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# Stratigraphy and lithologic heterogeneity in the Mannville Group (southeast Saskatchewan) defined by integrating 3-D seismic and log data

Sabrina Sarzalejo
*Department of Earth and Planetary Sciences*
*McGill University*
*Montreal, Quebec H3A 2A7*
sabrinas@eps.mcgill.ca

Bruce S. Hart
*Department of Earth and Planetary Sciences*
*McGill University*
*Montreal, Quebec H3A 2A7*
hart@eps.mcgill.ca

## Abstract

Wireline log and 3-D seismic data were integrated to define stratigraphic units and lithologic heterogeneity in the Mannville Group of southeast Saskatchewan. The Mannville in this area is a stratigraphically complex unit formed of fluvial to marine deposits that, although non-prospective for hydrocarbons in this area, share many similarities with time-equivalent strata in areas of heavy oil production. Seismic sequence stratigraphic principles permitted us to subdivide the Mannville into three packages. The ability to visualize the 3-D seismic data in a variety of ways, including arbitrary lines and stratal or horizon slicing techniques, helped us to define stratigraphic features that would affect fluid flow in hydrocarbon producing areas. These features include channels of various sizes and orientations, and channel elements such as scroll bars and lateral accretion surfaces, that are present within specific portions of the Group. Because the effectiveness of enhanced recovery methods such as steam-assisted gravity drainage depends on a development team's ability to recognize reservoir heterogeneity, similar integration of 3-D seismic, well logs and other data types would assist greatly in developing the Mannville in heavy oil areas. There is close, but not one-to-one, correspondence between the stratigraphic units we defined and those established by regional log- and core-based correlations. Seismic resolution problems or log correlation styles could be responsible for the differences.

## Résumé

Des données de diagraphies différées et de sismiques en 3-D ont été intégrées pour définir les unités stratigraphiques et l'hétérogénéité lithologique présentes dans le Groupe de Mannville au sud-est de la Saskatchewan. Dans cette région, le Mannville est une unité de stratigraphie complexe, formée de dépôts marins à fluviatiles qui, bien qu'ils n'y présentent pas de possibilités d'hydrocarbures, ont de nombreuses similitudes avec des strates de période équivalente dans des régions de production d'huile lourde. Des principes de séquences stratigraphiques en sismique nous ont permis de subdiviser le Mannville en trois paquets. La capacité de visualiser les données sismiques en 3-D sous plusieurs angles, incluant les lignes arbitraires et les techniques de coupes stratales ou d'horizon nous ont aidés à définir les caractéristiques stratigraphiques qui pourraient affecter le débit des fluides dans les zones de production d'hydrocarbures. Ces caractéristiques incluent des canaux de dimensions et d'orientations variables, et des éléments de canaux, tels que des bourrelets arqués et des surfaces d'accrétions latérales, qui sont présents à l'intérieur des portions spécifiques du Groupe. L'efficacité des méthodes de récupération assistée, tel que le drainage par gravité utilisant la vapeur, repose sur la faculté de l'équipe de développement à reconnaître l'hétérogénéité du réservoir. Ainsi, l'intégration de la sismique en 3-D similaire, avec les diagraphies et d'autres types de données pourraient aider grandement au développement du Mannville dans les zones d'huile lourde. Il existe une correspondance proche, mais non "une pour une", entre les unités stratigraphiques que nous avons définies et celles qui ont été établies à partir de corrélations régionales de diagraphies et de carottes. Les problèmes de résolutions sismiques ou les styles de corrélation avec les diagraphies peuvent être responsables des différences.

Traduction de Gabrielle Drivet

## Introduction

The lower Cretaceous Mannville Group has been the focus of many previous studies because it is one of the most prolific hydrocarbon intervals within the Western Canadian Sedimentary Basin. To date, geological studies of the Mannville Group in the province of Saskatchewan have been based on logs and core data. These studies (e.g., Christopher, 2003; Leckie et al., 1997) focused largely on depositional environments and stratigraphy at a regional scale. This paper will illustrate how 3-D seismic and well data may be integrated at a development-project scale to define stratigraphic units and depositional facies in complex units such as the Mannville Group.

Seismic images derived from 3-D volumes have proven to be very useful for imaging stratigraphic units and depositional architecture (e.g., Brown, 1999; Posamentier, 2004). Despite these successes elsewhere, we were unable to find previous publications that specifically examined the stratigraphic architecture of the Mannville Group using 3-D seismic data. In areas where enhanced recovery methods such as steam-assisted gravity drainage (SAG-D) or other methods are used, it is important to be able to predict lithologic heterogeneity associated with depositional features such as inclined heterolithic strata (IHS) and channel fills because these features potentially affect the movement of hydrocarbons and injected fluids. These features are best defined with the combined use of 3-D seismic and well-log data and can be even better defined in heavy-oil development areas where the wells are closely spaced.

The study area is located in the southeastern region of the province of Saskatchewan, in Townships 6 to 7, Ranges 9 to 10. The seismic and well data presented in this paper were collected to explore for and develop deeper targets — primarily Mississippian carbonates. The Mannville Group in the study area is wet, and is not considered to be a drilling target for hydrocarbon accumulations. Nevertheless, the seismic data quality is very good at the Mannville level and the data allow us to image depositional features that are analogous to those found in heavy-oil producing areas. As a corollary objective, we established correlations between stratigraphic units defined through our integrated seismic/log interpretations and formations identified by regional correlations (e.g., Christopher, 2003).

## Geological Setting

The study area is in the northern part of the intra-cratonic Williston Basin (Fig. 1). The interval of interest is the Lower Cretaceous Mannville Group, which forms part of the Lower Zuni Sequence that was deposited in the Western Canadian Foreland Basin (Cant, 1989). Previous studies of the Mannville Group divided it (from oldest to youngest) into the Success, Cantuar and Pense formations. Recent studies (Christopher, 2003) exclude the Success Formation (Jurassic to Neocomian) from the group and leave only the Cretaceous Aptian to Albian Cantuar and Pense formations as part of the Mannville Group (Fig. 2).

Cant and Abrahamson (1996) interpreted the Mannville Group as a third-order sequence overlying a second-order sequence boundary that represents a major reorganization of the foreland basin and the Cordillera. This Alberta-based interpretation divides the succession into transgressive and highstand systems tracts with a maximum flooding surface placed at the base of the Clearwater shales (Fig. 2). The transgressive portion in the Alberta region was defined as the Lower Mannville, Dina and Cummings formations, with units above the Clearwater Formation being assigned to the highstand systems tract.

The Williston Basin subsided during the Jurassic and then during Late Jurassic time the basin was filled and the area experienced regional uplift (Poulton et al., 1994*).* The S1 Member of the Success Formation was deposited at this time. Neocomian tectonic uplift of the Swift Current Platform and Sweetgrass Arch (Fig. 1) reversed the southerly topographic slope of the Jurassic Williston Basin, forming a major unconformity (Christopher, 1997). The S2 member of the Success Formation is separated from the S1 member by this regional sub-Cretaceous unconformity (Fig. 2). The present patchy distribution of the Success Formation is the result of later pre-Mannville erosion (Christopher, 2003).

The Williston Basin did not actively subside during the Cretaceous, and Mannville deposition took place over top of a profound unconformity that truncated Lower Cretaceous to Paleozoic strata (Hayes et al., 1994). During Aptian time, the sea invaded from the north and eventually covered the pre-Mannville topography. The Cantuar Formation, the lowest unit within the Mannville Group in this area, was deposited during late Aptian and early Albian time, and covers the underlying topography of pre-existing valleys and terraces (Christopher, 2003). The Cantuar Formation, comprising six members in southeast Saskatchewan (Fig. 2) with hiatuses and erosional discontinuities, underwent several marine transgressions

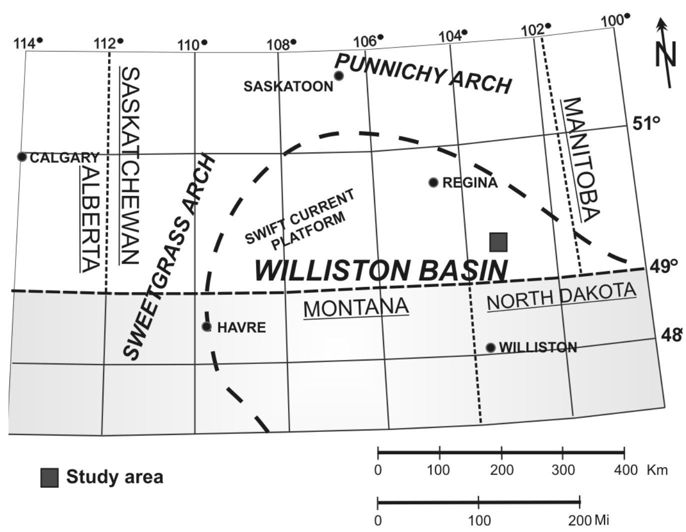


**Fig. 1.** Location of the study area in southeastern Saskatchewan. The figure also shows the location of the main structural elements of the region, including the approximate outline of the Williston Basin.

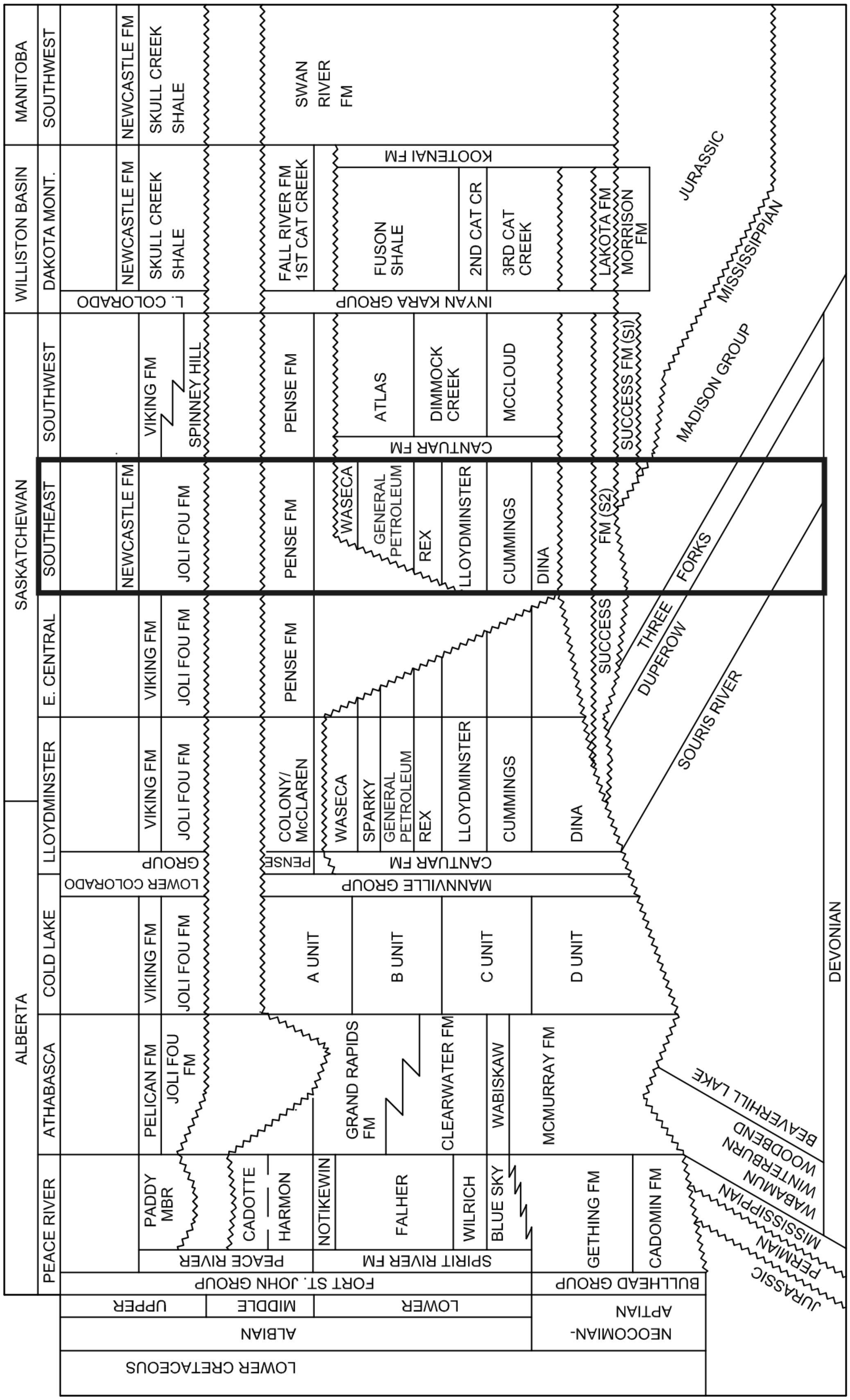


**Fig. 2.** Correlation chart of the Mannville Group (modified from Christopher, 2003). Stratigraphic nomenclature for southeast Saskatchewan is highlighted by box.

(Christopher, 2003). Uplift of the Punnichy Arch terminated Cantuar deposition and marine erosion removed poorly consolidated sediments of the Cantuar in the early Albian. Marine deposits of the Pense Formation were deposited above the Cantuar Formation as the Pense seaway flooded across Saskatchewan during a period of sea-level rise during the middle Albian (Christopher, 1997).

## Database and Methodology

The database for this project consists of a 3-D seismic survey covering 56 square kilometres, digital well-logs for 47 wells and paper logs for 16 additional wells (Fig. 3). The 3-D seismic survey has a bin size of 30 m by 30 m, a sample rate of 2 milliseconds, and a trace length of 3 seconds two-way time (TWT). The 30-fold seismic survey was acquired using a dynamite source in 1997. Seismic bandwidth ranges from 10 to 85 Hz at the Mannville level with a peak frequency of approximately 50 Hz. The vertical resolution of the data (defined as 1/4 of the wavelength) is approximately 12 m, calculated using log-derived velocities of 2300 m/sec in the interval of interest. Gamma ray (GR) logs were available for some of the wells, but the majority of the well correlations presented herein are based on spontaneous potential (SP) and resistivity log signatures.

Synthetic seismograms, such as those shown in Figure 4, were generated for the 15 wells that had sonic logs. These well ties allowed stratigraphic units defined in the wells to be correlated to the seismic data, and seismically defined surfaces to be identified in the wells. Well log cross-sections and corresponding seismic transects through the 3-D cube were interpreted throughout the area to generate a stratigraphic framework. Time slices (i.e., planes of constant TWT), horizon slices (i.e., images showing amplitude variations along seismic horizons, also known as "amplitude maps") and stratal slices (i.e., slices through the seismic cube that run parallel to overlying or underlying seismic horizons, cf. Zeng et al., 1998, 2000; stratal slices were termed "flattened time slices" by Posamentier, 2004) were extracted from the data volume to map and observe the spatial geometry of features interpreted on vertical seismic transects and log cross-sections. The horizons used to generate the stratal slices needed to be continuous throughout the 3-D survey and to correspond to depositional surfaces that were originally nearly horizontal (i.e., flooding surfaces can be appropriate choices, whereas unconformities or channel bases are poor choices). Because they eliminate the effects of regional dip (or other tectonic disturbance), stratal slices are preferred over simple timeslices for mapping stratigraphic features of interest.

Seismic stratigraphic and sequence stratigraphic principles, described by Mitchum et al. (1977), Vail et al. (1977), Posamentier et al. (1988), Bertram and Milton (1994) and others, were used to define key stratigraphic surfaces such as unconformities and flooding surfaces, and to establish the stratigraphic framework for the integration of seismic and well-log data. As described below, some surfaces were defined seismically as "candidate unconformities" based on truncated and onlapping reflection terminations as shown in Figure 5a, whereas other stratigraphic surfaces were defined based on a combination of well-log and seismic information (Fig. 5b). Although the definition of "candidate unconformities" might seem unusual, a true unconformity is associated with a significant hiatus, something we cannot demonstrate with only log and seismic data. Flooding surfaces were identified within marine shale intervals based on the combination of high gamma ray (where present) and low resistivity log signatures.

No core data exist for the water-saturated Mannville Group in the study area; consequently, and as illustrated below, we integrated seismic geomorphology techniques (i.e., the study of depositional systems using 3D-seismic derived images; Posamentier, 2000) with seismic facies and wireline log shapes to infer lithology and depositional environments in this paper. Posamentier (2004) showed images of sedimentary features interpreted as fluvial scroll bars and channels, which may be identified by their morphology in timeslices and stratal slices. Other authors have also used this approach. For example, Brown (1999) presented examples of meandering channels, point bars and crevasse splays in slices through 3-D seismic volumes.

## Interpretation

Christopher (2003) presented regional correlations of the Mannville Group in Saskatchewan, and his correlations were used in this study to identify the lithostratigraphic units present in our study area. Figure 6 incorporates wells from cross-sections C–C′ and D–D′ of Christopher (2003) with wells from

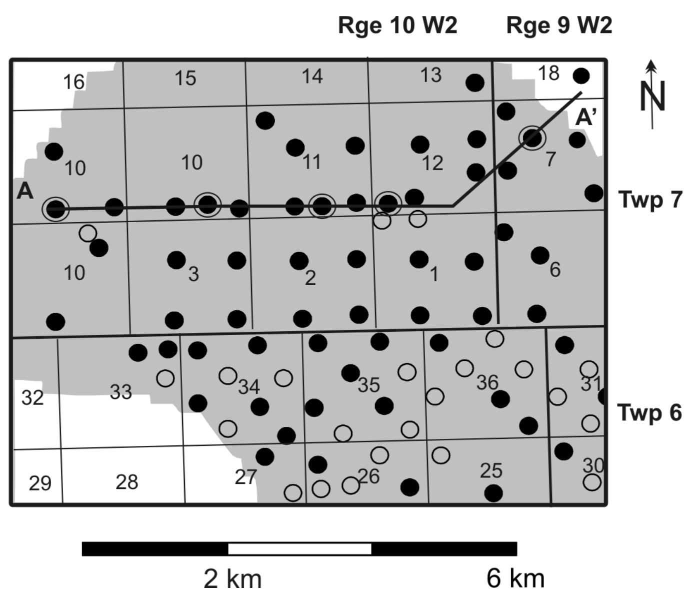


**Fig. 3.** Base map showing outline of 3-D seismic survey and well locations. Filled dots correspond to the wells used in the study. Location of cross-section A–A′ is indicated in the map. Circled filled dots show the wells in cross-section A–A′.

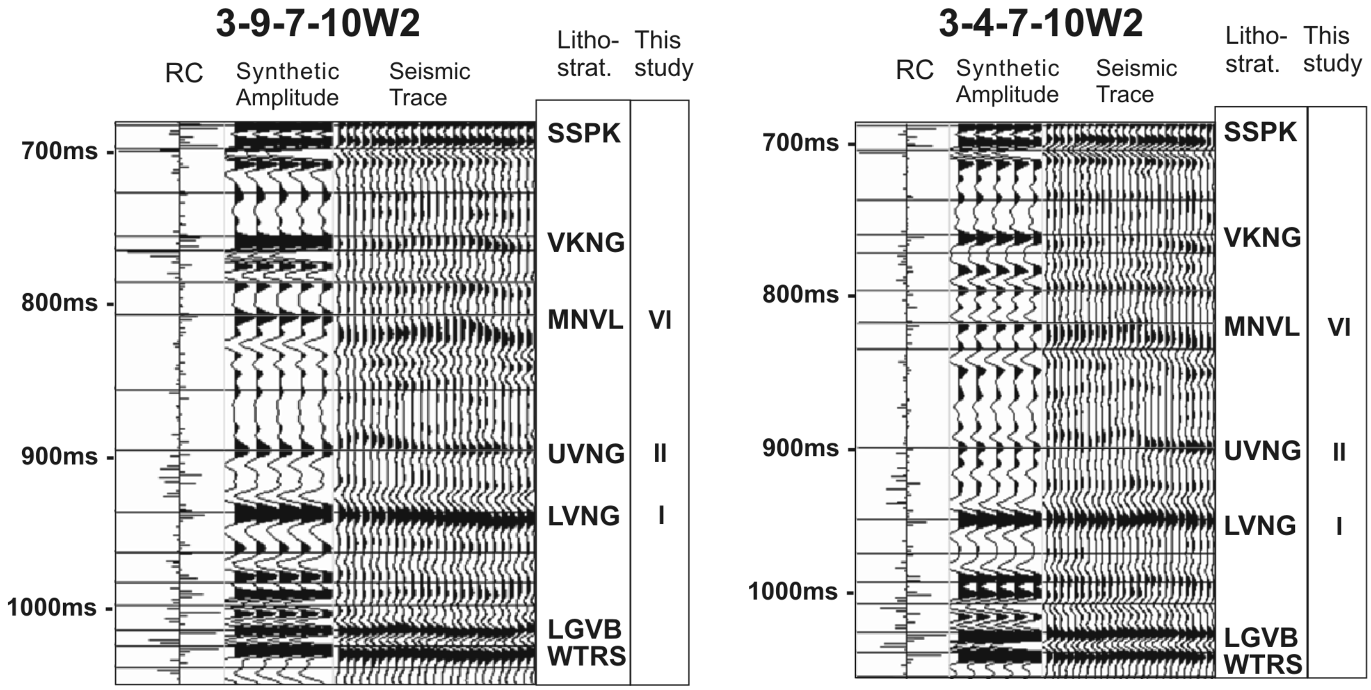


**Fig. 4.** Examples of synthetic seismograms used to tie the well logs to the seismic data. Abbreviated formation names shown are: SSPK – Second White Speckled Shale, VKNG – Viking, MNVL – Mannville (corresponds to Surface IV in this study), UVNG – Upper Vanguard (corresponds to Surface II), LVNG – Lower Vanguard (Surface I), LGVB – Lower Gravelbourg, WTRS – Watrous.

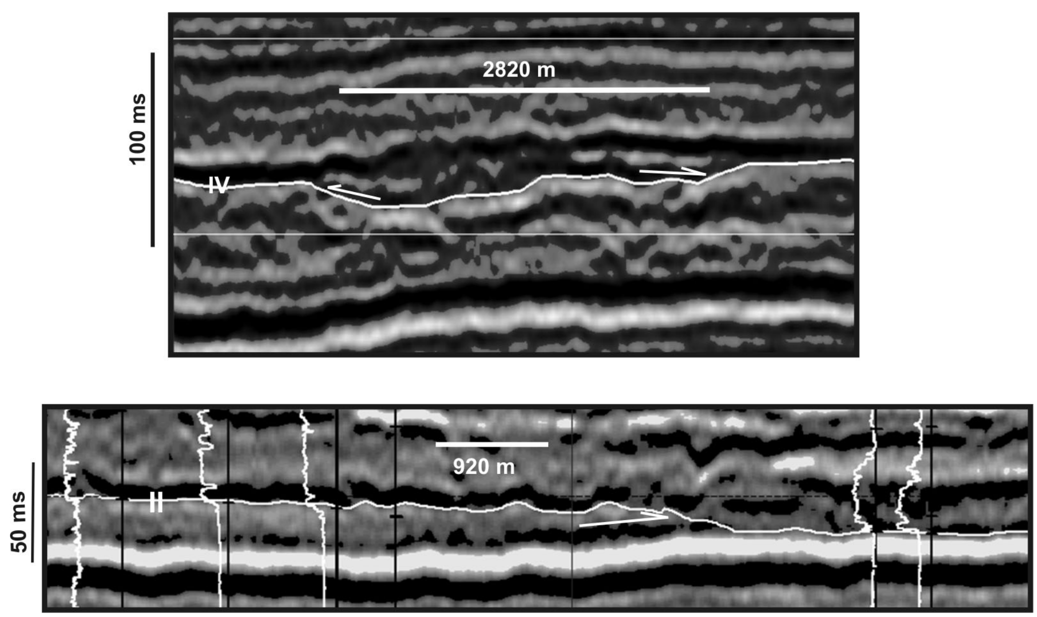


**Fig. 5. a)** (upper image) Sample seismic transect showing the use of onlapping reflections to identify an unconformity. This unconformity corresponds to Surface IV (e.g., Fig. 8). **b)** (lower image) Example of the combined use of logs and seismic data to define an unconformity. Reflection truncations correspond to the base of a sharp-based sandbody. This surface (Surface II) corresponds to the sub-Cretaceous unconformity that separates Jurassic rocks from overlying Cretaceous units of the Success Formation and Mannville Group. (e.g., Figs. 6–8).

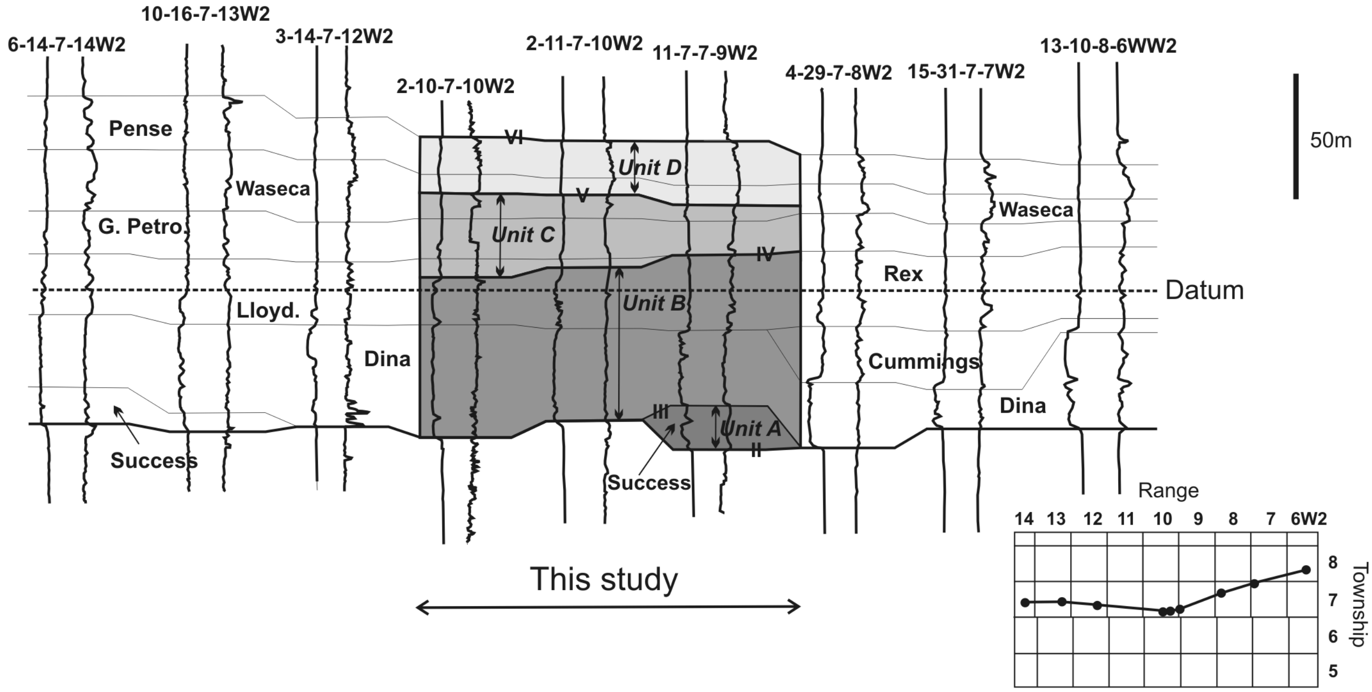


**Fig. 6.** Stratigraphic cross-section through southeastern Saskatchewan showing the relation between the lithostratigraphic units described by Christopher (2003) and the seismic units defined in this paper. The wells used by Christopher are on the extremes of the cross-section and the wells from the 3-D seismic study are located in the central part of the correlation. Greytones highlight seismic stratigraphic units defined in this paper. For each well the geophysical logs shown are Spontaneous Potential (left) and Resistivity (right). G. Petro – General Petroleum Member and Lloyd – Lloydminster Member.

our study area and intervening areas. The type log for the present study area (Fig. 7) shows the relationship between the lithostratigraphy of Christopher (2003) and the seismically defined surfaces picked in this study. As defined below, seven main surfaces, labeled I to VII, were defined in this study; each surface corresponds to a lithologic contact in logs. These changes in lithology are associated with changes in rock physical properties that generated the seismic reflections identified in this study. Figure 8 shows a representative well-log cross-section and corresponding seismic transect across the study area.

Surfaces I and VII underlie and overlie the Mannville Group, respectively. They were picked as stratigraphic markers to “bracket” the Mannville and to generate stratal slices. Our synthetic seismograms show that Surface I corresponds to the top of the Lower Vanguard (part of the Jurassic System shown in Fig. 2). This surface is located at the base of a shale interval (Fig. 7) and is a high-amplitude continuous reflection seen in seismic transects (Fig. 8). Surface VII is a flooding surface in the Joli Fou Formation. In logs, this surface corresponds to high gamma ray log values (where this log is available) and a low-resistivity marker within this shale package. Surfaces II and VI correspond to the base of the Cretaceous section and top of the Mannville Group, respectively, according to our synthetic seismograms (Fig. 4) and correlations with the stratigraphic framework established by Christopher (2003; Figs. 6, 7). Within the Mannville, the low gamma ray (GR) or high spontaneous potential (SP) and low (lower than shale) resistivity values seen in the well-logs are interpreted as water-saturated sands.

We identified three seismic packages within the Mannville Group that overlie a fourth Lower Cretaceous package. These packages, labeled Units A to D, are shown in Figures 6 to 8 and their lithologic and stratigraphic character is described next.

## Unit A

### *Description*

This unit is bounded by Surfaces II and III, and characterized by a parallel to semi-parallel fill reflection pattern (Fig. 8). Surface II, the sub-Cretaceous unconformity (Figs. 2, 6–8) truncates underlying seismic reflections and does not correspond to a continuous seismic reflection. Seismic transects and a time-structure map (Fig. 9) show that Surface II cuts down towards the east, defining the margin of an approximately NNE–SSW striking incision. The amount of incision is estimated to be up to 38 m from well log data. Logs through Unit A show that the incision is filled with sand and shale. Figures 8 and 5b show the seismic and wireline log criteria, including truncation of underlying reflections and sharp-based sands in logs, used to define Surface II as a candidate unconformity. Surface III is defined by the top of a discontinuous trough on the seismic data and by the well-log signature (see the base of blocky sands in Figs. 7, 8). Surface III overlies Surface II in the incision, but the two surfaces merge outside of the incision to the west.

### *Interpretation*

Unit A, bounded by Surfaces II and III, is interpreted to be the Success (S2) Formation. This formation has a patchy distribution in the basin due to the unconformities that affected the region (Christopher, 2003) and its presence within the incision observed in the study area seems reasonable. The incision at the base of the unit (delineated by Surface II) is probably part of the Assiniboia drainage pattern that generated the pre-Mannville topography (Christopher, 1984) and our 3-D survey appears to image part of the western margin of a larger incision. Surface III (Fig. 8) corresponds with the erosional surface that caps the Success S2 Member (Fig. 2), which has been observed in cores in southern Saskatchewan and was described by Christopher (1997) and Leckie et al. (1997).

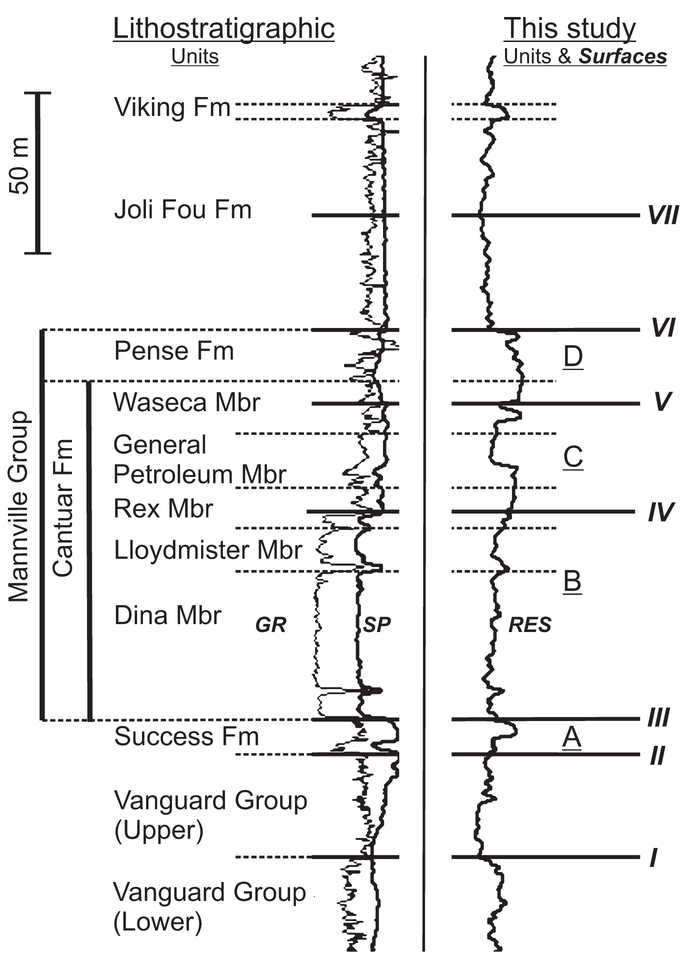


**Fig. 7.** Type Log for the area showing (to the left of the logs) the relation with the lithostratigraphic units described by Christopher (2003) and (to the right of the logs) the surfaces and units defined in this study.

## UNIT B

### *Description*

Unit B (Figs. 6–8) is bounded by Horizons III and IV, and shows a parallel fill in the western region and a more chaotic pattern in the central region of the study area. Logs indicate that it ranges from 56 to 86 m thick and that the basal part of the section is generally sandy. Well logs near the top of this package show a heterolithic fill consisting of sands interbedded with shales and some intervals show bell-shaped log profiles. The lithology changes laterally, in places over distances of hundreds of metres. A stratal slice in the middle of this unit (Fig. 10) shows amplitude lineaments that have variable widths (typically <300 m) and run in several directions. The lineaments correspond to the stratigraphic level of the lithologic variability seen in the logs.

Another stratal slice through the middle of Unit B shows a series of arcuate features in the northeast part of the survey that correspond to subtle north-dipping reflections in seismic transects (Fig. 11). These features are traceable for approximately 3 km in the stratal slice.

### *Interpretation*

Unit B encompasses the Dina and Lloydminster members of the Cantuar Formation (the Cummings Member is generally absent in this area; Fig. 6) and part of the Rex Member. Surface IV falls within the Rex, as seen in Figures 6 and 7.

We interpret many of the features visible in the stratal slices to be channels or channel elements. Posamentier (2004) showed channels with morphologies similar to those seen in this unit that he interpreted as Cretaceous fluvial systems in the Western Canada Sedimentary Basin. Zeng et al. (1998, 2000), Hardage and Remington (1999) and Miall (2002) have also shown 3-D seismic images of channel systems. The non-marine nature of the lower part of the Mannville Group has been established both in Saskatchewan (Christopher, 1997; Leckie 1997; Smith, 1994) and Alberta (Cant and Abrahamson, 1996) and so the presence of fluvial channels at this level is reasonable.

The arcuate features shown in Figure 11 are interpreted as scroll bars produced by point bar migration in a meandering river system. This interpretation is consistent with the dipping reflections seen in the seismic transect that are interpretable as lateral accretion surfaces. The curvature of the features seen in the horizon slice together with the dip in the reflections in the seismic line, indicate point bar migration to the north. Well-logs that cut the feature (Fig. 11) show a bell-shaped log signature (abrupt base and fining upward) 15 m thick (i.e., at or slightly above tuning thickness) that is typical of point bar deposits (Cant, 1992). The presence of point bar deposits (e.g., lateral accretion surfaces, scroll bars) in the upper part of the unit is consistent with the observations of Leckie et al. (1997) who noted that the upper portion of the Cantuar comprises meander belt, floodplain and estuarine deposits in south-western Saskatchewan.

Seismic data show incision associated with Surface IV that would be consistent with it being an unconformity (Figs. 5, 8) close to the top of the Rex Member. No unconformity has been recognized at this level on a regional basis (e.g., Christopher, 2003), and so it appears that Surface IV corresponds to a local erosional surface of relatively minor stratigraphic significance.

## Unit C

### *Description*

Unit C is between Surfaces IV and V, and shows a parallel fill pattern in some areas but in other areas (e.g., Fig. 12) it is characterized by an oblique-tangential reflection pattern. A stratal slice through Unit C (Fig. 12) displays several arcuate, semicircular features approximately 5 km long, at least 2.5 km across, and corresponds to an oblique-tangential reflection configuration on seismic transects that cross them. Figure 13 shows a NW–SE to E–W oriented curvilinear amplitude anomaly, approximately 400 m wide, that is present near the top of this unit in the southwestern part of the 3-D survey. The anomaly is penetrated by a single well filled with sand at this interval. Elsewhere, this stratigraphic level is shaly.

### *Interpretation*

Unit C encompasses the top of the Rex Member, the General Petroleum Member and part of the Waseca Member (Figs. 6–8). Like the underlying Unit B, the seismic and well-log data for this interval indicate a heterolithic fill dominated by channel deposits of various types. The stratal slice and east-dipping reflections in the seismic transect (Fig. 12) suggest eastward migration of a point bar. Note that the log of the well in the west indicates that the base of this unit is sandy in the area of the scroll bars, whereas the well to the east shows the base of the unit to be shaly in that area. The feature shown in Figure 13 is interpretable as a small channel. The channel has a positive relief that is probably the result of differential compaction between a sandy fill and the shales around it.

Surface V corresponds to an unconformity close to the top of the Cantuar in our lithostratigraphic correlation (Fig. 6, 7). Although it does not correspond exactly with the Pense–Cantuar contact, it is close and so Surface V could correspond to the unconformity of Christopher (2003) that locally eroded the entire Cantuar Formation. Wallace-Dudley et al. (1998) suggested that it is a ravinement surface or a sequence boundary. Toplap seen in Figure 12 supports the interpretation of this surface as an erosional unconformity.

## Unit D

### *Description*

Unit D is between Surfaces V and VI, and displays a nearly parallel fill in some areas, but also shows areas that are reflection

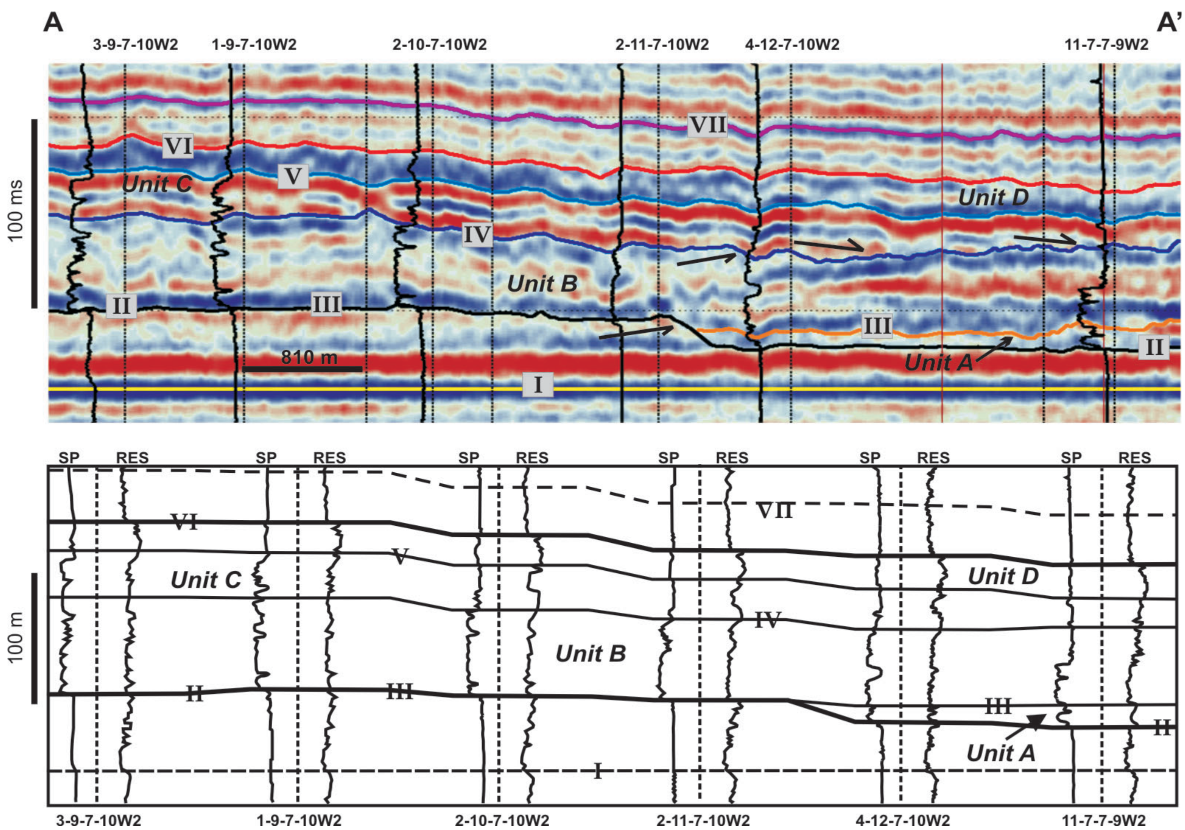


**Fig. 8.** Seismic transect and corresponding stratigraphic cross-section A-A′. The seismic and well log profiles show the key surfaces interpreted in this study (labeled I to VII). Surfaces VII (a flooding surface in the Joli Fou) and I (a log marker separating the Upper and Lower Vanguard units) are shown together with Surfaces II to VI and Units A–D. One-sided arrows highlight reflection terminations typical of those used to define stratigraphic surfaces. Location of the A-A′ cross-section is shown in Figure 3. Surface I is the stratigraphic datum in both sections.

free (Mitchum, 1977). Unit D does not show significant amplitude trends in time slices or stratal slices, although a small, approximately N–S oriented, meandering channel is observed near the base of the unit (Fig. 14).

### *Interpretation*

According to correlations presented here (Figs. 6–8), Unit D corresponds to the Pense and upper part of the Waseca formations. The parallel to transparent fill and general lack of channel features in seismic profiles through most of this interval is consistent with a shaly, shallow-marine depositional setting where stratification is more continuous than in fluvial or estuarine deposits. Wallace-Dudley et al. (1998) interpreted a maximum flooding surface in the lower part of the Pense Formation. The channel observed at the base of the unit must be below that surface and the overlying shallow-marine Pense deposits.

Surface VI corresponds to the top of the Mannville Group. According to Christopher (1997, 2003) there is a hiatus at the top of the Mannville (Fig. 2) which corresponds to a regional unconformity that can be observed over all the Western Canadian Sedimentary Basin. However, Wallace-Dudley et al. (1998) described the surface at the top of the Mannville (our Surface VI) as a major flooding surface at the top of a regressive (highstand) systems tract. Our small 3-D seismic survey does not show evidence (e.g., erosional truncation, onlapping reflections) that would support either interpretation.

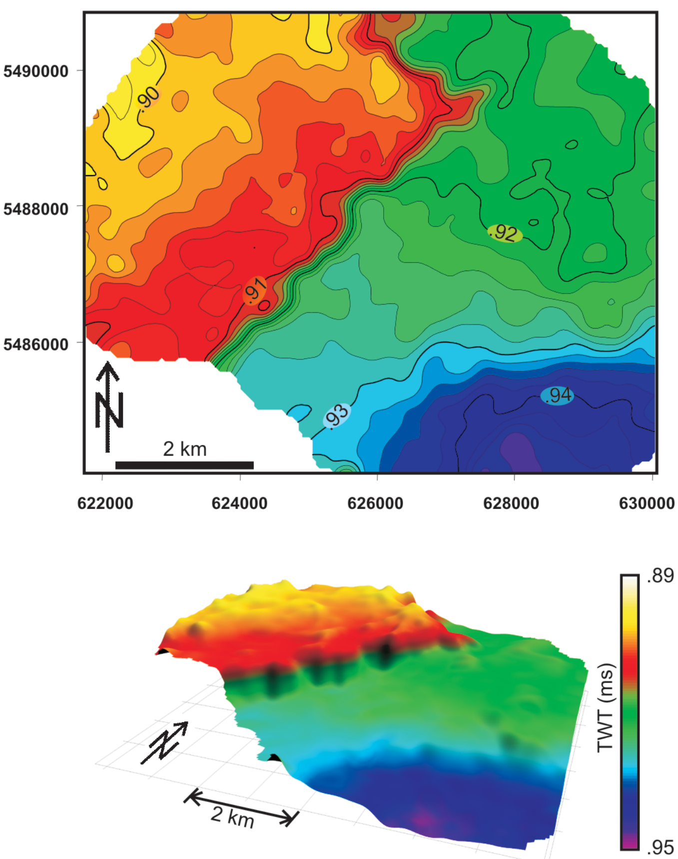


**Fig. 9.** Time-structure map (top) and perspective view (below) of Surface II, showing what may be the western margin of a valley of the Assiniboia drainage network. Map contours in seconds, two-way traveltime (TWT). Coordinates are UTM (Zone 13).

## Discussion

The data presented in this paper illustrate the value of 3-D seismic data for pool-scale stratigraphic correlation and mapping of depositional features, especially in heavy oil exploration and development areas where our results have most relevance. Although the Mannville is water saturated in our study area, the seismic images and log profiles presented in this paper show stratigraphic features similar to those interpreted from well logs and cores in heavy oil and oil sands areas (e.g., Van Hulten, 1984; Strobl et al., 1997). Additionally, the size of the 3-D seismic survey studied in this paper is comparable to the size of SAG-D development projects. We frame the remainder of the discussion in terms of the utility (a) integrating 3-D seismic data into stratigraphic studies, and (b) using 3-D seismic data for definition of stratigraphic features.

Leckie et al. (1995) stated that, in southern Saskatchewan, detailed stratigraphic correlations within the Mannville Group based on well-log control alone are imprecise and highly suspect. It is clear that, given the lateral facies variability seen within channelized deposits of the Cantuar Formation, detailed log-based correlations in the current study area would be ambiguous at best. The seismically defined stratigraphic packages show considerable internal lithologic heterogeneity and stratal slices show many stratigraphic features (e.g., channels) that are too narrow and sinuous to be accurately mapped with logs.

There appears to be close, but not one-to-one, correspondence between the surfaces we defined, by integrating seismic and log data, and those defined through correlations with the regional stratigraphic framework of Christopher (2003). Possible reasons for these differences include the following:

a) Problems with log-based correlations – Similar to Leckie et al. (1995), our experience suggests that log-based correlations of the Mannville can be ambiguous in this area, especially when they are based on different vintages and qualities of logs, and no corroborating core is present. Different correlations from those presented in Figure 6 are possible using available well control and log quality, but we have attempted to follow the correlation style of Christopher (2003). If our log picks can be changed, the stratigraphic units shown in that figure become less tabular (perhaps more realistic for fluvial/estuarine systems?) and all of our surfaces can be tied to those of Christopher (2003). Arguably, the stratigraphic geometries seen in the 3-D seismic data should influence correlation styles outside of the seismic survey area.

b) Seismic resolution problems – Regardless of correlation styles, it is clear that at least one of our units, defined by integrating 3-D seismic and log data, corresponds to more than one lithostratigraphically defined unit of the Mannville Group in

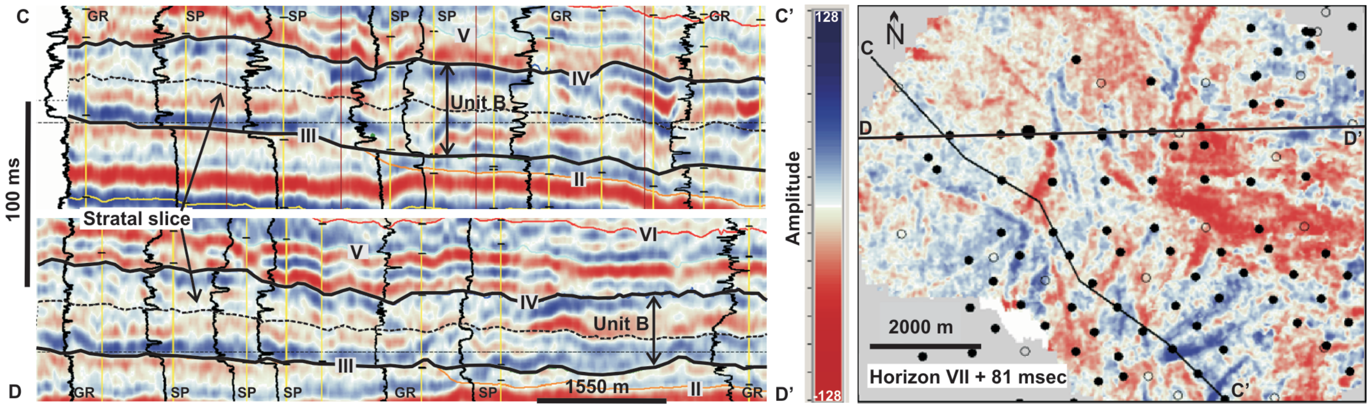


**Fig. 10.** Seismic lines C–C′ and D–D′ show the chaotic and semi-parallel fill reflections of Unit B as well as the location of the stratal slice (dotted line) through sand and shales of Unit B. Note the lateral variability in the log signature in Unit B, testifying to lateral lithologic heterogeneity in this interval. The stratal slice corresponds to a slice through the data 81 ms below Surface VII, and shows crossing and curvilinear amplitude trends that are interpreted as fluvial channels that run in various directions through the area.

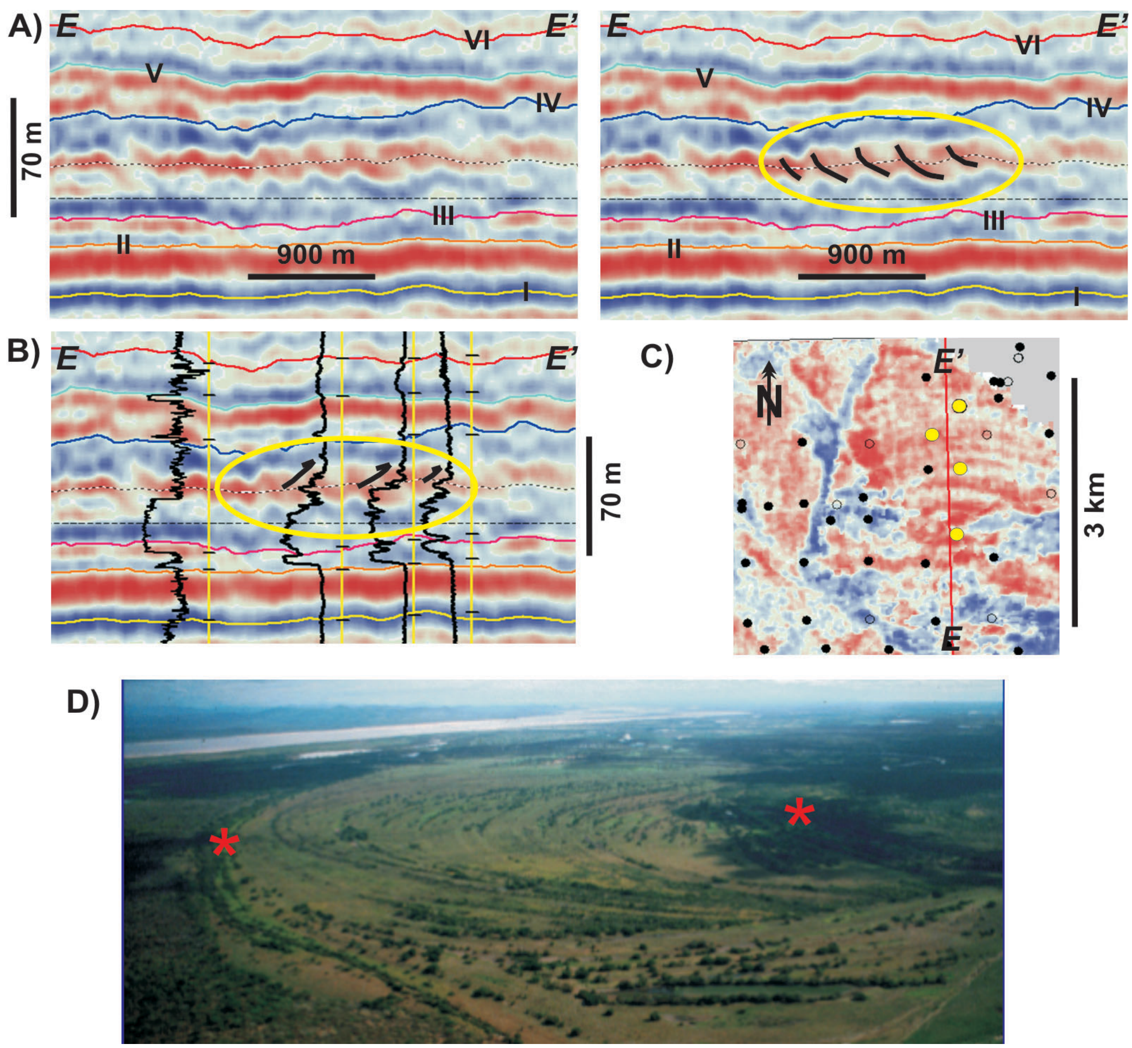


**Fig. 11.** Seismic images of a point bar. **A)** Uninterpreted (left) and interpreted (right) north-south seismic profile E–E′ shows a series of shingled troughs (yellow oval) that dip subtly to the right. Interpreted view highlights dipping reflections that represent lateral accretion surfaces. **B)** Same view as in A but with Gamma Ray log overlay. Note the fining-upward signature of the logs (arrows) in this interval. **C)** In a stratal slice, the lateral accretion surfaces correspond to arcuate amplitude trends that are similar in scale and shape to modern scroll bars. **D)** Example of modern scroll bars on the floodplain between the Apure and Apurito rivers in Venezuela; the distance between the asterisks is 3 km (Photo courtesy of R.H. Meade, USGS). Level of the stratal slice is indicated by the dashed line in the seismic profiles.

this area (i.e., Unit C corresponds to several members of the Cantuar Formation). It is possible that the relative thinness of the members and low acoustic-impedance contrasts between the deposits of some members combine to make the units unmappable using seismic data.

We argue that integration of 3-D seismic and log data allows the identification and stratigraphic mapping of bounding surfaces in the Mannville with much more confidence than is possible using either data type alone. Seismic surfaces and reflection configurations impose constraints and suggest log correlation options. We note that, because of its small size, the 3-D survey used in this study may not show all the diagnostic reflection terminations that are useful for seismic-based sequence stratigraphy (e.g., Mitchum et al., 1977; Emery and Myers, 1996). This will be a problem for other stratigraphic studies that use similar-sized 3-D seismic surveys. Regional log correlations help to determine whether erosion surfaces observed in these data represent local incision or stratigraphically significant surfaces (unconformities). Whatever their origin, and because any of these surfaces can juxtapose depositional facies associated with differing porosity and permeability, their recognition would be relevant as they could be associated with flow-unit boundaries in producing areas (e.g., Reynolds, 1996). The addition of core control would provide further insights by aiding in the interpretation of depositional facies (e.g., distinction between estuarine and fluvial channels), providing (possibly) biostratigraphic control, and with recognition of key stratigraphic surfaces. Unfortunately no core exists from the Mannville Group in the study area.

The other benefit of 3-D seismic data is the possibility of using seismic geomorphology and well logs to define and map stratigraphic features that can act as lateral barriers, baffles or conduits for fluid flow. 3-D interpretation technology allows the user to pick the orientation of seismic profiles that best images the stratigraphic features of interest. For example, lateral accretion surfaces are best imaged in seismic profiles that are perpendicular to them, and can be missed on profiles that have other orientations. Stratal slices showing scroll bars can be used to determine the optimum orientation for examining vertical transects. The lateral accretion surfaces illustrated in this paper have multiple orientations and are subtle in vertical transects through the 3-D cube. However, their presence is supported by stratal slices showing scroll bars, and by the characteristic bell-shaped log signatures typical of point bar deposits. If a grid of 2-D seismic lines is available from an area that has multiple orientations of point bars, it is highly probable that not all of the lateral accretion surfaces would be oriented perpendicular to the seismic lines, making their identification more difficult. The ability to extract time slices and stratal slices through 3-D volumes allows the interpreter to identify channels and morphologic features associated with channels, of various dimensions, that would probably be missed using logs or 2-D seismic data. These stratigraphic features are likely to have an impact on fluid flow (steam, hydrocarbons, etc.) in the subsurface.

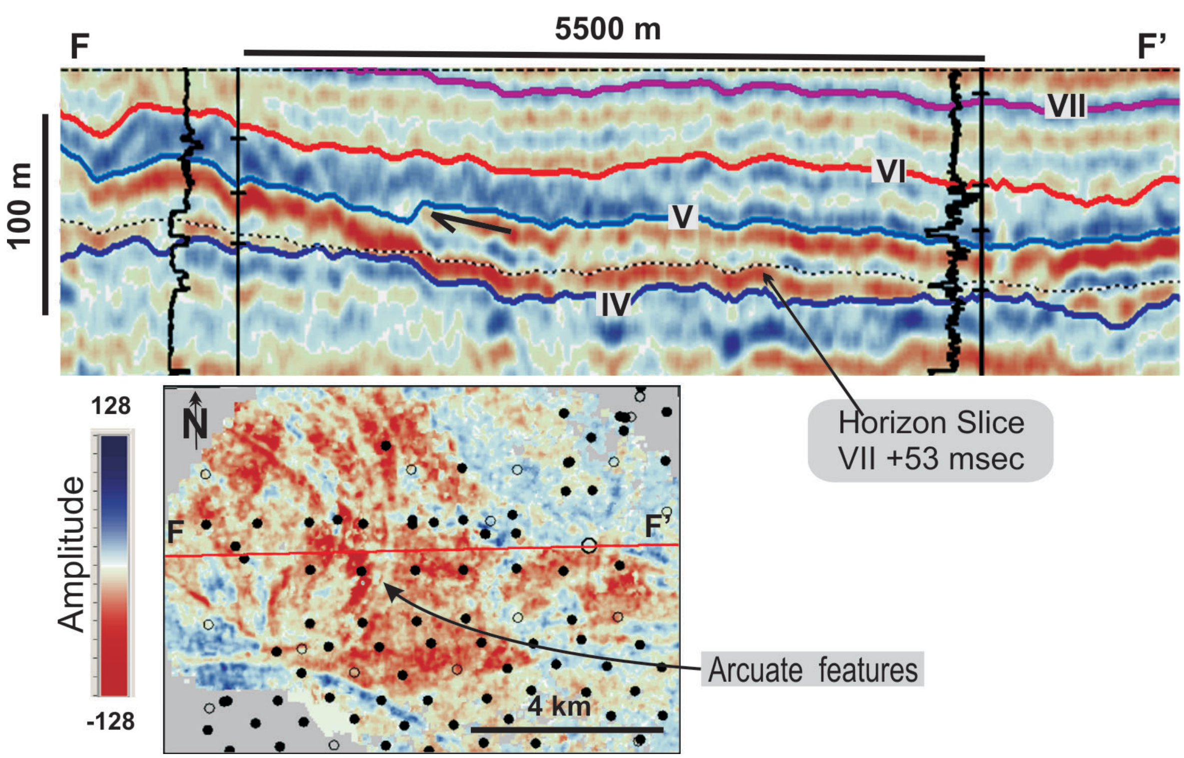


**Fig. 12.** Seismic profile F–F′ shows the oblique-tangential reflection configuration of Unit C and the location of a stratal slice that cuts across the features at its base. The stratal slice (53 ms below Surface VII) displays arcuate figures in the western part of the survey that are interpreted to be scroll bars (e.g., Fig. 11) of a meandering channel system. The upper arrow highlights possible toplap below Surface V. Unit C is located between Surfaces V and IV.

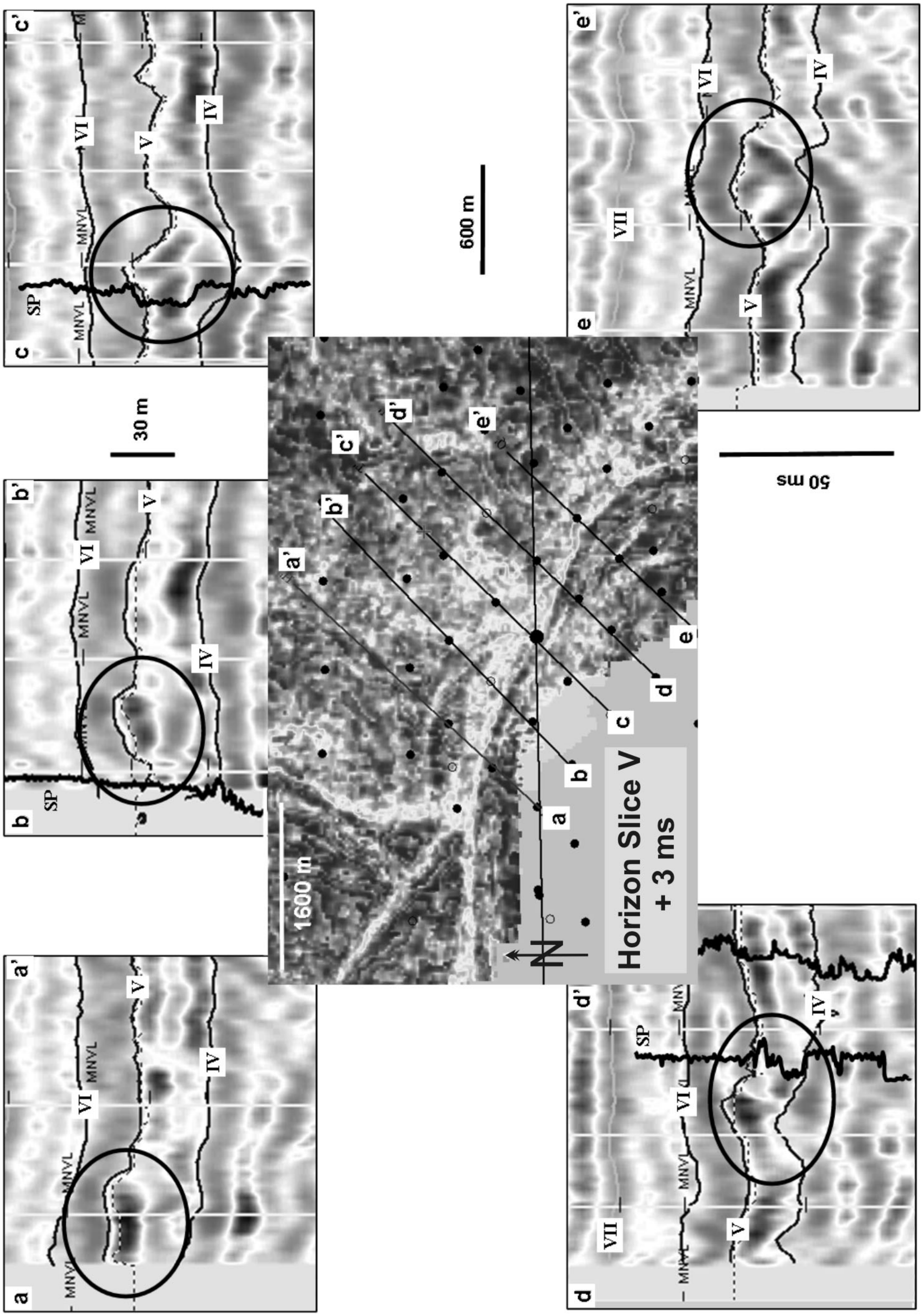


**Fig. 13.** Sequential seismic transects crossing a positive-relief, arcuate channel in Unit C. Channel location is circled in all transects. One well (shown in transect c–c') penetrates the channel and shows the channel to be sandy at that location. Elsewhere, the equivalent stratigraphic level is shaly (e.g., logs in transects b–b' and d–d'). The positive relief is, therefore, thought to be associated with differential compaction between the sand-filled channel and the surrounding shales. The stratal slice location is shown with a dashed line in the seismic profiles. Unit C is located between Surfaces V and IV.

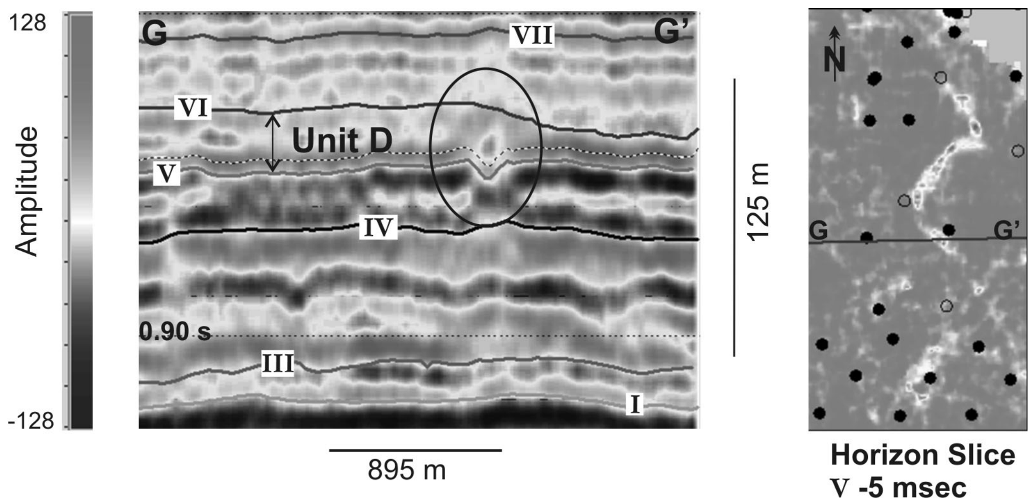


**Fig. 14.** Stratal slice 5 ms above Surface V showing a curvilinear feature interpreted to be a channel around 140 m wide at the eastern region of the seismic survey. The stratigraphic location of the stratal slice and the feature are displayed in the seismic profile G–G′.

## Conclusions

The integration of 3-D seismic data and well-log data proved to be an excellent tool to display and interpret the complex stratigraphy of the Mannville group in southeastern Saskatchewan. Four candidate unconformities and one flooding surface were recognized and mapped for the Mannville Group and adjacent stratigraphic units. Definition of these surfaces allowed us to divide the Mannville into three stratigraphic units, with the S2 Member of the Success Formation forming a fourth unit. Each unit displays different types of seismic facies that include parallel, semi-parallel, oblique-tangential, chaotic and reflection-free reflection patterns. Seismic facies from the vertical displays (traces and arbitrary lines) were combined with seismic geomorphology analysis of features seen in the horizontal slices (time slices and stratal slices) and log facies to interpret depositional features. Dimensions and aerial distribution of these features were obtained from the integrated dataset. For example, meandering channels in the Mannville are interpreted to vary in width between 100 and 600 m, and can be up to 30 m thick. Three kilometres of point bar migration, which generates stratigraphic features that can strongly affect hydrocarbon movement, were recognized in the northeast corner of the study area. A maze of channels that run in several directions through the study area, and characterize the middle strata of the Mannville Group, was interpreted from seismic time slices and well logs.

The channels, point bars, unconformities and other stratigraphic features identified in this study can affect the distribution and movement of fluids in the subsurface. Detecting and mapping similar features is especially important in heavy oil areas where enhanced recovery techniques are employed to stimulate production from the Mannville. It is important to note that integration of 3-D seismic and log datasets with core and production information would make the resultant reservoir models even more robust; unfortunately, such integration was not possible in this study.

Although the primary goal of this study was to focus on reservoir-scale definition of stratigraphic features, our results have significance for the stratigraphy of the Mannville Group in this area. The surfaces and units we defined using our integrated dataset do not correspond exactly to those defined through regional mapping. Although it is possible that seismic-resolution problems prevent us from identifying and mapping existing stratigraphic units, it is also possible that the stratigraphic framework of the Mannville in this area needs to be revisited.

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