and Wabamun formations are faint. Baseline reflections in some areas exhibit relatively constant time-structure, excepting some minor drape on the Ireton reflection over Slave field. To assist and corroborate the interpretation, a seismic model was constructed by repeating the 8-23 and 3-24 logs on the opposite side. The synthetic seismic section (Fig. 3.36) comprises a weak reflection at the 8-23 location, representing acoustic basement; Ireton, Beaverhill Lake to Slave Point, occurring between traces 172 and 211. The deepest, continuous seismic event identified, originates from the top of the Beaverhill Lake Group. The acoustic interface between low velocity shales of the Woodbend Group and more calcareous Waterways Fm sediments generates a strong, coherent seismic event. Slave field is manifested by approximately 15 ms of time-structural relief on the Beaverhill Lake reflection; time-structure over the field is relatively static with steep slopes occurring on the flanks of the feature. Structural relief between the 8-23 and 6-23 wells depicted on the geological cross-section, is not apparent on the accompanying seismic section. The absence of extremely variable topography, the discrepancy is attributed to projecting the 6-23 well onto the seismic section from 400 m off-line. Figure 3.35 Correlation of seismic data (left) with a synthetic seismogram derived from the 3-24 sonic-log (Slave). Figure 3.36 Vertical incidence seismic model of Slave field, filtered with a 25 ms zero-phase Ricker wavelet.

Acoustic energy below the Beaverhill Lake event is relatively weak but correlate with the synthetic seismic trace at 3-24 (Fig. 3.35) permits identification of Slave Point and Precambrian events. A weak reflection from the Precambrian surface is resolved to areas of low relief, where a thicker section of Granite Wash clastics provides the necessary acoustic boundary. Over the Slave field basement knoll, Granite Wash is virtually absent and the Slave Point reflection represents acoustic basement. A coherent, albeit weak, event from the Slave Point horizon can be correlated across much of the section. At the 8-23 and 3-24 well locations, thickness of Waterways Fm shale and frequency content of the data are such that a temporally discrete, Slave Point event is resolved. However, on the basement structure immediately west of 8-23, the Beaverhill Lake and Slave Point events form a seismic doublet. The doublet waveform continues westward to the projected location of the 6-23 well. Assuming a constant seismic bandwidth, the above phenomenon refers a thinning of the Waterways Fm which, in turn, implies a structurally higher basement. Thus, although the Precambrian surface underlying Slave field is not seismically resolved, characteristics of the acoustic basement event suggest the highest part of the Precambrian knob exists between the 8-23 and 6-23 projected locations. West of the structure, a thicker section of Waterways Fm shales is inferred from the broader time cycle from Beaverhill Lake to Slave Point, occurring between traces 172 and 211.

Structural features of the seismic model and associated waveform characteristics are consistent with the previously described interpretation. Structure on the Beaverhill Lake and Slave Point reflections over the basement, and the termination of the Precambrian relief are both apparent. The discrete Slave Point reflection at the 8-23 location, representing acoustic basement, eventually forms a doublet with the Beaverhill Lake event as Precambrian relief increases (6-23). Thinning of the Waterways Fm shales over the structure, combined with the bandlimited nature of the seismic data, account for the loss of resolution. Subtle structural drape on the Ireton event is also expressed on the synthetic section.
Figure 3.33 Slave field geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.34 Seismic expression across Slave field.
Sawn Lake field consists of Fort Vermilion, Slave Point and Waterways formations (Fig. 3.25). Stratigraphy of the Beaverhill Lake Group at Sawn Lake consists of Fort Vermilion, Slave Point and Waterways formations (Fig. 3.25). The stratigraphic chart illustrates the diachronous nature of the Slave Point Formation as sediments of the Beaverhill Lake Group transgress the Peace River Arch. Slave Point sedimentation at Sawn Lake field is stratigraphically equivalent to the Firebag Member of the Beaverhill Lake Group (Fig. 3.25). The Fort Vermilion Formation comprises approximately 20 m of interbedded carbonate and anhydrite overlying Elk Point clastic sediments. The evaporitic Fort Vermilion Formation is superposed on the Slave Point Formation limestone platforms of variable thickness (10 - 30 m). A relatively thick sequence of argillaceous limestones and shales of the Waterways Field comprises the Beaverhill Lake Group stratigraphy. The Waterways Field is underlain by the Firebag (shale), Calumet (carbonate), Christina (shale), Moberly (carbonate) and Mildred (carbonate) Members (Fig. 3.37). At Sawn Lake, shallow water carbonates of the Slave Point Formation were deposited as the Beaverhill Lake sea transgressed the northeast flank of the Peace River Arch. The depositional environment of the Slave Point Field at Sawn Lake is illustrated schematically in Figure 3.37 (after Craig, 1987). Increased carbonate production in the area resulted in the upward growth of the limestone shelf and contemporaneous, isolated reef or reefal development. Integrating well log information with limited seismic control, Sawn Lake field is interpreted as an assemblage of stratigraphic traps. Internal reefs are confirmed by a postulated updip silent of the Slave Point shelf edge. In addition to the discrete carbonate builds (Fig. 3.37), the term "platform reef" will be used informally to describe the isolated carbonate aggregates.

Sawn Lake is the most northerly situated Slave Point oil field discovered to date. Productive area of the field is confined by stratigraphy and regional dip to approximately 26 km². Pressure and net pay averages for the reservoir are 729 atm and 96 m, respectively. Estimated original volume of oil in place is 12,827 x 10³ m³, with 2863.3 x 10³ m³ (primary) and 375 x 10³ m³ (secondary) recoverable reserves. Cumulative production to the end of December 1987 is 261.2 x 10³ m³ of 39° API gravity oil from the Slave Point pools. The seismic template line, oriented northeastern-southwestern, crosses the northern part of Sawn Lake field (Fig. 3.37). The line of study extends from Slave Point, across an isolated platform reef and onto the carbonate shelf. Carbonate build-ups are manifested by thickening of the Slave Point to Muskeg isochron and associated thinning of the overlying Waterways Field time interval. Onlapping of the lowermost shale interval within the Firebag Member is apparent. Structural interpretation suggests that conditions conducive to reef growth were probably initiated by remnant topographic highs.

**GEOLOGICAL CROSS-SECTION**

Orientation of the geological cross-section (Fig. 3.38) approximately parallels the seismic example, as depicted in Figure 3.37. The cross-section extends from 9-3, the Slave Point platform (9-3), across an isolated platform reef (10-32) and onto the carbonate shelf. Coarse-grained reefs are isolated by the Firebag, Christina and Calumet (carbonate) members. Sawn Lake field is cross-sectionally equivalent to the Firebag Member of the Beaverhill Lake Group. The base of the Beaverhill Lake Group, is overlain by the Slave Point formation. Paleotopography of the Precambrian basement influenced the depositional regime of Granite Wash clastic sediments. The Elk Point Group is represented by a more uniform, interbedded evaporitic sequence of the Mistagab Member overlain by the Mistakab Member. The Fort Vermilion Formation, a carbonate-evaporite sequence at the base of the Beaverhill Lake Group, is overlain by the Slave Point carbonate platform. The isopach of the Fort Vermilion Formation is relatively constant (19 - 22 m), compared with that of the Slave Point carbonate facies (10 - 27 m). Statigraphic log response demonstrates the absence of a significant acoustic boundary between the two formations. Since the Slave Point-Fort Vermilion assemblage forms a single, uniform unit, the uniformity of the evaporite sequence is an important criterion for the seismic interpretation (see next section).

Overlying the Firebag shale, the remaining members of the Waterways Field are more uniform; the sequence of argillaceous limestones and shales is approximately 8 m across the cross-section. The Beaverhill Lake Group is overlain by argillaceous limestones and shales of the Ironton Formation. Sawn Lake field is one of the remaining members of the Waterways Field to be discovered. Today, the relative low relief carbonate build-ups have no significant influence on the structure of overlying shales. Porosity in the upper limestone facies of the Slave Point Formation averages 10% in the 12-19 (shelf) location. Oil production figures reflect the porosity variation with cumulative 27,158 x 10³ m³ (since 1984) and 5,615 x 10³ m³ (since 1985) produced, respectively.

**SEISMIC SECTION**

The approximate location of the seismic template line is shown schematically in Figure 3.37. These 1200% CDP seismic data were acquired in 1984 using a 2 x 1 kg dynamite source, 96 recording channels over 2 x 1200 m split spread, 100 m source intervals and 25 m group intervals. The line was reprocessed in 1987 following a conventional processing sequence, including spiking deconvolution.
The seismic interpretation suggests that conditions conducive to reef or shoal development were probably initiated by remnant topographic highs related to the underlying basement structures.

To support the seismic interpretation an acoustic model was generated using sonic logs from the 9-3 and 10-32 wells. The stratigraphic, synthetic section (Fig. 3.41) comprises zero-offset, primary reflection coefficients convolved with a 20 ms, zero-phase Ricker wavelet. The model incorporates the stratigraphy from lower Ireton to Precambrian basement; Beaverhill Lake, Firebag, Slave Point, Muskeg and Precambrian events are annotated.

The acoustic model verifies the interpretation of the seismic image across Slave Lake field. Proximal thickening of the Slave Point to Muskeg isochron is evident, accompanied by thinning of the Firebag Mbr time interval over the Slave Point carbonate shelf.

Figure 3.40. Regional setting of Clarke Lake field along the mid-Devonian carbonate front (modified after Phripps, 1982).

The Slave Point Fm at Clarke Lake field attains a maximum thickness of approximately 12 m and together with the underlying
Figure 3.38 Sawi Lake field geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.39 Seismic expression across Sawn Lake field.
Estimated volume of gas in place is ~

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Devonian stratigraphy in Northeastern British Columbia and Slave Point Fm in the study area, Figure 3.43 compares the Middle excess of 340 m thick. Illustrating the stratigraphic context of the Griffin, 1965).

Elk Point carbonates forms a massive dolomitized barrier-reef in

Figure 3.44 Schematic diagram of Clarke Lake field, locating the study area (Fig. 3.45).

Northern Alberta. Regionally, the Slave Point Fm is disconformous in the study area, Figure 3.45 compares the Middle Devonian stratigraphy in Northeastern British Columbia and Alberta west of the 6th Meridian.

Elk Point carbonates form a massive dolomitized barrier-reef in excess of 340 m thick. Illustrating the stratigraphic context of the Slave Point Fm in the study area, Figure 3.45 compares the Middle Devonian stratigraphy in Northeastern British Columbia and Alberta west of the 6th Meridian.

Figure 3.44 Schematic diagram of Clarke Lake field, locating the study area (Fig. 3.45).

Northern Alberta. Regionally, the Slave Point Fm is disconformous and the reef front carbonate at Clarke Lake is the facies equivalent of the lower members of the argillaceous Waterways Fm. Locally, an abrupt facies change occurs where the Slave Point - Sulphur Point carbonate barrier passes, precipitously, into basinial shales of the Horn River Fm.

Clarke Lake field is of sigmoidal form, 40 km in extent and between 2.5 and 6 km wide (Fig. 3.44). In the western part of the field, dolomite reservoir is spacially interspersed by zones of non-porous limestone. The northeast extremity of the gas pool is situated over the Klua shale embayment (Fig. 3.44), characterized by a tongue of Horn River shales underlyng the Sulphur Point Fm.

Figure 3.44 Schematic diagram of Clarke Lake field, locating the study area (Fig. 3.45).

Reservoir at Clarke Lake is restricted to an area defined by the front of the Pine Point reef where dolomitization pervaded the massive Slave Point-Elk Point barrier-reef. Slave Point and Pine Point carbonate fronts diverge at the Klua embayment and vermiform zones of dolomitization coincide with the edge of the deeper reef (Fig. 3.44). Barrier-limestone facies overlying the Klua embayment remain unaltered. A detailed explanation of the distribution of Slave Point dolomites is provided by the geological model used by Phipps (1982). In summary, the model suggests that dolomitized zones should occur in reefal carbonates in communication with both fresh and marine waters. Phipps (1982) proposed that the edges of the main barrier and Klua embayments were exposed to such conditions.

Hydrocarbons are structurally and stratigraphically trapped in the dolomites at Clarke Lake. The productive area of the field is approximately 120 km²; porosity and net pay averages are 7.1% and 35.3 m, respectively. Estimated original volume of gas in place is 62,025 x 10⁶ m³, with 35,294 x 10⁶ m³ of recoverable reserves. Cumulative production to the end of December 1987, is 38,846 x 10⁶ m³ of gas, exceeding the estimated recoverable reserves.

The exemplary seismic line, situated at the northeast corner of the Klua embayment, crosses the Slave Point edge, Klua embayment and onto the Pine Point reef (Fig. 3.45). Morphology of the middle Devonian barrier-reef complex is exemplified by Slave Point time-structure, and porous zones within the Slave Point - Sulphur Point assemblage are inferred by seismic "bright spot" anomalies. Spatial distribution of the porosity indicators is consistent with dolomitization pervading the barrier-reef where Slave Point-Sulphur Point carbonates are superposed. Compaction induced drape on the Muskwa Fm is manifested by time-structural relief on the Otter Park reflection (basinal equivalent of Slave Point event).

The Pine Point carbonate surface provides four characteristic seismic signatures representing distinct geological facies:

1) Within the shale basin, reflections from atop the Pine Point surface and the base of the shale tongue (within the Pine Point interval) are both resolved, Enroaching basinial shales represent a temporary deepening of the Elk Point basin. In this area, the front of the Slave Point - Sulphur Point carbonate assemblage oversteps the underlying Pine Point carbonate bank edge, as depicted in Figure 3.43.

Figure 3.45 Schematic diagram of Clarke Lake field, locating the seismic and geological cross-sections.

123% 122% 121% 120% 119% 118% 117% 116% 115% 114% 113% 112% 111% 110% 109% 108% 107% 106% 105% 104% 103% 102% 101% 100% 99% 98% 97% 96% 95% 94%
2) Klua shale - Pine Point carbonate interface provides a strong acoustic boundary for seismic delineation of the Klua embayment.

3) Within the Klua embayment, a seismic 'bright spot' anomaly, formed by a polarity reversal of the Klua event, is interpreted as Pine Point reef, and

4) Across the massive Slave Point-Ekl Point carbonate barrier, seismic definition of the Pine Point horizon is nebulous.

Seismic criteria also include time-structural drape on the Slave Point reflector over the Klua embayment, and velocity generated pull-up on the Pine Point event below the reefs.

**GEOLOGICAL CROSS-SECTION**

Orientation of the geological cross-section (Fig. 3.46) approximates the seismic example, excepting the deviation to the d-10-A well, as shown in Figure 3.45. The section extends north to south, from shale basin (d-10-A) across the Slave Point reef flank (d-4-D) and dolomitized barrier-reef facies (c-94-L, a-75-L) onto the back-reef environment (d-96-L). The line of study also transects the Klua shale embayment, Sonic log data are displayed for each well in the geological cross-section, excepting c-94-L for which gamma ray - neutron is substituted.

The oldest rocks encountered in the c-94-L well are quartzite, probably Cambrian or Precambrian in age (Gray and Kassube, 1963). The oldest Middle Devonian unit, the Chinchaga Fm, consists of interbedded dolomite, anhydrite and terrigenous clastics. Pre-Devonian and Chinchaga horizons, penetrated by the c-94-L and d-10-A wells, which produced 1214.98 x 10⁶ m³ of gas from 49 m of net pay. At the northwest corner of the Klua embayment, the shale tongue is more continuous, and a few wells encountered dolomitized Slave Point reef, below the underlying shale section; c-94-L is such a case.

**SEISMIC SECTION**

Approximate location of the exemplary seismic line is depicted in Figure 3.45. These 1200% CDP seismic data were acquired in 1983 using a 2 x 3 kg dynamite source, 96 recording channels over 2 x 2400 m split spread, 160 m source intervals and 40 m group intervals. The line was reprocessed in 1987 using a conventional processing scheme, including stochastic deconvolution, post-stack wave-equation migration and a final bandpass filter of 12/16 0.9-1.15 to 1.05-1.08 seconds 2-way time.

The deepest reflection identified represents the Pine Point Fm carbonate surface, penetrated by the c-94-L and d-10-A wells. The discontinuous Pine Point event includes two characteristic seismic signatures, representing distinct geological facies.

1) Within the shale basin, correlation with the synthetic seismogram generated from the d-10-A sonic log expedites the interpretation (Fig. 3.48). Reflected energy (peak) from atop the Pine Point Fm is weaker than anticipated from the inferred reservoir, constituting a suboptimal seismic response. The shale excursion is resolved destructive interference with the Pine Point event weakens the amplitude response of the reflectivity sequence. The backscatter limit of the overstepping...
Figure 3.46 Clarke Lake field geological cross-section, incorporating the seismic interpretation (facing page).
Figure 3.47 Seismic expression across Clarke Lake field.

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AUTHOR: R.M. FERRY
2) Across the Klus embayment, an abrupt increase in amplitude and decrease in frequency of the seismic image characterizes the Pine Point carbonate surface. Correlation with the synthetic seismic trace derived from the c-94-L well penetrates a non-porous limestone sequence which produces a relatively quiet seismic response below the dominant Slave Point event (Fig. 3.50). The high amplitude trough, half the seismic response below the dominant Slave Point event over the Pine Point bank edge is attributed to projecting the d-lO-A well onto the seismic section from nearly 6 km off-line. In contrast, porous dolomite facies predominates at c-94-L and a strong seismic event below subordinate limestone interval generates a strong seismic event below the Slave Point event (traces 224 and 351 of Fig. 3.47) is intended to depict the differential compaction, augmented by late stage tectonic activity. The a-4-D well penetrated the flank of the main reef. Seismic response over the Pine Point bank edge or an isolated Pine Point reef. Seismic character of the discontinuity and increase in frequency of the seismic signature are replaced by an apparent polarity reversal of the Klus point horizon. Correlation of a nebulous seismic event (between traces 224 and 351 of Fig. 347) is intended to depict the approximative locations of the Pine Point Fin. Velocity generated buildup and/or time-structure on the Pine Point event below younger reefs is superimposed on the variable seismic signature. The reflection exhibits 17 ms of apparent time-structure between shale lumps (6-10-A) and carbonate barrier (c-94-L). Incongruity with Pine Point structure depicted on the geologic cross-section is attributed to projecting the d-lO-A well onto the seismic section from nearly 6 km off-line.

The reflection from the upper Slave Point extends the morphology of the barrier-reef complex. Time-structural drapes on the Slave Point event over the overlying Muskwa Fm. An additional 20 ms of time-structural drape on the Slave Point event coincides with the edge of the postulated Sulphur Point promontory in front of the main reef. Stellower reflections from the Upper Devonian Tetcho and Kakisa formations are identified on the interpreted seismic section. Tetcho (or Kakisa) to Slave Point plane defines maximum reefal development (isochron thins) and confirms time-structural drape on the Slave Point event over the Klua embayment (isochron thins). Time-structure on the Upper Devonian events manifests post-Dervonian teuto with a subordinate contribution from structural drapes. Time-structure between shale lumps (6-10-A) and carbonate barrier (c-94-L). Incongruity with Pine Point structure depicted on the geologic cross-section is attributed to projecting the d-lO-A well onto the seismic section from nearly 6 km off-line. In contrast, porous dolomite facies predominates at c-94-L and a strong seismic event below subordinate limestone interval generates a strong seismic event below the Slave Point event (Fig. 3.50). The high amplitude trough, half the seismic response below the dominant Slave Point event, reflects porosity and the following peak is generated at the porous dolomite - tight limestone boundary. Correlation of differences in porosity between the pores, dolomitized zones. In the absence of the limestone barrier, seismic response would resemble that of the tight, rock-reef facies (Fig. 3.50). Distribution of "bright spot" anomalies within the Slave Point-Sulphur Point interface are replaced by an apparent polarity reversal of the Klus point horizon. Correlation of a nebulous seismic event (between traces 224 and 351 of Fig. 3.47) is intended to depict the approximative locations of the Pine Point Fin. Velocity generated buildup and/or time-structure on the Pine Point event below younger reefs is superimposed on the variable seismic signature. The reflection exhibits 17 ms of apparent time-structure between shale lumps (6-10-A) and carbonate barrier (c-94-L). Incongruity with Pine Point structure depicted on the geologic cross-section is attributed to projecting the d-lO-A well onto the seismic section from nearly 6 km off-line.

3) Within the Klus shale embayment, an abrupt transformation of seismic signature (between traces 129 and 174 of Fig. 3.47) is here interpreted as a transition to a Pine Point bank edge or an isolated Pine Point reef. Seismic characteristic of the discontinuity and increase in frequency of the seismic signature are replaced by an apparent polarity reversal of the Klus point horizon. Correlation of a nebulous seismic event (between traces 224 and 351 of Fig. 3.47) is intended to depict the approximative locations of the Pine Point Fin. Velocity generated buildup and/or time-structure on the Pine Point event below younger reefs is superimposed on the variable seismic signature. The reflection exhibits 17 ms of apparent time-structure between shale lumps (6-10-A) and carbonate barrier (c-94-L). Incongruity with Pine Point structure depicted on the geologic cross-section is attributed to projecting the d-lO-A well onto the seismic section from nearly 6 km off-line.