INTRODUCTION

No complete section of Mississippian Period strata remains in the Western Canada Sedimentary Basin, as a result of four periods of erosion, following widespread uplift which began in late Pennsylvanian and ended in Early Cretaceous (MacAuley et al., 1964). The thickest remaining section (> 1600 m) is found in the Peace River area of northern Alberta and northeastern British Columbia. It is completely eroded throughout much of the Western Canada Sedimentary basin (Fig. 6.1).

Primarily deposited in a shallow-marine environment, Mississippian rocks can be separated into two lithologic units (MacAuley et al., 1964). The lowest is mainly shales and calcareous shales and may include silstones, sandstones and argillaceous carbonates. The earliest of these formations (Table 6.1) is the Bakken Fm of southern Alberta and southeastern British Columbia. A fine-grained sandstone sandwiched between two shales and its western Alberta equivalent, the Exshaw Fm. The overlying beds are thin Jurassic clastics or Cretaceous sediments often tightly cemented. Closer to the Rocky Mountains, the original structural relationships and to some extent, lithology, of the rocks have been altered by thrust faulting. Mississippian rocks outcrop along much of the length of the Rockies.

In northern Alberta and northeastern British Columbia, where the nomenclature changes, the section is thickest. Carbonates have significant shale content and interbedded shales are thicker and more common. Thrust faulting is present but is less severe than in southwestern Alberta. Alexis is an outlier of Harmattan-Elkton and Alexis of southwestern Alberta. Alexis, Harmattan-Elkton and Alexis are in this category. Alexis is an outlier of southwestern Alberta. Harmattan-Elkton and Alexis of southwestern Alberta.

INTRODUCTION

Three examples, Alida, in southeastern Alberta and the Debolt Fm of northern Alberta and northeastern British Columbia. Another type of structure found from southwestern Manitoba to southeastern Alberta is caused by salt dissolution, of which the Hummingbird field is an example. It was the first south field in Canada proved to have been formed by multiple stage salt removal.

Two fields (Viewfield and Seal) represent unusual or uncommon Mississippian features. Both are structurally controlled. The Viewfield example is a structure originally though to be associated with salt dissolution. Although salt has not contributed to the structure, there are many other conditions present indicating a meteoric impact origin (Donofrio, 1981). Seal is comprised of Pekisko Fm carbonate mud mounds. These mud mounds grew, reef-like, on a carbonate bank in a shale basin and are the only known reef-type structure in the Mississippian.

The seismic lines which illustrate these eight fields range from early 1970's data (Viewfield) to mid-1980's (Blueberry). The sources are both surface (Vibroseis and Airgun) and subsurface (dynamite). All are multi-fold data. All sections were processed using a conventional sequence which included instrument and geophone dephasing, zero-phase deconvolution, elevation and first break deconvolution, elevation and first break deconvolution, and surface consistent statics (for surface and sub-surface sources), surface consistent statics. Some exceptions to this processing were necessary. Seal required a minimum phase spiking deconvolution to improve coherence of the data. Four examples Blueberry, Turner Valley, Viewfield and Seal with significant structures were migrated. The other four were not, although it is now becoming standard practice to migrate even apparently flat data. Finally, continuity of reflections on three examples, Viewfield, Harmattan-Elkton and Alexis, was enhanced by the use of mild post-stack F-K filtering.

Interpretation based on one or two seismic lines is, at best, somewhat arbitrary but the extensive well control in these fields has significantly helped. All the examples are interpreted structurally, no attempt was made to interpret porosity based on wavelet character other than in a subjective sense. However, one of the examples, Alexis, includes a description of the effect that gas in a reservoir has on seismic reflections.

Because Mississippian reservoirs are primarily associated with the subcrop, they are often difficult seismic targets. The target is frequently a structure but the many different lithologies of the overlying beds can either mask or exaggerate the identification of the unconformity. Deeper within the Mississippian strata, reservoirs are apt to go undetected seismically because adequate acoustic contrast is lacking.

This despite the apparent ease with which seismic can be used to map structural rather than stratigraphic features, the search for Mississippian reservoirs has been and continues to be a very challenging use of seismic techniques.

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ALEXIS FIELD

INTRODUCTION

Situated 65 km northwest of Edmonton, Alberta, the Alexis field (Fig. 6.2) is one of several similar fields which produce oil and gas from local Mississippian erosional highs. With an area of less than 800 ha, the Alexis pool is small compared to the much larger Cherhill field.

Production is from an extensively dolomitized carbonate of the Banff Fm, which has been partially eroded leaving remnant structural highs. Overlain by lower velocity sandstones and shales of the Lower Cretaceous, the erosional contact is seismically visible and allows geophysics to be a valuable tool in mapping the pool.

The first Alexis well, 15-36-55-5 W5M, was drilled in 1968. Since then 16 more wells have been drilled, 10 of which were in production in 1987. Typical porosity is 13%. Horizontal permeability, based on cores, is as high as 245 md. Original estimates of recoverable reserves were $7.58 \times 10^3$ m$^3$ of oil in place (O.I.P.) (with 15% recovery) and $267.4 \times 10^3$ m$^3$ of gas in place (G.I.P.). To date, (December, 1987), 405,889 m$^3$ of oil and $292.8 \times 10^3$ m$^3$ of gas have been produced.

GEOLOGIC CROSS-SECTION

The eastern limit of the Banff Fm lies several kilometres east of the Alexis pool. There is a thick Banff section at the Alexis pool, composed predominantly of shales, calcareous shales and shaly and clean carbonates. The reservoir rock is a dolomitized carbonate, frequently referred to as the Clarke's Mbr. It was extensively and differentially eroded and is overlain by sediments of the Mannville Gp. The combination of structurally high, porous Banff dolomite and overlying impermeable Lower Mannville Gp shales has formed the reservoir and trap respectively for this field. The structural configuration of the Mississippian in this area is illustrated in Figure 6.3 with the Alexis pool as the centre structure.

Figure 6.1. Regional geology of the Carboniferous.

Figure 6.2. Location and structure of the Alexis field adjacent to the Cherhill field. Production is from a structurally high remnant of dolomitized carbonate of the Banff Fm. Gas/oil and oil/water contacts are shown (Contour interval 10 m).

Figure 6.3. Erosion left remnants of porous Clarke's Mbr (Banff Fm) and subsequent burial under basal Mannville Gp shales provided the trap at Alexis.
Strong gas effect on the 14-31 sonic. The 7-5 well, although a true Mississippian structure. This has implications to seismic interpretations which are often based on isochron rather than time structure mapping.

SEISMIC SECTION

The example seismic section (Fig. 6.5) traverses the field, east to west. Reflections identified are a strong trough corresponding to the top of the Ireton Fm shale, the Banff Fm subcrop (a peak), the top of the Mannville Gp (a somewhat broken peak) and the strong trough associated with the Joli Fou Fm shale.

Outside the Alexis pool, the Banff event is a strong peak, but within the field, (traces 60 - 120) it moderates in amplitude then splits into a doublet in the presence of a sufficiently thick gas zone (e.g. 15-56 in trace 112). Structural closure is 20 to 25 ms in time.
Figure 6.4. Geological cross-section of the Alexis field.
Figure 6.5. Seismic section of the Alexis field.
Isochron mapping is frequently used to infer structure on one of two events with the other event assumed to be flat or regionally dipping. For the Joli Fou to Banff Fm isochrons, the Joli Fou is assumed to be flat. However, differential compaction of Mannville sediments introduces local structure on the Joli Fou. In addition, the velocity is higher and density is greater in the more compacted rocks. The time between the two events is correspondingly reduced. Consequently, the Joli Fou to Banff Fm isochron observed on seismic show smaller variations (as little as 5 ms) and a calculated structural component that could be seismically visible. More than 120 wells have been drilled to date in the field has accounted for 39 x 10^8 m^3 gas and 953 x 10^6 m^3 oil of gas and improve oil recovery. The extent of the gas cap is one of the factors that allows this field to be seismically visible.

CONCLUSION

The Atla is pool is one of a number of seismically visible Mississippian pools which have been developed or faulted by seismic analysis. The structural component is evident on the example seismic section as a time structure change and a Joli Fou-Banff Fm isochron analysis. The structural component is evident on the example seismic section as a time structure change and a Joli Fou-Banff Fm isochron analysis. Pore size and gas in the reservoir are indicated by changes in the Joli Fou seismic event which is altered from a strong peak off structure to a doublet over the porous area.

Figure 6.5. In A) the seismic logs show 50 m of the Clarite's Mbr in 15-36 eroded in 3-1. In B) the Mississippian event is a medium-amplitude peak over a strong, deeper peak. In the upper, the upper peak disappears and the lower peak shifts deeper in time. Both figures use a Viking Fm datum.

HARRIMAN-ELKTON FIELD

INTRODUCTION

The Harmattan-Elkton field, as designated by the Energy Resources Conservation Board, covers an area in excess of 10,000 ha. However, the major oil production, which this paper will discuss, occurs in a long and narrow pool that trends north-south along the west side of the Little Red Deer River and covers less than half of the field area. Geophysics is useful for mapping the structural component of this field. It also yields some porosity information.

Discovered initially in 1954 in a gas field, it wasn't until the end of 1955 that the first commercially successful oil was drilled. More than 120 with have been drilled to date in the field has accounted for 39 x 10^8 m^3 gas and 953 x 10^6 m^3 oil. The field, which has a large gas cap with a relatively thin oil column, is underlie by a limited aquifer (Downhake and Bohannan 1965). It produces gas and oil from a porous dolomite of the Elkton Mbr of the Turner Valley Fm. Early in the development phase, the presence of this large gas cap and the absence of gas markets puts future production in doubt. However, in 1960, the field was utilized into a two-equally unit and plans were devised to introduce a scheme of gas cycling which would preserve the gas and improve oil recovery. The extent of the gas cap is one of the factors that allows this field to be seismically visible.

The areal extent of the field is estimated at 4.491 ha for oil and 7.020 ha for gas with an average pay thickness of 9.56 m for oil, 26.45 m for gas (Virtual Computing Services Ltd). Reserves average 10.5% for gas and 12.8% for oil, permeabilities are, respectively, 125.8 md and 133.5 md (arithmetic average). The western limit of the field is defined by the oil-water line. In the south the reservoir rocks are dolomite but the limestone content increases to the north and east where several wells encountered dense limestone. This change from a dolomite to a limestone facies reduces reservoir porosity considerably for many wells.

GEOLOGIC CROSS-SECTION

The Elkton Mbr, the lower member of the Turner Valley Fm (Rundle Gp, Fig. 6.8), is a dolomite with some interbedded dense limestone facies. The zero edge of this member lies east of the Harmattan-Elkton field. However, the Elkton Mbr may be absent locally due to post-Mississippian channeling. Two wells, 9-31-32-4 W5M, are channel wells with the Elkton Mbr entirely eroded and infilled with clastics. Although the bed over the Mississippian in the Harmattan-Elkton area are clastics, there are a few occurrences where a dense Jurassic limestone is remnant (partially eroded) and is sufficiently hard that it affects the seismic interpretation. The main trap for the oil pool is stratigraphic. Portion of the dolomite is replaced by secondary calcite cementation of the pores and intercrystalline spaces. In some areas this calcite includes a dense Nordegg Fm (Jurassic) chert which can generate a strong seismic reflection and mask the actual top of the Mississippian.

The Mississippian surface dips seaward at about 20 m/km across the field (Fig. 6.11) which accounts for the narrowness of the production area. Through most of the field, the Elkton Mbr is the subcropping unit and is overlain by clastics of the Lower Mannville Gp. In some areas these clastics include a dense Nordegg Fm (Jurassic) chert which can generate a strong seismic reflection and mask the actual top of the Mississippian.

Figure 6.6 is a representative geological cross-section which corresponds to the location of the Elkton Mbr on the seismic section. Because the rocks were drilled in the late 50's and early 60's, neutron logs were run as the main tool for porosity determination.

Figure 6.7. Mississippian stratigraphic correlation chart.
Figure 6.11. Mississippian structure map of the Harmattan-Elkton pool (Contour interval 10 m).

River, good seismic information is difficult to obtain close to the up-dip edge of the field. The example line was recorded, 12 fold, in 1983 using a Vibroseis source. A 7-second 56–14 Hz downsweep was input as 12 sweeps over 108 m. Near and far offsets were 300 and 2600 m respectively. A 60 Hz notch filter was used to allow the crew to monitor data quality. This did not affect the data as the sweep was already limited to 56 Hz.

The seismic reflections identified correspond to the Benton shale (a trough), the Mississippian sub-crop (peak), the base of the Middle Mannville Gp sandstones (trough) and the Viking Fm (peak).

The Mississippian structure map (Fig. 6.11) outlines an undulating surface with a low in the middle of Twp 32, a rise of 20 m through Section 6 and a more rapid drop to the south. The seismic line corroborates this structure which exists on many of the later Cretaceous events. When a surface source such as Vibroseis is used, the lack of refractive time may cause static control during processing. Consequently, there will be less confidence in time structure maps and horizon mapping will be strongly time related as well. On this example line, thickening of the Mississippian-Ireton isochron is interpreted to indicate Mississippian structural highs and thus corroborates the highs identified by the structure alone.

The presence of gas in this reservoir affects the seismic reflection as it did in the previous Alexis pool example. At the north end of the field, the poor porosity of the Elkton Fm drastically reduces the event, and the Mississippian time is deeper in the section due to the destructive interference common with thin bed seismic reflections and because it is thin, it masks the top of the Mississippian due to the destructive interference common with thin bed seismic resolution.

The reservoir at Alida East is a porous Alida limestone of low permeability overlain by a thin anhydrite zone which serves as a seal.

ALIDA EAST

INTRODUCTION

The Alida East field is one of a series of elongate fields in southeastern Saskatchewan which produce gas-saturated oil from the Frobisher or Alida beds of the Mississippian Mission Canyon Fm (Fig. 6.12). Located approximately 225 km southeast of Regina, Saskatchewan, T. 6, R. 33 W1M, the field takes its name from the nearby town of Alida.
Figure 6.9. Geological cross-section Harmattan-Elkton field.
Figure 6.10. Seismic section Harmattan-Elkton field.
Both structural and stratigraphic components are pertinent to this field, but geophysics is useful for the structural aspect only.

The earliest wells were drilled in 1954. Production began in early 1955 and continues to the present time. To date (December, 1987) oil production has been 1,946,068 m$^3$ and gas 7,892,856 x 10$^3$ m$^3$.

**GEOLGICAL CROSS-SECTION**

The Mississippian Mission Canyon Fm has been subdivided into five subunits (Fig. 6.13), only one of which, Mission Canyon 3, is productive in this area. Where the sub-units are less distinguishable, the upper Mission Canyon is divided into two members, Frobisher (eroded in Alida East) and Alida (equivalent to Mission Canyon 3).

Originally deposited as limestone along the eastern side of the Williston Basin, probably in a shallow environment, the Alida beds thin to a zero depth a short distance east of this field. During post-Mississippian erosion, a diagenetic change occurred to the uppermost Mississippian whereby limestone was replaced by anhydrite to a depth of several metres. This provided a dense unit which acts as a seal and is recognizable as a geological marker horizon. Figure 6.14A, a map view (Fig. 6.14A), the dotted line indicates the limit of anhydrite replacement, anhydrite to the east (right) and limestone to the west. Some anhydrite was eroded (dashed line), removing the seal. The solid line is the Mission Canyon erosional edge. Figure 6.14B is a sketch of the geology, both in the dip (A-A') and strike (B-B') direction.

Below the anhydrite, the limestone is porous, but has low permeability. For this reason, the Alida zone was normally cored and perforation points determined based on core oil saturation.

A map of the Mississippian structure (Fig. 6.12) shows closure to the northeast, but such closure is deceptive because the Alida Mbr thins north-eastward by erosion and becomes unproductive prior to reaching its erosional edge due to diagenetic loss of porosity.

The geological cross-section in Figure 6.15 esums the Alida East field in an east-west direction. The deepest formation penetrated by drilling is the Mississippian Mission Canyon Fm with the Alida Mbr uppermost. Overlying the anhydrite, the pre-Jurassic unconformity, are the radioactive sandstones of the Watrous Fm (Jurassic). Other horizons are the Shaunavon Fm (Jurassic) and the top of the Mannville Grp (Lower Cretaceous).

There is a significant velocity contrast between the Red Beds and the underlying anhydrite, a factor which is important geophysically. The porous Alida limestone and the Red Beds have similar velocities and the top of the unconformity would be difficult to identify seismically without the anhydrite.

**SEISMIC SECTION**

The example seismic section (Fig. 6.16) starts within the field at the east edge, crosses it and ends just outside its western limit (Fig. 6.12). Recorded in 1984 with an air gun source, the line parallels the geologic cross-section. Three guns of 60 cu. in. ea. were used in a linear pattern over 17 m, with a pop per gun. The split spread had far offsets of 1225 m, near offsets of 50 m, a group interval of 25 m and source interval of 50 m. Geophones were 28 Hz, 9 over 25 m. Field filters were set at 18-12 Hz with a notch filter applied during recording.

Figure 6.17 is a suite of logs for one of the wells in Figure 6.16, 1-2-63 W1M, displayed in time to match the synthetic seismogram. It is representative of many wells in Alida East. The strongest seismic event corresponds to the Lower Shaunavon top.

Figure 6.18A compares the synthetic seismograms of wells 10-4, 5-1, 3-2 and 1-2 from Figure 6.15. Figure 6.18B is a diagram of the feature using the Red Beds as a datum. The anhydrite gives rise to the Mississippian seismic marker horizon which is present across the section but changes character, depending on lithology and thickness. A strong positive peak corresponds to a thick (8-10 m) anhydrite zone (104 W1M). As both the anhydrite and the Red Beds thin and streaks of unconsolidated sandstones appear in the anhydrite, the peaks dims (3-1, 3-2). In 3-2 the Red Beds are thicker and the peak is

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**Figure 6.13.** Stratigraphic column E.1: Saskatchewan (from, Dept. of Mineral Resources, Petroleum and Natural Gas Branch, Regina, Sask. Drawing No. G-193, October 1963).
INTRODUCTION

Although not the earliest field drilled in the Canadian Rockies, the Turner Valley Fm occupies the upper part of the Rundle Gp (Fig. 6.19) and may be either medium- to coarse-grained crystalline, crinoidal limestone or medium-grained crystalline silty dolomite. Original sediment was most commonly an echinoderm- biogenous limestone. Biostratigraphy of the zone is difficult to identify due to subsequent dolomitization and re-crystallization (MacQueen et al., 1972). The formation was originally separated into three informal members, Upper Porous, Middle Dense and Lower Porous. The Lower Porous is now designated the Elkton Mbr and is the major gas producer in the footwall fields (MacQueen et al., 1972).

Porosity and permeability information for the field is limited. Very few logs were run as the earliest drilling pre-dated well logging and later (1940s) electric logging tools were primitive. Many thin beds were cut and in some of the earlier wells, no samples were recorded. Development had to depend on production derived from these sparse samples. Although the Elkton Mbr is generally porous, it is not necessarily permeable and it is believed that fracturing was also an important factor in producing the reservoir.

Figure 6.20 is a Mississippian structure map with a 500 ft (152 m) contour interval. It shows how great the relief is on the structure. The major thrust faults are indicated by wavy lines. Minor faulting is not shown.

Seismic played no part in Turner Valley's development, but the field became a geophysical model in the subsequent search for similar sub-surface Mississippian structures.

GEOLOGICAL CROSS-SECTION

Turner Valley lies at the eastern end of the Foothills Belt (Jones, 1982). Early drifters looked for surface outcrops, precipitating co-incident deep structure. Fortunately, Turner Valley fit this criterion, though many other fields do not.

The structural framework of the Foothills is a series of folded thrust faults with steeply dipping beds. Many of these thrusts are sole faults which follow shale or coal beds and periodically rise sharply through the thinner limestones and sandstones. Deformation is attributed to the Laramide Orogeny. The Turner Valley field, like many other Foothill structures, may have had a degree of folding prior to faulting and, as well, has since had folding imposed on these faults. Thus the reservoirs formed as anticlines, rather than fault traps.

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Figure 6.15. Geological cross-section Alida field.
Figure 6.16. Seismic section Alida field.
Figure 6.21. Geological cross-section Turner Valley field.
Figure 6.22. Seismic section Turner Valley field.
CONCLUSION

Though not discovered seismically, the Turner Valley field nevertheless became important in the development of both reflection and refraction seismic techniques. Template lines such as the example in Figure 6.21 were recorded by many companies in an effort to achieve two goals. Firstly, to find similar structures, with the result that fields including Jumping Pound, Quick Creek and Fischer Creek were either discovered or developed utilizing seismic. Secondly, seismic data has been valuable in unravelling some of the complexities of the thrusting and folding of Foothills strata. It is evident, in Turner Valley, that the main trap is the anticline formed by today’s explorationists.

BLUEBERRY FIELD

INTRODUCTION

Discovered in the late 1950’s, the Blueberry field is located in northeastern British Columbia, approximately 80 km northwest of Fort St. John near the Alaska Highway. Production is from a dolomitized carbonate of the Debolt Fm (Mississippian Rundle Gp).
The Blueberry Field is long and narrow (20 by 2 km) and is structurally controlled by a major thrust fault (one of many such faults in the general area) on its northeast up-dip edge. Vertical displacement on these faults is 100 m or more. The western edge of the field is bounded by the oil-water contact, a feature which changes from south to north, indicating separation of the field into more than one pool. Seismic data recorded in the early 1960’s defined the major fault and indicated the presence of several others which are probably the reason for the different oil-water contacts.

Both oil and gas are present with most gas found in a gas cap in wells nearest the main fault. Earliest oil production was seriously hampered by high gas/oil ratios in some wells. Porosities range from 9.3 to 11%, average horizontal permeability is 26.96 md. Net oil pays from 6 to 37 m. Production to December, 1987, was 906,529,800 m³ of gas and 2,195,127 m³ of oil.

GEOLOGIC CROSS-SECTION

The subcropping Mississippian unit in the Blueberry field is the Debolt Formation (Fig. 6.26), time equivalent to the Turner Valley and Mount Head formations of southwestern Alberta. It is comprised of carbonates interbedded with shales. At Blueberry, the reservoir rock is a microcrystalline dolomite with fine, vuggy and intercrystalline porosity. Production is from the top of the zone.

Where the rock is not dolomitized, the limestone facies is non-porous. Overlying the dolomite is a massive 6 to 10 m thick chert, which forms an effective seal against upward loss of hydrocarbons. Corea show minor vertical fracturing and stylolites within the Debolt Fac.

Faulting and differing water lines effectively separate the Blueberry Field into at least four pools, one of which is mapped in Figure 6.27. The Mississippian structure contours are based on well control, whereas the main thrust fault location is defined by seismic data recorded in the early 1960’s.

Since the faulting occurred too late in time to create an effective trap, it is postulated that the structure was antecedent to thrust faulting and that these faults served both to enhance permeability and prevent further migration of gas and oil.

No wells in this pool penetrate beyond the first 100 m of Mississippian and very few have been drilled off-structure. An exception was b-100-K 94-A-12, which was drilled east of the fault in a more regional position and encountered a porous but wet Debolt at 100 m substructure. Structure on the shallower horizons tends to be sub-parallel to the Mississippian.

The wells in Figure 6.24 illustrate the geology along the example seismic line. The d-50-K well lies close to the crest of the up-thrust Debolt, whereas d-40-K is downdip to the southwest, and b-100-K well. The d-38-K well, a shallow Dunlevy (Cadomin) gas producer, does not penetrate the Mississippian and is downdip from the off-structure well to the east, b-100-K. Structure on the Fernie and Nordegg in 6-36-K indicates a return to the more regional conditions east of the thrust.

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Figure 6.24. Geological cross-section Blueberry field.
Figure 6.25. Seismic section Blueberry field.
SEISMIC SECTION

Seismic data played a prominent part in the development of this field. Although the main thrust fault edge was defined within a narrow zone by 1960's data, the location of minor faults controlling the oil-water line and a more precise positioning of the main fault required further work. Consequently, seismic was recorded in the late 1970's and again in the mid 1980's.

The lithology of the Fm. Bakken and Ratcliffe Mbr is well related to the seismic response in Figure 6.23. On the left, the lithology log is drawn to match the sonic and seismic seismogram, displayed in time on the right. The major seismic events correspond to the Gething Fm Sand (peak), the Cudiman conglomerate (peak), a Triassic dolomite (peak), the Diabar Gp (peak) and the Debolt Fm chert over dolomite sequence (a peak). The porosity in the Debolt Fm appears as low-velocity zones on the sonic and as a strong trough on the seismogram. The low-velocity event on the left side of the section rises 35 ms, 2 way velocity zones on the sonic and as a strong trough on the seismogram, suggesting the trace of the main fault as it dips into the section.

Several faults, not suspected on earlier interpretations, can now be identified and faults can be determined with a high degree of accuracy. The dip direction, northeast to southwest.

In the example, the Debolt Fm is cut by the main thrust at trace 207 and two separate Debolt events appear to the right of the break. The Debolt event on the left side of the section rises 35 ms, 2 way traveltime, to where it terminates at trace 190. The lower Debolt event can be mapped and used to help predict the presence of faults occurring both in the Mississippian to the left of trace 180 and in the Triassic near trace 150.

The seismic line (Fig. 6.25) recorded in 1986 crosses the field in the dip direction, northeast to southwest. It is an example of the improvement in seismic quality in the intervening 25 years since discovery of the field. It was recorded with 2 kg of dynamite in a single, 18 m deep bore, a shot spaced with a 1500 m offset, 25 m group interval amid 100 m source interval to produce 15 fold coverage. Receivers were Mark Products 10 Hz geophones, 9 in-line over 25 m. This example has been processed using a spiking deconvolution with an 80 ms long operator. A post-stack dip filter was recorded with 2 kg of dynamite in a single, 18 m deep bore, a shot spaced with a 1500 m offset, 25 m group interval amid 100 m source interval to produce 15 fold coverage. Receivers were Mark Products 10 Hz geophones, 9 in-line over 25 m. This example has been processed using a spiking deconvolution with an 80 ms long operator. A post-stack dip filter.

Several faults, not suspected on earlier interpretations, can now be identified and faults can be determined with a high degree of accuracy. The dip direction, northeast to southwest.

CONCLUSIONS

As a thrust fault controlled field, Blueberry is the type of prospect that has been improved by the use of the seismic technique. Both discovery and extension of this field have relied on seismic as the major exploration tool. The field lies far enough east of the major thrusts are observed to be in the shallower zones where the Triassic is cut by a minor fault between traces 151 and 156.

The loss of reflection in the upper half of the section to the left of trace 210 is caused by the dispersion and diffraction of energy both by fracturing in the rocks and by the poor near-surface ground conditions. Because the far offsets are less affected, the deeper horizons are still interpretable.

Because the field is structurally controlled, no effort is made to predict porosity. However, the trough below the Mississippian peak does indicate porosity. The reduction in amplitude of this trough to where it terminates at trace 155 indicates that the dolomitized zone may thin considerably to the north.

Several faults, not suspected on earlier interpretations, can now be identified and faults can be determined with a high degree of accuracy. The dip direction, northeast to southwest.

HUMMINGBIRD FIELD

INTRODUCTION

Situated approximately 70 km southwest of Weyburn, Sask­atchewan, the Hummingbird field is a multi-pool gas and oil producer first drilled in 1964. Initially identified as an oil trap, the structure was a structural closed Paleozoic feature in 1963, it now produces from the Ratcliffe Mbr. The producing zone of the Ratcliffe Mbr is 565 209 m 3 oil and 23 594 800 m 3 gas. Porosity and permeability within the Bakken Fm and Ratcliffe Mbr are 6% and 3 md, 14% and 7.5 md respectively.

The field is small, barely 250 ha in size, but has been quite prolific. The Bakken Fm produces from an argillaceous fine-grained sandstone. The producing zone of the Ratcliffe Mbr is a porous dolomitic bioclastic limestone. Production (to December, 1987) from the Ratcliffe Mbr is 565 209 m 3 oil and 23 594 800 m 3 gas. Porosity and permeability within the Bakken Field and Ratcliffe Mbr are 6% and 3 md, 14% and 7.5 md respectively.

Other similar features in the area, smaller than Hummingbird, have also been identified and successfully developed. Thus, Hummingbird became one of the key geological and geophysical models for multi-stage salt dissolution features in the Paleozoic.

Figure 6.29. Stages of differential salt dissolution.
began to subside again through the remainder of Paleozoic time, continuing until late Devonian (Smith and Fuller, 1987).

During Devonian time, the Prairie Evaporite Fm salt was deposited in a large part of the basin. It is not known how much salt was originally present at Hummingbird, but evidence suggests that over 90 m has been lost. The nearest well with salt is over 6 km to the northeast (9-3-18 W2M) and has 85 m of Prairie Evaporite Fm. Of the deep wells drilled in Hummingbird, including the 10-26 discovery well, none encountered salt, thus supporting a salt dissolution origin.

Differential dissolution of salt began near the end of Middle Devonian time with most loss occurring in Late Devonian. (Fig. 6.31). Of the deep wells drilled in Hummingbird, including the 10-26 discovery well, nine encountered salt, thus supporting a salt dissolution origin.

The discovery well, 10-26-2-19 W2M, was drilled to the Ordovician Minnepig Fm and logged to a depth of 10 224 ft (3 523 m). Hydrocarbons were tested in several Mississippian areas and the Devonian Birdcave Fm. It was completed as a Birdcave well. Several subsequent wells were drilled to produce from both the Birdcave Fm and Ratcliffe Mbr. Beginning in 1985, the Birdcave zone was abandoned in some wells and production began from the Bakken Fm.

The geologic cross-section in Figure 6.33 parallels the seismic line in Figure 6.34 over the Hummingbird field. Structure is evident on all horizons below the pre-Jurassic unconformity. The Mississippian top is relatively flat due in part to subsequent erosion as well as to salt subidence. Horizons identified are the Birdcave Fm, Three Forks Fm (both Devonian in age) the Bakken Fm, the base of a deep Mississippian shale marker, the Oungre (an informally named zone within the Bakken Fm) and the Ratcliffe Mbr and the top of the Mississippian.

SEISMIC SECTION

The example seismic section (Fig. 6.34) lies along the west flank of the Hummingbird field (Fig. 6.31) and parallels the geological cross-section. This line was recorded, 12 fold, in the winter of 1983. It is interesting to compare this survey to the 1963 discovery seismic data published in earlier literature, recorded singlefold with a dynamite source of 4.5 to 9 kg. The 1983 discovery seismic data printed in earlier literature, recorded singlefold with a dynamite source of 4.5 to 9 kg. Although in the old data reflections were broken into short, slightly curved line events as a result of single fold acquisition and inadequate data processing, it is still more than adequate to identify the feature. This screen must partly be credited to the fact that this area has excellent ground coupling conditions for recording seismic. The main improvements are in the higher frequency content and the ability to migrate the data to better define the limits of the structure.

The display is reverse polarity which shows the low velocity producing zones as peaks. Events identified correspond to the following: the Winnipegosis Fm (a strong peak), the Bakken Fm (a peak), the Ratcliffe Mbr (a moderate-amplitude peak), the top of the Mississippian (a trough), and the Jurassic Shaunavon Fm (a trough).

Figure 6.34. Stratigraphy southeastern Saskatchewan.

CONCLUSIONS

Until the Hummingbird structure was tested, multi-stage salt dissolution had not been proven in Western Canada. The discovery and development of this feature became one of the more exciting success stories of the early 1980's where geology and geophysics were used to complement each other.

VIEWFIELD FIELD

INTRODUCTION

Identified by seismic and developed in the early 1970's, the Viewfield Field is the most exciting success story of the early 1980's where geology and geophysics were used to complement each other.

Figure 6.34. Stratigraphy southeastern Saskatchewan.
Figure 6.32. Geological cross-section Hummingbird field.

KILOMETRES

5-26  11-26  1-35

PROJECTED
3-35-2-19 W.2

METRES

MISSISSIPPIAN

RATCLIFFE
OUNGRE

SHALE MARKER

BAKKEN
THREE FORKS
BIRD BEAR

-975

-1615

RILEY'S DatasHARE International LTD.  AUTHOR: DOROTHY-ANN REIMER
Figure 6.33. Seismic section Hummingbird field.
Situated in the Williston Basin amid many fields created by salt dissolution, this field is difficult to explain solely by salt tectonics. An alternate origin was postulated by Sawatsky (1972) in which the structure was described as a small post-Mississippian impact crater or astrobleme which was subsequently modified by erosion and by later dissolution of Devonian salt. The lack of meteorite particles or shock features in core prevents a conclusive classification, but there is still sufficient evidence to warrant a "possible" classification as an impact crater (Donofrio, 1981).

Viewfield production is from the Mississippian Frobisher beds of the Mission Canyon Fm and from an overlying breccia identified as Mississippian in origin, and often referred to as the "Rim" facies. To date (December, 1987) 1,417,832 m³ of oil and 115,407,400 m³ of gas have been recovered. Seismic was used to map the Mississippian structure and the majority of wells were drilled on seismically determined highs.

**GEOLOGICAL CROSS-SECTION**

One of the earliest wells drilled in Viewfield was Shell's 1957 Viewfield 'B' 13-30-7-8 W2M. It was abandoned after testing oil- and gas-cut mud. It wasn't until early 1969 when the United Canso Viewfield 8-30 well was drilled and tested oil that development of the field began.

The normal stratigraphic sequence shown in Figure 6.34 is interrupted in many of the Viewfield wells. The Lower Watrous Fm (Triassic), composed of red to reddish-brown shales and siltstones, is encountered both above and below varying thicknesses of Mississippian sediments. These Mississippian sediments, highly brecciated carbonates, are described as the "Rim" facies.

Figure 6.35 is a map of the Mississippian structure and includes the "Rim" facies where present. The feature is that of a large ring with a high circular ridge surrounding a deep depression. Three wells (5-29, 13-29, 15-29-7-8 W2M) confirm this deep feature. The deepest well, 13-29, was drilled to 788 m subsea without finding Mississippian strata, a full 100 m below regional. The diagram in Figure 6.36 is a cross-sectional sketch of the feature.

The presence of Mississippian rocks over later Red Beds sediments, the brecciated condition of the "Rim" facies rocks and geometric configuration of a raised rim around a central cavity are considered indicative of an impact origin.

The geological cross-section, A-A' (Fig. 6.37) follows the northeast rim of the feature and parallels the seismic line labelled A. Underlying the Watrous Fm is a very thin Red Beds section ranging from less than a meter in 9A-32 to several meters in 10A-28. These separate the Watrous Fm from the "Rim" facies below. This "Rim" unit is the reservoir rock in most wells. At the base of the brecciated rim, a second, thicker Red Beds section is encountered.

The second cross-section B-B' (Fig. 6.37) traverses the south slope of the feature's north rim, crosses the crest and extends beyond the field. It parallels the example seismic line B. The "Rim" facies is evident in three of the wells. The 5-32 well has a thick, but low rim section between two Red Bed units. The Rim facies is absent from the regional 11-34-7-8 W2M well.
SEISMIC SECTION

The first indication of a geophysical anomaly and a possible support for the inferred origin theory in Viewfield is the aberration in survey grid lines (Fig. 6.35). The east-west lines, which should be straight and parallel now deviate due to possible deflections during the survey. Such deflections can be attributed to the presence of other than sedimentary rocks such as plutons. In this example, the cause may be a buried meteorite or rock that was heated and altered during impact with a meteor.

Development of this field benefited greatly from two relatively new technologies, continuous depth point seismic and the sonic tool. Though the early sonics were often full of cycle skips, crest, corresponding to a thinning of the geological section.

Prairie Evaporite Fm. Salt in this well supports the possibility of salt horizon (a strong peak), the Watrous Fm (a peak) and Lower Structure on the deeper horizons coincident with the rim, may be heated and altered during impact with a meteor.

Using a dynamite source of 1.1 kg in 18 m holes. The recording system was a 24-channel DSF III, and a sample rate of 2 ms was used at a time when most seismic was still being recorded at 4 ms.

Near and far offsets for the split spread were 33.5 and 771 m respectively, coverage was 300%. Coupled with the excellent ground conditions, near and far offsets, these parameter allows current processing capabilities to bring out the high frequency content and coherency of the data.

The seismic events identified correspond to a Jurassic marker horizon (a strong peak), the Watrous Fm (a peak) and Winnipegosis Fm (an intermittent peak). The origins of Viewfield field are certainly complex. Because of its relatively small size (about 2 km in diameter), the crater would have been considerably eroded before it was fully covered and preserved by later sediments. In addition salt dissolution has most likely affected the structure. The salt itself may have fractured and dissolved as a result of fracturing of the upper zones. Regardless of its origin, however, Viewfield must be considered an excellent example of a geophysically defined field.

CONCLUSION

The seismic data for the 6-33 well, filtered with a 35 Hz Ricker wavelet, is shown on the left of the diagram. The seismic events identified correspond to a Jurassic marker horizon (a strong peak), the Watrous Fm (a peak) and Winnipegosis Fm (an intermittent peak). The origins of Viewfield field are certainly complex. Because of its relatively small size (about 2 km in diameter), the crater would have been considerably eroded before it was fully covered and preserved by later sediments. In addition salt dissolution has most likely affected the structure. The salt itself may have fractured and dissolved as a result of fracturing of the upper zones. Regardless of its origin, however, Viewfield must be considered an excellent example of a geophysically defined field.

SEAl

INTRODUCTION

In the early 1970’s, several wells were drilled in the Seal area, approximately 30 km northwest of Edmonton, Alberta. The targets were oil in the Devonian Slave Point Fm and gas in the Mississippian Debolt Fm.

Considerable seismic had been recorded as an aid in positioning these wells. Several reef-like features within the Mississippian Pekisko Fm were evident in what was believed to be a low relief, 10 mound. Figure 6.39 is an enlarged segment, reverse polarity, from line B between the 11-34 and 6-33 wells. On the right, the early sonics were often full of cycle skips, crest, corresponding to a thinning of the geological section.

Debolt Fm.

Formation

A number of seismic anomalies identified in the region were investigated further. The Debolt Fm. was the first of these anomalies to be drilled, based on seismic data, and has found Pekisko carbonate build-ups ranging from 34 to 50 m thick. Unfortunately the oil is too heavy to be produced economically at the present time.

Porosity ranges from less than 6% at the base of the mound to 25% in the mound core. Permeability also ranges from very low, less than 1 md at the base, to very good, 1 to 10 in the core. In-place oil reserves for the discovery well, 7-6-12 W5M, are estimated to be between 2 and 5 x 10^6 bbls. Since these mounds are similarly similar to pinnacle reefs, they are ideal geophysical targets.

Figure 6.40. Mississippian stratigraphy, northcentral Alberta.

GEOLOGICAL CROSS-SECTION

The Pekisko Fm is the lowest unit of the Rundle Group. Overlying the Banff Fm (Fig. 6.40) it exhibits both carbonate and shale facies. In the Seal area, the basal unit of the Pekisko Fm is a thin platform-type carbonate overlain by thick shales. Arising from the platform are a series of small carbonate mounds identified as "Waulsortian" mounds (Edwards, 1986), which range from 20 to nearly 50 m in thickness. Figure 6.41 shows a map of the Pekisko Fm carbonate buildup.

The Banff structure (Fig. 6.42) is generally regional, but a minor overall low extends northeastward along the southwest edge of the field and may have affected deposition of the Pekisko Fm. The mounds on the updip flank of this depression,
Figure 6.37. Geological cross-section Viewfield field.
Figure 6.38. Seismic section Viewfield field.
Figure 6.43. Geological cross-section Seal area.
Figure 6.44. Seismic section Seal area.

SHUNDA
PEKISKO SHALE
PEKISKO CARBONATE
BANFF
WABAMUN
BANFF—Canadian Society of Petroleum Geologists and Canadian Geologists

McCrossan, RG. and Glaister, RP.

Figure 6.42. Banff structure contour map, Seal area. (Contour interval 10 m). Dashed line is location of example seismic line (Fig. 6.44).

Figure 6.45A. 1-16-83-12W5M on the left has 23 m of Banff Fm carbonate which is replaced by shale to the right. The Banff is "pulled-up" on the left and the carbonate event is a broader peak.

The seismic reflection (Fig. 6.45B) is in the 10-34 well but absent in the 12-16 well. A thick Pekisko Fm carbonate bank is present in all wells. In the 7-6 well, there is about 45 m of mound. The sonic indicates the mound core. There has been significant recrystallization and stylolitization.

The reflection is similar to that of reefs hence the criteria used for reef-finding is valid for these features. Seismic is currently the only tool being used to locate these mounds. They vary in size and shape, from a cross-over to a peak and the peak above the Banff Fm trough becomes broader and stronger.

Several changes are observed between traces 340 and 375, which is the location of a Pekisko mound (Fig. 6.44). The most noticeable is the poor coherency at all levels below the Shunda Fm, which is attributed to reduction and dispersion of energy within the mound.

The expressions is similar to that of reefs hence the criteria used for reef-finding is valid for these features. Seismic is currently the only tool being used to locate these mounds. They vary in size and shape, from a cross-over to a peak and the peak above the Banff Fm trough becomes broader and stronger.

The reflections identified on the seismic section correspond to the Shunda Fm carbonate (a peak), Pekisko Fm shale (trough), Pekisko Fm carbonate (a peak), a Banff Fm shale (strong trough) and Wabamun Gp carbonate (peak). It should be noted that unless it is built up in thick mounds, the Pekisko Fm carbonate at 10 to 12 m thickness, is very thin to be seen seismically.

CONCLUSIONS

Until the Seal wells were drilled and analyzed, reefing in the Pekisko Fm was considered unlikely or, at most, quite rare. Although these structures are not reefs, the criteria used for reef-finding is valid for these features. Seismic is currently the only tool being used to locate these mounds. They vary in size and shape, but all are small, probably not more than 400 m in length and up to 50 m high. Since the mound core is the reservoir, it is necessary to drill the highest point of the mound and the Pekisko carbonate event rises, merging with the peak above it.

Of the wells, only 7-6 lies on the seismic line. The 10-34 well is southeast of the line and 12-16 is approximately three kilometres to the north. These latter two wells have been projected into the line to illustrate the regional geology beyond the mound drilled in 7-6.

REFERENCES


Figure 6.45. The seismic log curve (Fig. 6.45A) from 16-1-83-12W5M on the left has 23 m of Banff Fm carbonate which is replaced by shale to the right. In the corresponding seismic response (Fig. 6.45B) the Banff is "pulled-up" on the left and the carbonate event is a broader peak.

The reflections identified on the seismic section correspond to the Shunda Fm carbonate (a peak), Pekisko Fm shale (trough), Pekisko Fm carbonate (a peak), a Banff Fm shale (strong trough) and Wabamun Gp carbonate (peak). It should be noted that unless it is built up in thick mounds, the Pekisko Fm carbonate at 10 to 12 m thickness, is very thin to be seen seismically.

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Of the wells, only 7-6 lies on the seismic line. The 10-34 well is southeast of the line and 12-16 is approximately three kilometres to the north. These latter two wells have been projected into the line to illustrate the regional geology beyond the mound drilled in 7-6.

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