

**A seismic and gravity study  
of salt dissolution at  
the Westhazel General Petroleums (GP) pool,  
west-central Saskatchewan, Canada**

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## ABSTRACT

The Westhazel GP pool of west-central Saskatchewan, Canada, produces from the General Petroleum (GP) member of the Mannville Group, Lower Cretaceous. This reservoir is structurally closed across the updip, dissolutional edge of the underlying Middle Devonian age salt of the Prairie Formation. The leaching of these salts occurred in post-Mannville time in the Westhazel area, and caused the regional southwest dip of the General Petroleums member to be locally reversed.

The Westhazel GP pool is characteristic of many of the Lower Cretaceous pools situated along the dissolutional edge of the Prairie salt in that the reservoir facies itself does not exhibit a diagnostic signature on either seismic or gravity data. Rather it is the updip edge of the salt, across which the reservoir is closed, which can be confidently mapped using geophysical techniques.

On the seismic data the dissolutional edge of the Prairie salt is characterized by: 1) a relatively abrupt thinning of key Paleozoic intervals; 2) dip reversal along the Beaverhill Lake (Late Devonian) event; 3) dip reversal along the Mannville (Lower Cretaceous) event;

4) a structural low at ground level across the western part of the seismic line; and 5) time-structural "push down" of Lower Cretaceous and underlying reflections in zones of interpreted recent salt dissolution. On the gravity profile the edge of the salt is manifested as 1.5 mgal anomaly. The interpretation of both geophysical data sets is consistent with available geologic control.

## INTRODUCTION

The Westhazel GP pool (T50 R22 W3M) is located in west-central Saskatchewan, Canada, about 75 km from Lloydminster, Saskatchewan (Figures 1 and 2). The reservoir consists of fine- to medium-grained quartzose sandstones. The lateral uniformity and coarsening upwards appearance of this unit suggests that deposition occurred in a relatively shallow, marine environment. The pool was discovered in 1971 and has produced in excess of 60,000 m<sup>3</sup> of heavy oil from the marine sandstones of the General Petroleums (GP) member, Mannville Group (Figures 3 and 4; Table 1).

The heavy oil at Westhazel pool is trapped where the regional monoclinal southwestern dip of the Cretaceous strata is locally reversed as a result of the dissolution of the underlying Prairie Formation salt (Figures 3 and 5). The General Petroleums is structurally closed across the updip edge of the remnant salt. This pool is an excellent example of the structural trapping of hydrocarbons as a result of salt dissolution. The seismic and gravity data, incorporated into this paper, illustrate the utility of these techniques in the search for such salt-related hydrocarbon pools.

## PRAIRIE FORMATION SALT

The Prairie Formation (Upper Elk Point Group, Middle Devonian age; Figures 1 and 3) in west-central Saskatchewan and east-central Alberta, is an interbedded succession of halite, sylvite, bedded anhydrite and minor dolostones which grade westward into shales, carbonates and anhydrites, and northward into the Muskeg formation (Figure 1). The salts of the Prairie Formation are thought to have been uniformly distributed throughout the central part of the Upper Elk Point Basin; in the Westhazel study area they attained a net depositional thickness on the order of 140 m (Anderson, 1988; Cederwall, 1989). However, as a result of leaching the present-day distribution of these salts is not what it once was.

Well log control indicates that the Westhazel study area is now dissected by the regionally westward-stepping, north-northwest trending main Prairie Evaporite dissolutional edge (Figures 1, 2, 3 and 5). Thick salts are preserved to the west of this edge; to the east the salts are absent except for a few isolated remnants of irregular shape, variable thickness, and limited areal extent. Collapse features (as interpreted on seismic data), gravity anomalies, and anomalous variations in structural relief along post-Elk Point strata are associated

with both the main dissolutional edge and the isolated salt remnants to the east, supporting the thesis that the Prairie salts were widely distributed, uniformly deposited, and extensively leached (Anderson, 1988; Cederwall, 1989). Figure 1 shows the present-day generalized distribution of the Prairie and Muskeg salts as trending north-northwest through eastern and northern Alberta.

Work to-date by the authors (Anderson and Brown, 1991a,b; Anderson et al., 1988) suggests that the dissolution of the Prairie and other Devonian salts in western Canada was initiated and/or enhanced by some or all of five principal processes: 1) the near-surface exposure of the salt; 2) the influx of meteoric water from the east; 3) regional faulting and/or fracturing; 4) glacial unloading; 5) the partial dissolution of the underlying Devonian salts (Lower Elk Point Group, Middle Devonian age).

The near-surface exposure of the salt is thought to have occurred to the east of the Westhazel study area and as a result of the erosion of the overlying Paleozoic sediment during the post-Paleozoic/pre-Cretaceous hiatus. The dissolution front, which was established along the subcrop edge, appears to have migrated over time to the west, suggesting that leaching is a self-perpetuating process. It is thought that

the migration of the main salt edge was accentuated by the westward flow of meteoric water through the adjacent sediment. These waters could have entered the system along the Elk Point outcrop to the east of the study area.

The linear patterns of salt dissolution displayed by the Prairie salt in the study area and by other principal Devonian salts in southern and east-central Alberta (Cold Lake Formation, Leduc Formation and Wabamun Group; Figure 3) suggests that secondary dissolution fronts (basinward of the front migrating from the subcrop edge) could have developed along regional fault/fracture planes during the Cretaceous (Anderson, 1991; Anderson and Brown, 1991a). Lineaments are also observed within the drainage patterns; the Saskatchewan River for example, which transects the Westhazel study area, flows in a southeasterly course along and immediately to the east of the main Prairie salt edge between townships 40 and 51. Many of the lakes and rivers in east-central Alberta and west-central Saskatchewan are also situated in areas where the Prairie Evaporite salts are thin or absent, suggesting that there was a significant amount of Prairie Evaporite salt leaching in post-glacial times, possibly in response to glacial loading and unloading. Conceivably, expansion fracturing along pre-existing planes of weakness could have occurred in response to the

removal of the ice sheet.

In the Lower Elk Point Basin area, to the north of the Meadow Lake Escarpment, the dissolution of the Prairie salt could have been triggered by the leaching of the underlying Cold Lake Formation and/or Lotsberg Formation salts (Figure 3). Such leaching could have occurred at any time after the deposition of the Prairie Evaporite salt. This process is not considered a factor in the Westhazel area as these early Devonian salts were not deposited here (Anderson, 1988; Meijer Drees, 1986).

The timing and the extent of the dissolution of the Prairie salts is of interest to the explorationist for several reasons: 1) stratigraphic traps can form where reservoir facies were either preferentially deposited or preserved in salt-dissolution lows; 2) reservoir facies can develop in high energy environments such as topographic highs that are controlled by salt edges or remnants; 3) structural traps can form where reservoir facies are draped across salt remnants or collapse features; and 4) salt remnants can be misinterpreted as reefs, faults or other structural features (Anderson, 1988, 1991; Anderson and Brown, 1991a,b). The importance of salt dissolution is illustrated by the Westhazel GP pool where the reservoir sandstones of the General

Petroleum members are structurally closed across the updip edge of remnant Prairie salt.

### **WESTHAZEL GP POOL**

Production at the Westhazel GP pool (Figure 2, 4 and 5; Table 1) is principally from the sandstone unit within the General Petroleum member of the Mannville Group (Figure 3). The sandstone facies is vertically sealed by tight shales and structurally closed across the updip edge of the Prairie salt. These sandstones are characterized by a coarsening upward (regressive marine) sequence on well logs and, where tested in the study area, are of uniform thickness (about 10 m) except at the 12-34 location where they are replaced by a post-General Petroleum shale-filled channel cut, similar to that described by Vigrass (1977). This erosion and infill feature is not essential to the trapping of hydrocarbons at Westhazel, but could be the cause of some inter-pool separations. The 15-33, 12-34 and 11-34 wells all produce from the General Petroleum member at approximately 100 m above sea level (ground level is between 550 and 600 m above sea level). The General Petroleum sandstone in the 10-34 well is wet: production is from a secondary horizon.

The uniformity of bed thicknesses and depositional styles within the Mannville (Figures 3 and 6) suggest that these strata were deposited in a relatively stable, low-relief and shallow marine environment and that the extreme present-day subsurface relief was caused by the later dissolution of the Prairie salts. As suggested by the cross-section, Prairie Formation salt is preserved beneath and to the west of the pool (about 75 of the original 140 m), and absent to the east. These data suggest that the dissolution of the Prairie salt in the Westhazel area occurred, for the most part, in post-Mannville and probably Upper Cretaceous time or later. The assumption that there was no trapping mechanism in place prior to the dissolution of the Prairie salt suggests that the oil entrapped in the General Petroleum member migrated into place in post-Mannville time (Cederwall, 1989).

## **SEISMIC SECTION**

The 5 km long, interpreted seismic line (24 fold, P-shooter energy source) of Figure 7 was acquired in 1985 to aid in the development of the Westhazel GP pool. The events on this seismic section were identified and correlated with the aid of several models, including the

10-23 one-dimensional, normal-polarity, synthetic seismogram of Figure 8.

The 10-23-50-22W3M well did not encounter any salt: the corresponding synthetic seimogram can be projected onto the seismic line at trace 64. Note that on the synthetic seismogram, the Mannville, Beaverhill Lake, First Red Beds, Winnipegosis, and Ordivician events are shown to be of relatively high amplitude. In the study area: a) the Prairie Formation salt, where present, overlies the Winnipegosis Formation; b) the base Fish Scale Zone represents the Upper Cretaceous/Lower Cretaceous boundary; c) the Beaverhill Lake Group is the top of the Paleozoic (sub-Cretaceous unconformity; and d) the Cambrian is the sub-Devonian unconformity; Figure 3).

On the seismic section (Figure 7) several interesting relationships are observed:

- 1) The Paleozoic and Devonian sections (Beaverhill Lake/Precambrian interval and the Beaverhill Lake/Cambrian interval, respectively) thin from west to east (trace 288 to trace 0), by about 35 ms. This transition is consistent with the regional geological control which suggests that about 75 m of salt are pre-

served in the western part of the study area. A relatively abrupt transition from thick to absent salt occurs in the vicinity of trace 120.

2) The pattern of time-structural relief along the Beaverhill Lake event varies appreciably across the seismic section. Relative to the regional trend, this event is locally dip reversed, being up to 30 ms (possibly as much as 50 m) lower at trace 0 than at trace 288. This time structural relief is consistent with the 75 m estimate for the thickening of the Prairie salt along the entire length of the seismic line and supports our thesis that significant salt dissolution occurred in post-Paleozoic time.

3) The base Fish Scales (base Upper Cretaceous) reflection, is locally dip reversed, being about 50 ms (possibly as much as 65 m) lower at trace 0 than at trace 288. This time structural relief is consistent with the 75 m estimate for the thickening of the Prairie salt along the entire length of the seismic line, and suggests that a significant amount of salt dissolution occurred in post-Lower Cretaceous time.

4) The surface elevation profile (not shown) along the seismic

line indicates that ground level is about 45 m lower across the western part of the seismic line (traces 192 - 288) than elsewhere. It is conceivable that this anomalous low was caused by salt dissolution during post-Pleistocene time. This late phase of leaching could have been triggered by glacial unloading.

5) The Lower Cretaceous and Paleozoic reflections between traces 128 and 168, are "pushed down" locally by up to 20 ms, and elsewhere to a lesser extent. This "push down" appears to mask the true extent to which the post-salt strata are dip reversed across the updip, eastern dissolutional edge of the Prairie formation. Our preferred explanation is that these anomalies are shallow velocity variation effects and possibly due to late phases of salt dissolution. Alternatively, they could be related to: a) structure along the sub-Cretaceous unconformity; b) collapse related velocity variations within the Paleozoic section; and/or c) faulting.

6) The 20 m thick General Petroleum member does not generate a mappable event on the seismic line; the 10 m thick sandstone reservoir itself is not manifested as a seismic anomaly. The sandstone interval is too thin (10 m;

7 ms two-way travel time) to be resolved on conventional seismic data with wavelengths on the order of 25 ms; very possibly it could be resolved using high-resolution seismic techniques.

The seismic data supports the concept that about 140 m of Prairie salt was uniformly deposited within the study area and subsequently leached. A significant amount of this dissolution appears to have occurred in post-Lower Cretaceous time and conceivably in the post-Pleistocene. As noted neither the General Petroleum member nor the sandstone reservoir itself can be resolved on the example seismic data. Rather it is the edge of the salt, across which the reservoir is closed, which can be confidently mapped.

## **GRAVITY DATA**

In Figure 9 a bouger gravity profile, roughly coincident with the seismic section of Figure 7, is presented (Figure 2). We have superposed two regional gravity envelopes onto these data: one for a relatively thick salt (60 m of Prairie salt at 2200 kg/m<sub>3</sub>; 60 m of drape at the sub-Cretaceous unconformity) and a second for a zero salt section (60 m of post-Paleozoic clastics at 2600 kg/m<sub>3</sub>). Note that the bouger

gravity profile gradually changes across the interpreted dissolutional edge of the salt. The western part of the profile is consistent with the absence of salt: the eastern part is consistent with the presence of relatively thick salt. This modelled dissolutional edge is similar to that presented by Smith et al. (1984) for the Westhazel area (Figure 5), and is consistent with both the geological cross-section (Figure 6) and the seismic line (Figure 7). These data illustrate that the dissolutional edge of the Prairie salt can be mapped using the gravity technique.

## CONCLUSIONS

The Westhazel GP pool illustrates the structural trapping of hydrocarbons within the sandstones of the General Petroleum member of the Mannville Group, Lower Cretaceous as a result of dip reversal due to the dissolution of the underlying Prairie Formation salts. The Westhazel GP pool is characteristic of many of the Cretaceous pools situated along the dissolutional edge of the Prairie salt in that the reservoir facies itself does not exhibit a diagnostic signature on either gravity or conventional seismic data. Rather it is the edge of the salt, across which the reservoir is closed, which can be confidently mapped using these techniques.

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## TABLES

Table 1. Reserves and significant reservoir paramters: Westhazel GP pool (Cederwall, 1989).

## FIGURES

Figure 1. Facies distribution and paleogeography of the lower part of the Upper Elk Point Subgroup and its equivalents in the western Interior Plains, and the location of the Westhazel study area. (Modified after Meijer Drees, 1986).

Figure 2. Map of the Westhazel study area. The approximate locations of the gravity and seismic profiles are shown by the long and short dashed lines, respectively. The larger river in the study area, the Saskatchewan, effectively parallels the eastern main dissolutional edge of the Prairie salt between T40 and T52.

Figure 3. Stratigraphic chart for the east-central plains of Alberta, Canada. In east-central and southern Alberta, Devonian salts are present in several stratigraphic intervals including the Lotsberg, Cold Lake, Prairie, Beaverhill Lake, Leduc, and Wabamun. In the Westhazel study area, however, only those of the Prairie Formation are thought to have been deposited.

Figure 4. Cumulative production curve for the Westhazel GP pool.

Figure 5. Schematic sections illustrating the eastern dissolutional

edge of the Prairie Formation (modified after Smith et al., 1984). The Westhazel study area straddles Townships 50 and 51.

Figure 6. Geologic cross-section through the Westhazel GP pool. The wells incorporated into the cross-section can be located on Westhazel study area map (Figure 2). Well depths are in meters and relative to sea level. Ground level is approximately 550-600 m above sea level.

Figure 7. Normal-polarity, migrated seismic section from the Westhazel study area. This 5 km long, 24 fold seismic line was acquired using a P-shooter energy source. The 10-34, 11-34, 12-34, and 14-33 wells (Figures 2 and 6) can be tied to the seismic line at traces 112, 144, 176, and 240, respectively.

Figure 8. Normal-polarity synthetic seismogram for the 10-23-50-22W3M well. The 10-23 well is about 3 km south of the seismic line and can be located on Westhazel study area map (Figure 2). It did not encounter any remnant Prairie salt; the corresponding synthetic was generated using a zero-phase, 20 ms Ricker wavelet and can be tied to the seismic line at trace 64.

Figure 9. Bouger gravity profile across the eastern dissolutional edge of the Prairie salt (Figure 2). Two regional gravity envelopes have

been superposed onto these data: one for a relatively thick salt (60 m of Prairie salt at 2200 kg/m<sub>3</sub>; 60 m of drape at the sub-Cretaceous unconformity) and a second for a zero salt section (60 m of post-Paleozoic clastics at 2600 kg/m<sub>3</sub>). Note that the bouger gravity profile gradually changes across the interpreted dissolutional edge of the salt. The western part of the profile is consistent with the absence of salt: the eastern part is consistent with the presence of relatively thick salt.

<b>Original Oil in Place</b>	<b>6031 x 10<sup>3</sup>m<sup>3</sup></b>
<b>Estimated Primary Recovery</b>	<b>4.1%</b>
<b>Initial Established Reserves</b>	<b>247 x 10<sup>3</sup>m<sup>3</sup></b>
<b>Production to Dec 31/85</b>	<b>55 x 10<sup>3</sup>m<sup>3</sup></b>
<b>Remaining Reserves</b>	<b>192 x 10<sup>3</sup>m<sup>3</sup></b>
<b>Developed Area</b>	<b>324 ha</b>
<b>Average Pay</b>	<b>8.0 m</b>
<b>Average Porosity</b>	<b>35%</b>
<b>Average Water Saturation</b>	<b>30%</b>
<b>Oil Density</b>	<b>977 kg/m<sup>3</sup></b>
<b>Average Depth</b>	<b>485 m</b>
<b>Discovery Year</b>	<b>1971</b>

















