Regional-scale Modelling of the Paleozoic Succession Beneath the Athabasca and Cold Lake Oil Sands Areas: Devonian Paleogeography, Evaporite Dissolution, and Controls on Cretaceous Depositional Patterns on the Sub-Cretaceous Unconformity

Introduction

The geology of northeastern Alberta accounts for a substantial percentage of hydrocarbon production within the province. Much of the geological focus in this area has been given to the Lower Cretaceous Mannville Group strata, in which vast bitumen and heavy oil deposits are found. With the exception of the carbonate-hosted bitumen deposits of the Grosmont Formation, less consideration has been given to the underlying Paleozoic succession, despite the fact that Devonian subcropping strata can form major aquifers in direct communication with the lower Mannville Group, and are a major control on the stratigraphic architecture of the overlying Cretaceous succession. The distribution and extent of Paleozoic strata, represented by Middle Cambrian to uppermost Devonian units, underlying 874 townships in northeastern Alberta have been updated based on detailed regional-scale lithostratigraphic mapping and modelling. Detailed correlation and modelling provide the basis to: 1) reassess regional paleogeography of the Keg River and Prairie Evaporite formations, 2) redefine the location of the Prairie Evaporite halite dissolution scarp, and assess the internal architecture therein, 3) model the sub-Cretaceous unconformity and delineate Paleozoic subcrop belts, and 4) demonstrate the control that various Paleozoic formations had on depositional patterns in the lower Mannville Group at the sub-Cretaceous unconformity.

Study Area

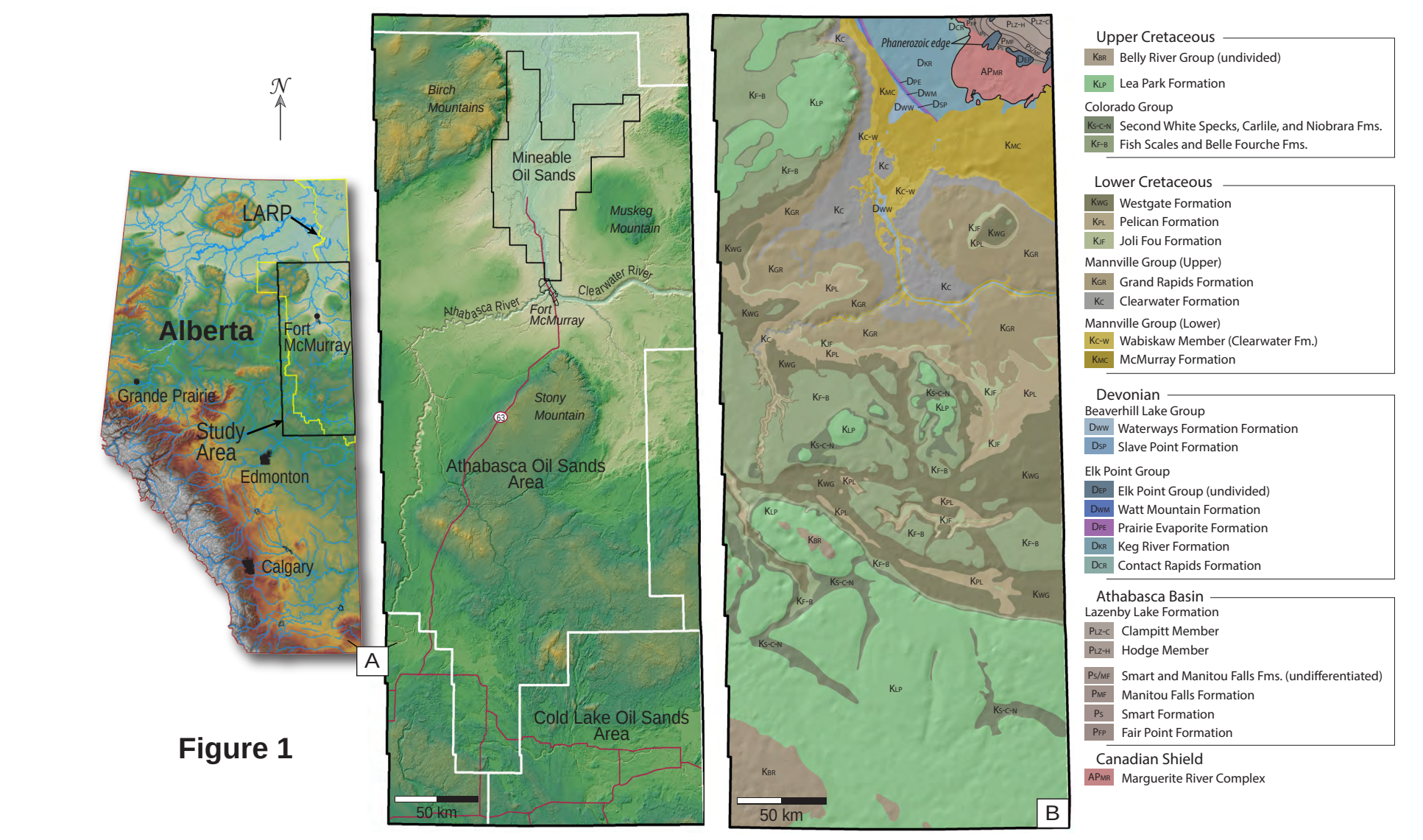

LARP
Alberta
Fort McMurray
Grande Prairie
Study Area
Edmonton
Calgary
A
Birch Mountains
Mineable Oil Sands
Muskeg Mountain
Athabasca Oil Sands Area
Cold Lake Oil Sands Area
50 km
B
Upper Cretaceous
Belly River Group (undivided)
Lea Park Formation
Colorado Group
Second White Specks, Carlile, and Niobrara Fms.
Fish Scales and Belle Fourche Fms.
Lower Cretaceous
Westgate Formation
Pelican Formation
Joli Fou Formation
Mannville Group (Upper)
Grand Rapids Formation
Clearwater Formation
Mannville Group (Lower)
Wabiskaw Member (Clearwater Fm.)
McMurray Formation
Devonian
Beaverhill Lake Group
Waterways Formation Formation
Slave Point Formation
Elk Point Group
Elk Point Group (undivided)
Watt Mountain Formation
Prairie Evaporite Formation
Keg River Formation
Contact Rapids Formation
Athabasca Basin
Lazenby Lake Formation
Clampitt Member
Hodge Member
Smart and Manitou Falls Fms. (undifferentiated)
Manitou Falls Formation
Smart Formation
Fair Point Formation
Canadian Shield
Marguerite River Complex

Figure 1

The study area encompasses most of the Lower Athabasca Regional Plan (LARP) area (yellow line, Fig. 1A). The sedimentary succession here is divided into a lower, Paleozoic succession and an overlying Cretaceous succession, separated by the sub-Cretaceous unconformity. The erosional basin margin for Phanerozoic rocks is located in the far northeast of the study area (Fig. 1B), which has had marked consequences for the structure and diagenesis of Devonian strata through karst in both carbonates and evaporites. The bedrock units (Fig. 1B) are covered by a variable thickness of unconsolidated Quaternary sediments.

Well Control

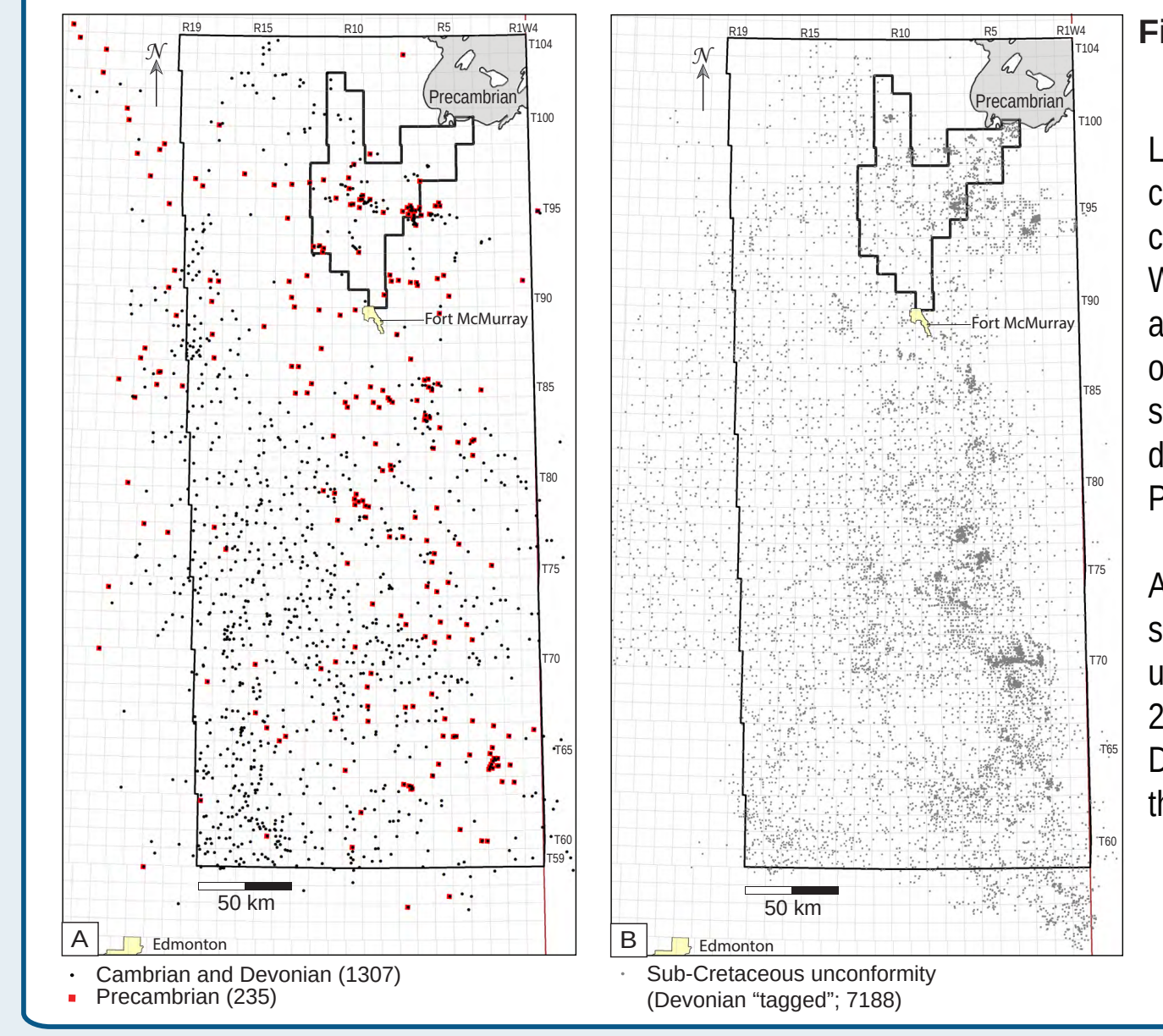

R15
R10
R5
R1W4
T104
T100
T95
T90
T85
T80
T75
T70
T65
T60
Precambrian
Fort McMurray
50 km
A
Edmonton
Cambrian and Devonian (1307)
Precambrian (235)
B
Edmonton
Sub-Cretaceous unconformity (Devonian "tagged"; 7188)

Figure 2

Lithostratigraphic mapping with wireline logs and core (where available) was the primary means to correlate Paleozoic strata within the study area. Well control within Paleozoic strata is sparse due to a general lack of hydrocarbon prospectivity, with only 1307 penetrating deep enough to provide stratigraphic information. Of these, only 235 were drilled through the Paleozoic succession to the Precambrian basement (Fig. 2A).

An additional 7188 wells that "tag" the Devonian strata at the sub-Cretaceous unconformity were used to reconstruct the position of this surface (Fig. 2B). These wells bottom out 10 - 20 m into the Devonian succession, which hampers determining the precise stratigraphic unit with confidence.

Stratigraphy and Geological Setting

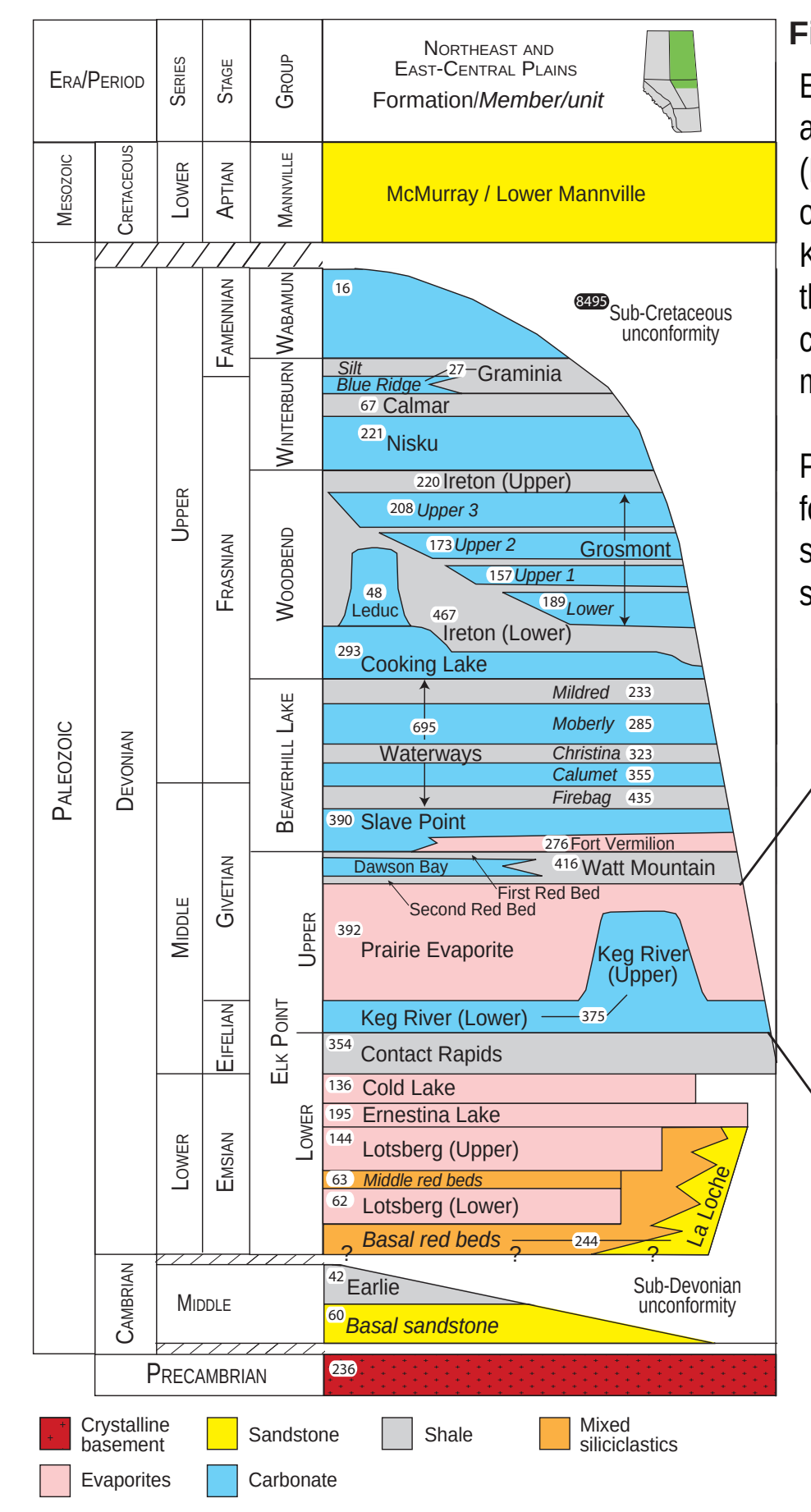
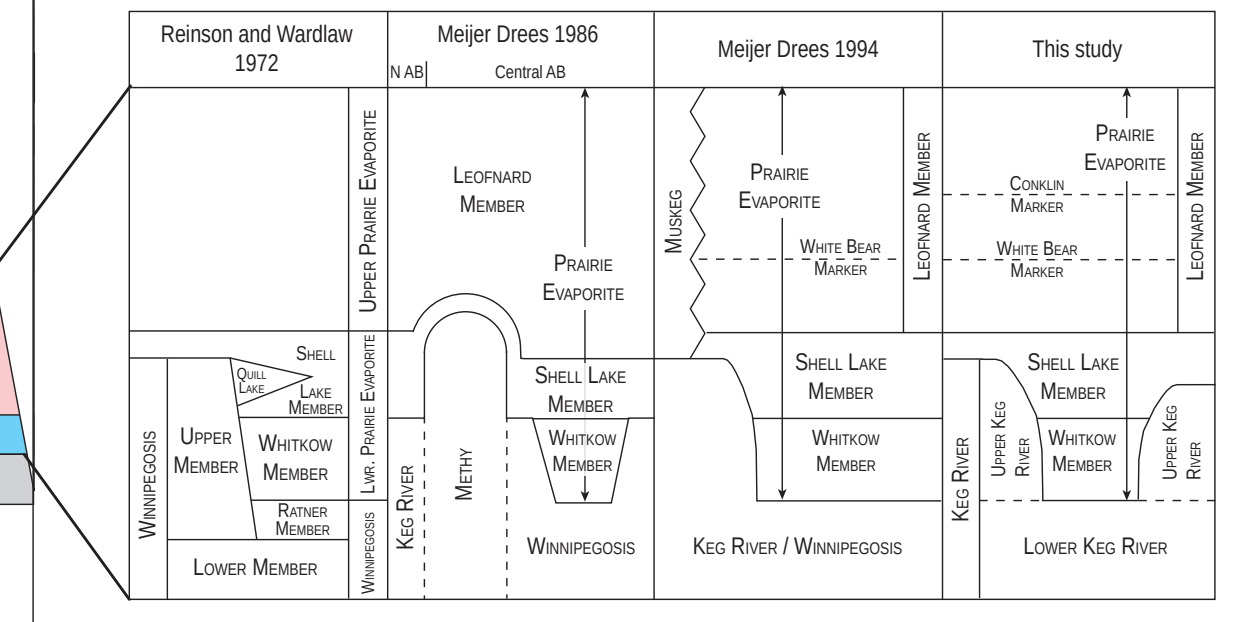


Figure 3

Erosionally truncated Middle Cambrian units (sub-Devonian unconformity), and Lower to Upper Devonian strata comprise the Paleozoic succession (Fig. 3). Evaporites, including thick halite deposits, comprise the majority of the Elk Point Group. Major carbonate reef growth is recorded by the Keg River Formation during a pause in restricted basin conditions. During the Beaverhill Lake through to Wabamun Group deposition, reef growth coupled with a large volume of terrigenous clastics marks a major shift away from restricted conditions and evaporite deposition.

Present-day Paleozoic structure is a result of orogenic loading during the formation of the Canadian Cordillera, and as such, Devonian strata subcrop youngest to oldest successively from west to east at the sub-Cretaceous unconformity.


Reinson and Wardlaw 1972
Meijer Drees 1986
Central AB
Meijer Drees 1994
This study
Leofnard Member
Prairie Evaporite
White Bear Marker
Shell Lake Member
Whitkow Member
Ratner Member
Lower Member
Upper Member
Winnipegosis
Keg River
Methy
Keg River / Winnipegosis
Conklin Marker
Lower Keg River
Upper Keg River

The Keg River and Prairie Evaporite formations of the Upper Elk Point Subgroup represent important mapped Devonian units (Fig. 3 inset). The formations have been subdivided based on member- and marker-bed stratigraphy (some established, some new), aimed at better understanding the paleogeography at the time, and the effects of halite and sulphate dissolution within the Prairie Evaporite Formation along the basin margin.

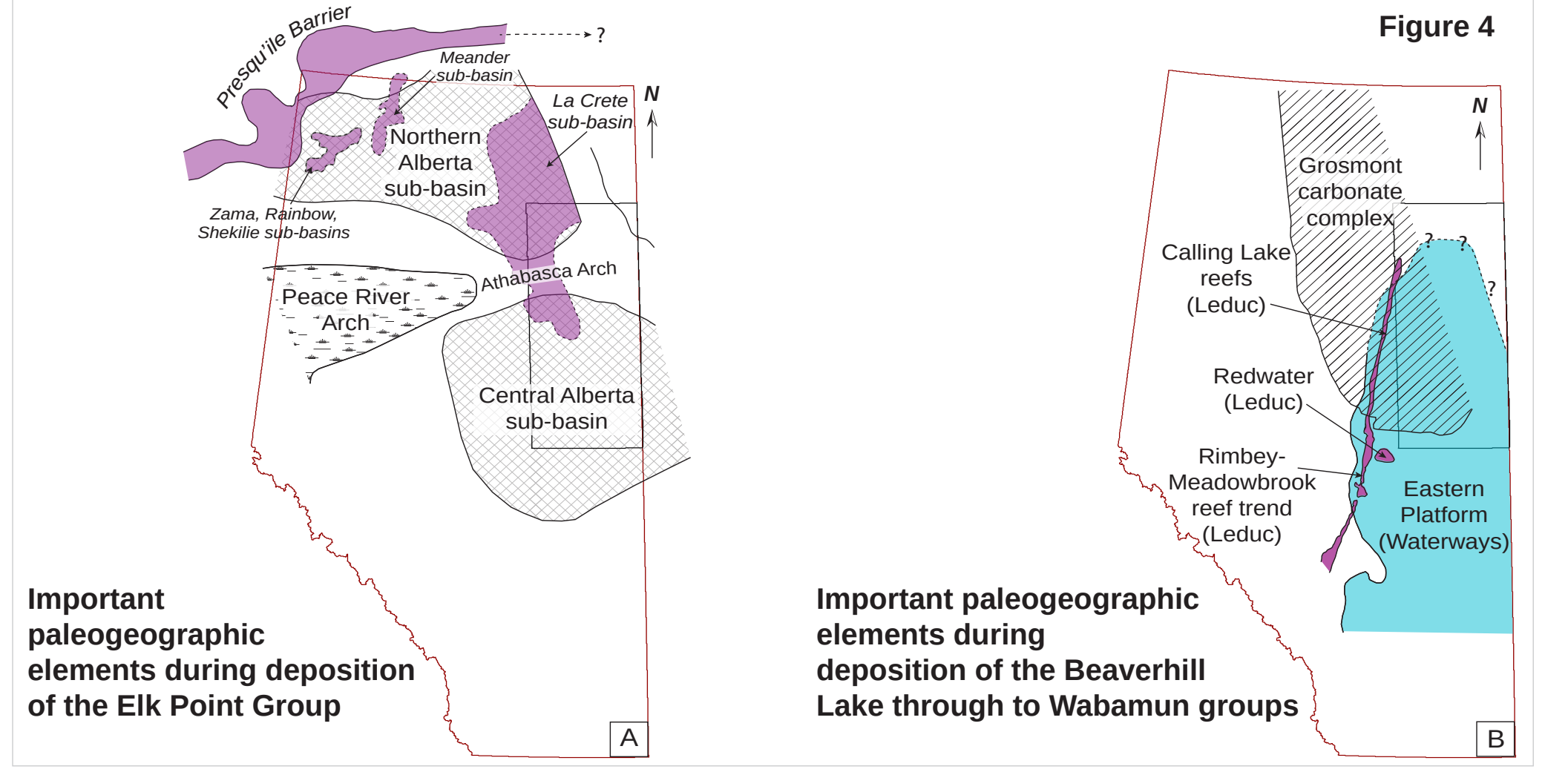

Presqu'ile Barrier
Meander sub-basin
La Crete sub-basin
Northern Alberta sub-basin
Zama, Rainbow, Shekilie sub-basins
Peace River Arch
Athabasca Arch
Central Alberta sub-basin
Important paleogeographic elements during deposition of the Elk Point Group
A
Grosmont carbonate complex
Calling Lake reefs (Leduc)
Redwater (Leduc)
Rimbey-Meadowbrook reef trend (Leduc)
Eastern Platform (Waterways)
Important paleogeographic elements during deposition of the Beaverhill Lake through to Wabamun groups
B

Figure 4

Strata of the Lower Elk Point Subgroup were deposited in two major depocentres on the sub-Devonian unconformity: the northern and central Alberta sub-basins separated by the Peace River - Athabasca Arch. During deposition of the Keg River Formation, an early lower platform developed into a series of sub-basins flanked by rimmed banks, with isolated reefs and mounds within the sub-basins (e.g., La Crete sub-basin, Fig. 4A). Keg River reefs coalesced to form the contiguous Presqu'ile Barrier during late Keg River time, which acted to restrict the basin from the open-marine connection. Evaporites of the Prairie Evaporite Formation were subsequently deposited on the Keg River Formation.

Strata of the Beaverhill Lake and Woodbend groups make up the majority of the Devonian units that subcrop at the sub-Cretaceous unconformity. Shallow-marine limestones of the Calumet and Moberly members make up part of an extensive carbonate bank with some minor isolated carbonate reefs, known as the Eastern Platform (Wendte and Uyeno, 2005) (Fig. 4B), intercalated with the argillaceous carbonates and calcareous shales of the Firebag, Christina, and Mildred members (Fig. 3). Woodbend Group carbonate complexes include the northern extent of the Rimbey-Meadowbrook Leduc reef trend, and the widespread Grosmont platform complex (Fig. 4B), both of which form significant carbonate-hosted bitumen reservoirs in LARP.

Regional-scale Modelling of the Paleozoic Succession Beneath the Athabasca and Cold Lake Oil Sands Areas: Devonian Paleogeography, Evaporite Dissolution, and Controls on Cretaceous Depositional Patterns on the Sub-Cretaceous Unconformity

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Edmonton, AB
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Lithostratigraphic Mapping

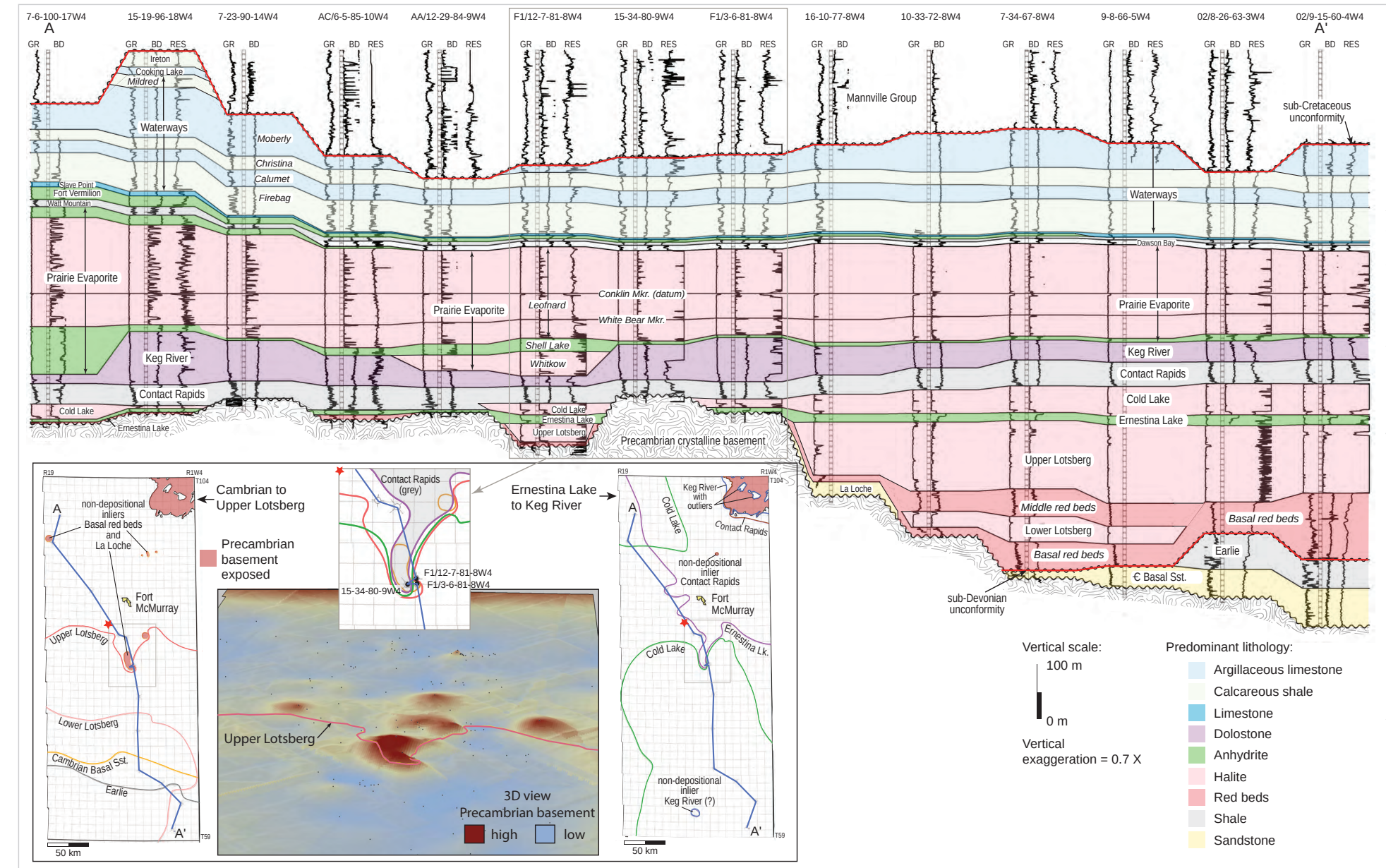

A
A'
Mannville Group
Waterways
Prairie Evaporite
Keg River
Contact Rapids
Cold Lake
Ernestina Lake
Upper Lotsberg
Middle red beds
Lower Lotsberg
Basal red beds
Earlie
Precambrian crystalline basement
sub-Cretaceous unconformity
sub-Devonian unconformity
Cambrian to Upper Lotsberg
Precambrian basement exposed
Ernestina Lake to Keg River
Upper Lotsberg
3D view Precambrian basement
high
low
50 km
Vertical scale:
100 m
0 m
Vertical exaggeration = 0.7 X
Predominant lithology:
Argillaceous limestone
Calcareous shale
Limestone
Dolostone
Anhydrite
Halite
Red beds
Shale
Sandstone

Figure 5

- Pronounced Precambrian paleotopography along the northern margin of the central Alberta sub-basin greatly affected the distribution of Elk Point strata; this location corresponds to the southern margin of the Athabasca Arch.
- Precambrian paleotopography was eventually covered by shaly strata of the Contact Rapids Formation.
- Keg River carbonates show increased thickness (upper Keg River) over Precambrian basement highs along the Athabasca Arch.
- In the north, Prairie Evaporite strata at the Whitkow Member level comprise anhydrites.

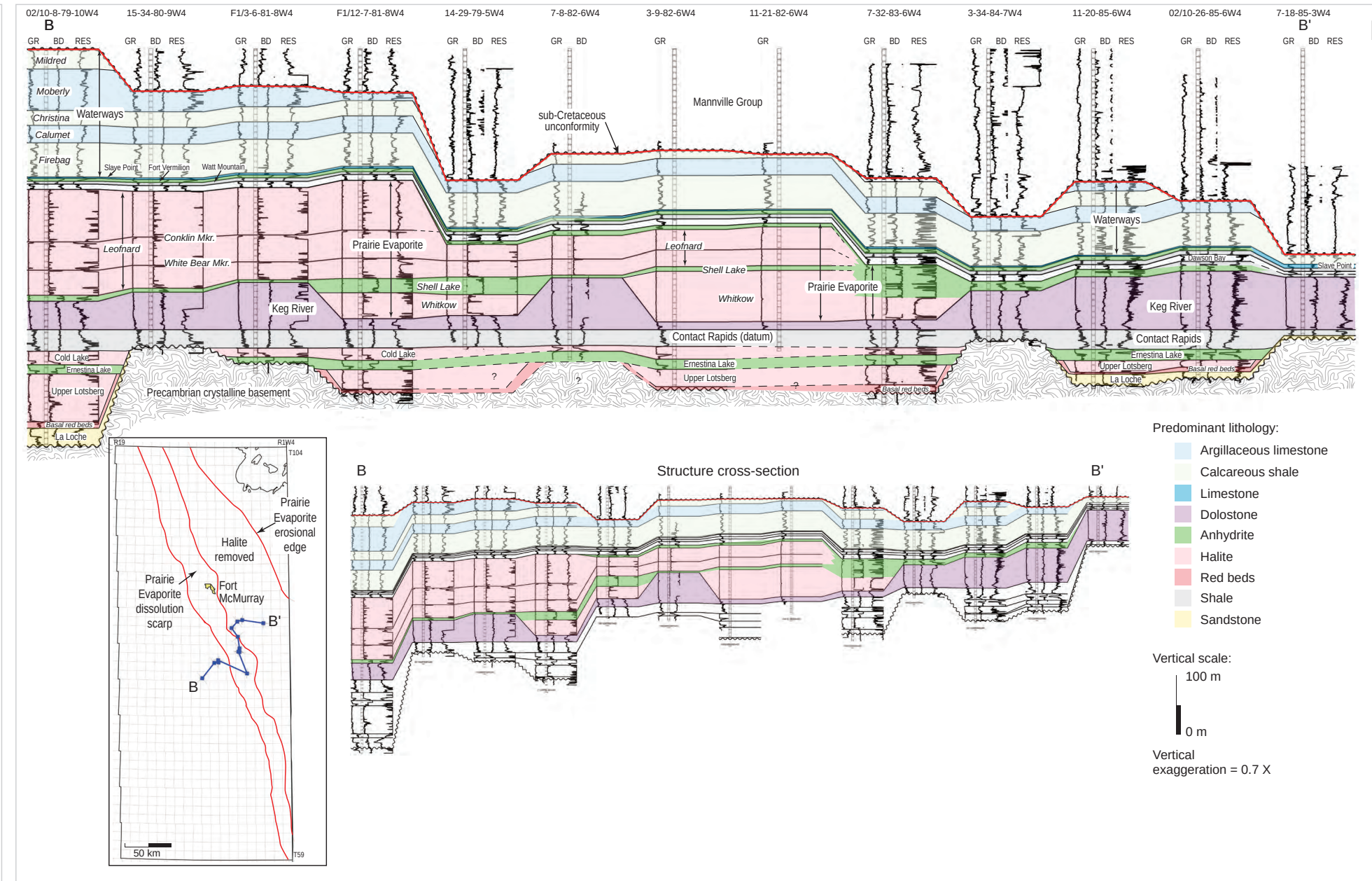

B
B'
Mannville Group
sub-Cretaceous unconformity
Leofnard
Conklin Mkr.
White Bear Mkr.
Prairie Evaporite
Shell Lake
Whitkow
Keg River
Contact Rapids (datum)
Cold Lake
Ernestina Lake
Upper Lotsberg
Precambrian crystalline basement
Halite removed
Prairie Evaporite dissolution scarp
Prairie Evaporite erosional edge
Fort McMurray
Structure cross-section
50 km
Vertical scale:
100 m
0 m
Vertical exaggeration = 0.7 X
Predominant lithology:
Argillaceous limestone
Calcareous shale
Limestone
Dolostone
Anhydrite
Halite
Red beds
Shale
Sandstone

Figure 6

- Precambrian basement highs appear to be local sources for discontinuous sandstones of the La Loche Formation.
- Halite of the Whitkow Member of the Prairie Evaporite was deposited within basins flanked by upper Keg River buildups.
- Intrastratal dissolution of halite within the Prairie Evaporite results in a distinct NNW-trending scarp through the study area.
- A marked regional dip reversal can be seen in Devonian strata overlying the halite dissolution scarp resulting from the removal of section.

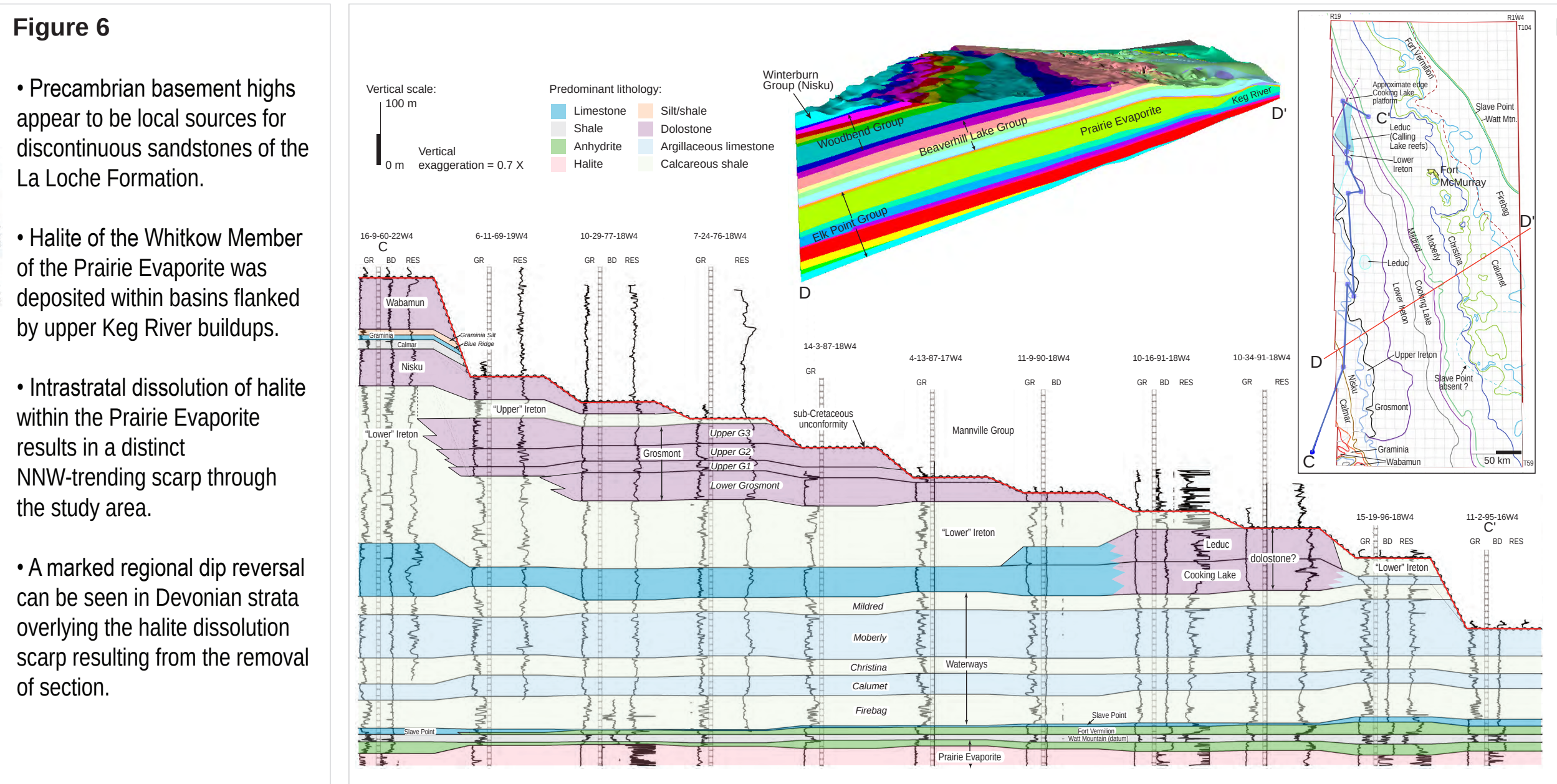
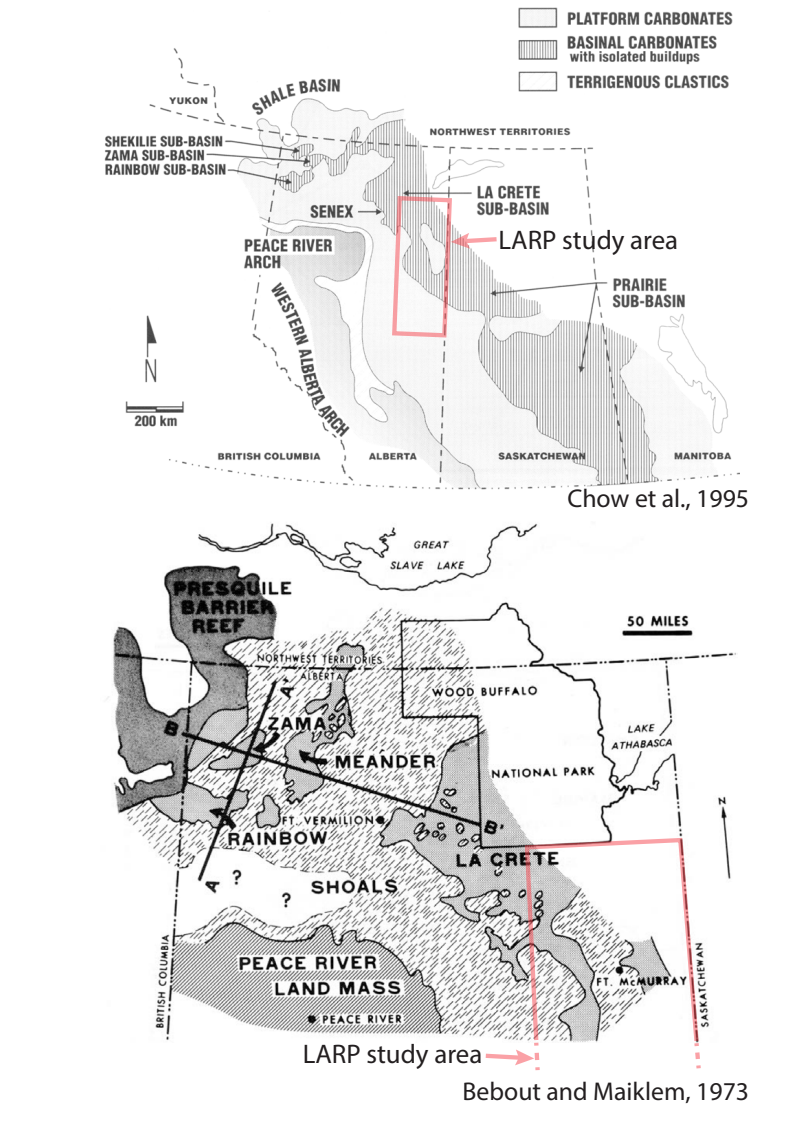

Vertical scale:
100 m
0 m
Vertical exaggeration = 0.7 X
Predominant lithology:
Limestone
Shale
Anhydrite
Halite
Silt/shale
Dolostone
Argillaceous limestone
Calcareous shale
Winterburn Group (Nisku)
Woodbend Group
Beaverhill Lake Group
Prairie Evaporite
Keg River
Elk Point Group
C
C'
D
D'
Wabamun
Nisku
"Upper" Ireton
"Lower" Ireton
Grosmont
Upper G3
Upper G2
Upper G1
Lower Grosmont
Mannville Group
sub-Cretaceous unconformity
Leduc
Cooking Lake
dolostone?
Mildred
Moberly
Christina
Calumet
Firebag
Waterways
Slave Point
Prairie Evaporite
Fort McMurray
50 km

Figure 7

- Strata of the Beaverhill Lake, Woodbend, Winterburn and Wabamun groups form the majority of the subcrop belts at the sub-Cretaceous unconformity.
- Subcrop belts parallel the orogenic front to the west, except for the Waterways members due to structural collapse over the Prairie Evaporite halite dissolution scarp.
- Carbonates of the Leduc, Grosmont, and Nisku formations host bitumen in karsted reservoirs at their respective subcrops at the sub-Cretaceous unconformity.

Keg River - Prairie Evaporite Paleogeography


Platform carbonates
Basinal carbonates with isolated buildups
Terrigenous clastics
Shale Basin
Yukon
Northwest Territories
Shekilie sub-basin
Zama sub-basin
Rainbow sub-basin
Senex
La Crete sub-basin
LARP study area
Prairie sub-basin
Peace River Arch
Western Alberta Arch
British Columbia
Alberta
Saskatchewan
Manitoba
200 km
Chow et al., 1995
Presqu'ile Barrier Reef
Meander
Rainbow
Shoals
La Crete
Peace River Land Mass
LARP study area
50 miles
Bebout and Maiklem, 1973

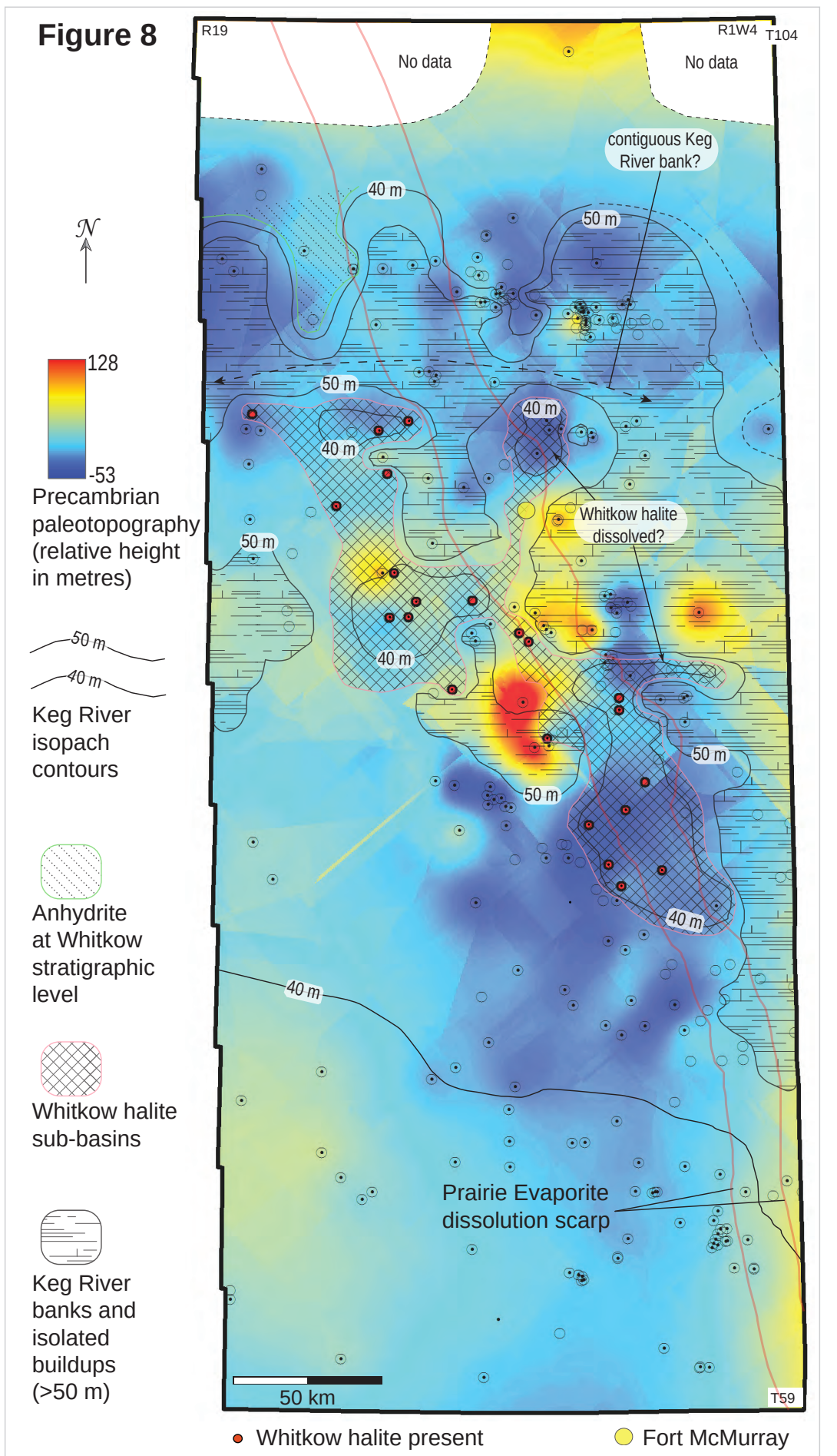

R19
R1W4
T104
No data
No data
contiguous Keg River bank?
40 m
50 m
Whitkow halite dissolved?
Prairie Evaporite dissolution scarp
128
-53
Precambrian paleotopography (relative height in metres)
Keg River isopach contours
Anhydrite at Whitkow stratigraphic level
Whitkow halite sub-basins
Keg River banks and isolated buildups (>50 m)
Whitkow halite present
Keg River isopach control
Precambrian basement structure control
Fort McMurray
50 km
T59

Figure 8

The Keg River–Prairie Evaporite succession is well-known from the Rainbow and Zama areas in northwest Alberta, and from the La Crete sub-basin of northeast Alberta. Less is known of the succession in the LARP study area. Here, upper Keg River buildups nucleated on and around Precambrian basement highs (warm colours, Fig. 8). Conversely, where the basement is low, the Keg River is commonly less than 40 m thick (Fig. 8), and these areas correspond to deposition of the Whitkow Member halite in interbuildup areas. Upper Keg River deposits also formed along the northern margin of the basement paleohighs, corresponding to the northern margin of the Athabasca Arch. In this location the Keg River coalesced to form a contiguous Keg River bank, which is deduced from Keg River isopach mapping and stratigraphic relationships in the overlying Prairie Evaporite Formation. Increased relative restriction and drawdown within the Whitkow Member sub-basins was facilitated by the interpreted contiguous Keg River bank. The barrier separated anhydritic intervals at the Whitkow stratigraphic level in the north and northwest, from southern halite-rich intervals (Whitkow Member halite).

Reassessing Intrastratal Karst in the Prairie Evaporite Halite Dissolution Scarp: Top-Down Removal Dissolution

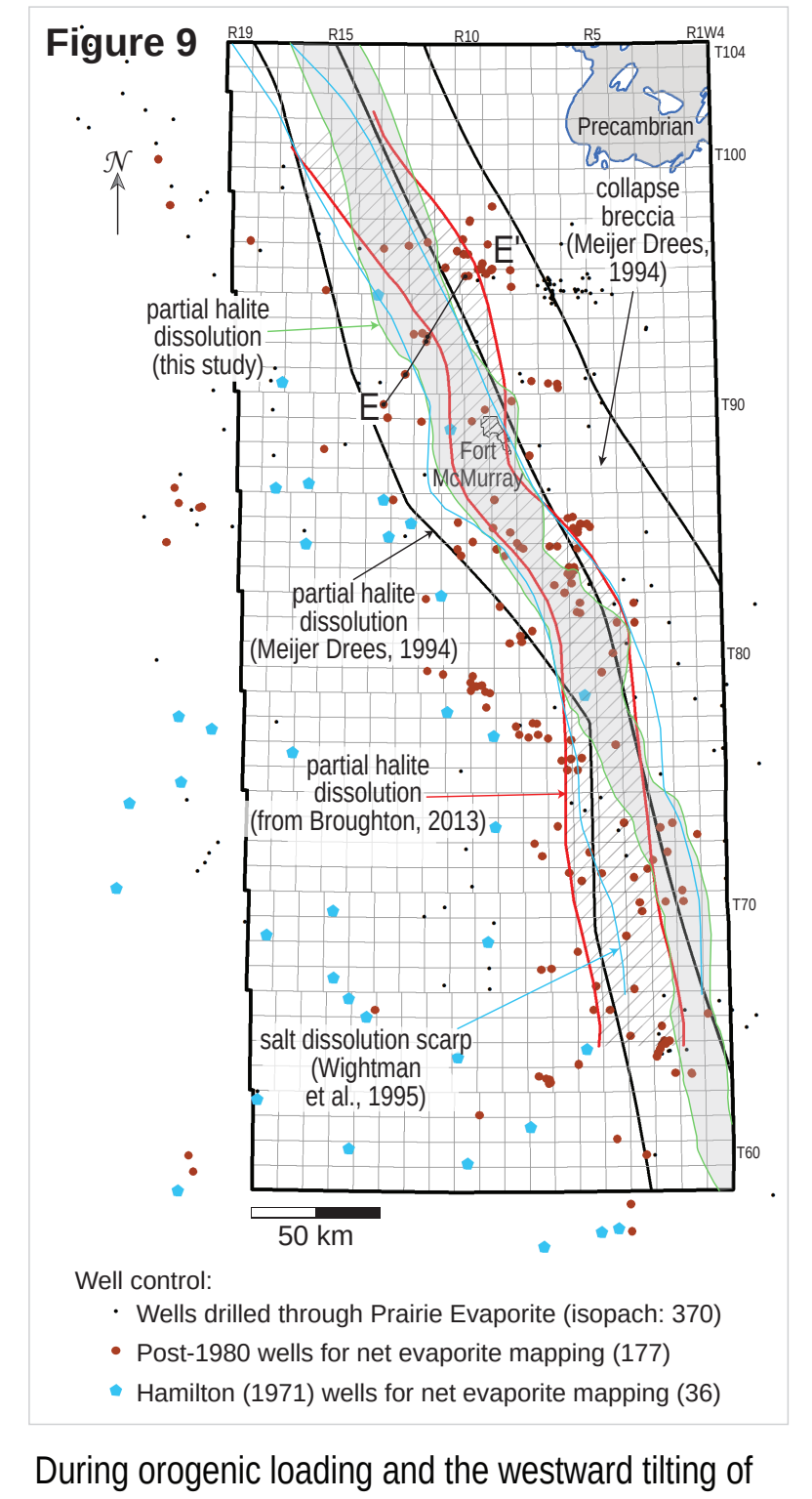

R19
R15
R10
R5
R1W4
T104
T100
T90
T80
T70
T60
Precambrian
collapse breccia (Meijer Drees, 1994)
partial halite dissolution (this study)
E
E'
Fort McMurray
partial halite dissolution (Meijer Drees, 1994)
partial halite dissolution (from Broughton, 2013)
salt dissolution scarp (Wightman et al., 1995)
50 km

Figure 9

Well control:
- Wells drilled through Prairie Evaporite (isopach: 370)
- Post-1980 wells for net evaporite mapping (177)
- Hamilton (1971) wells for net evaporite mapping (36)

During orogenic loading and the westward tilting of the Devonian succession, subaerial exposure along the basin margin resulted in intrastratal karst within evaporites through influx of water into the Prairie Evaporite succession and removal of significant volumes of halite. Removal of halite ensued at the basin margin forming an elongate subsidence trough bordered to the west by a NNW–SSE trending dissolution scarp. The position of the salt scarp on a regional scale has not received a major update in the past two decades even though there have been over 160 wells drilled through the formation since 1990.

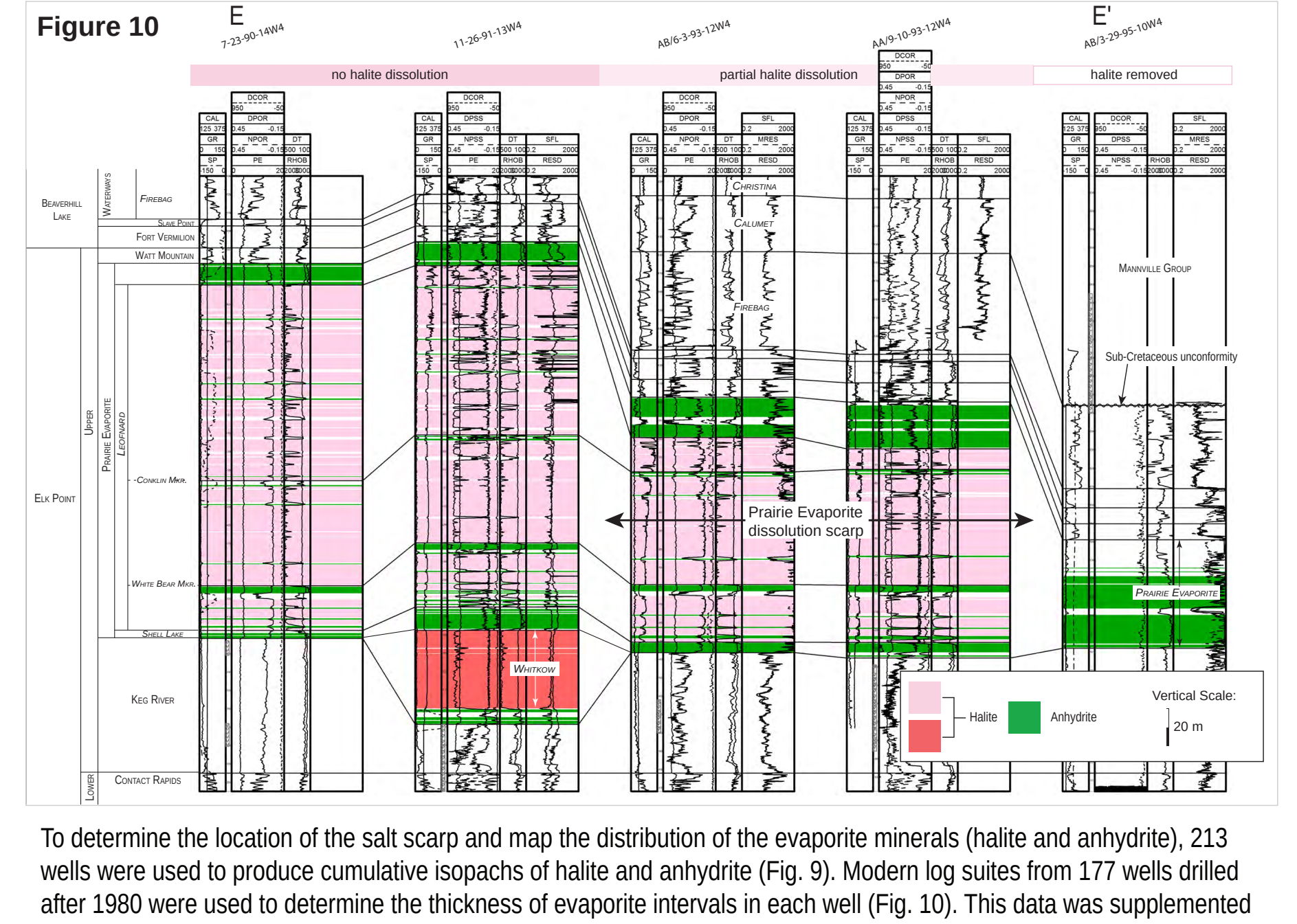

E
E'
no halite dissolution
partial halite dissolution
halite removed
Mannville Group
Sub-Cretaceous unconformity
Prairie Evaporite dissolution scarp
Halite
Anhydrite
Vertical Scale:
20 m

Figure 10

To determine the location of the salt scarp and map the distribution of the evaporite minerals (halite and anhydrite), 213 wells were used to produce cumulative isopachs of halite and anhydrite (Fig. 9). Modern log suites from 177 wells drilled after 1980 were used to determine the thickness of evaporite intervals in each well (Fig. 10). This data was supplemented with observations from core and drill cuttings from an additional 36 wells in areas where modern well log suites are absent (Hamilton, 1971). A set of regionally extensive members and marker beds within the Prairie Evaporite Formation were used to parse the formation into mappable lithostratigraphic packages (Fig. 10). The use of the member- and marker-bed stratigraphy, along with isopach mapping of halite and anhydrite, reveals that halite was dissolved from the top-down, with halite in the Leofnard Member dissolving first (Fig. 11). This is apparent along the length of the dissolution scarp (cross-sections, Fig. 11).

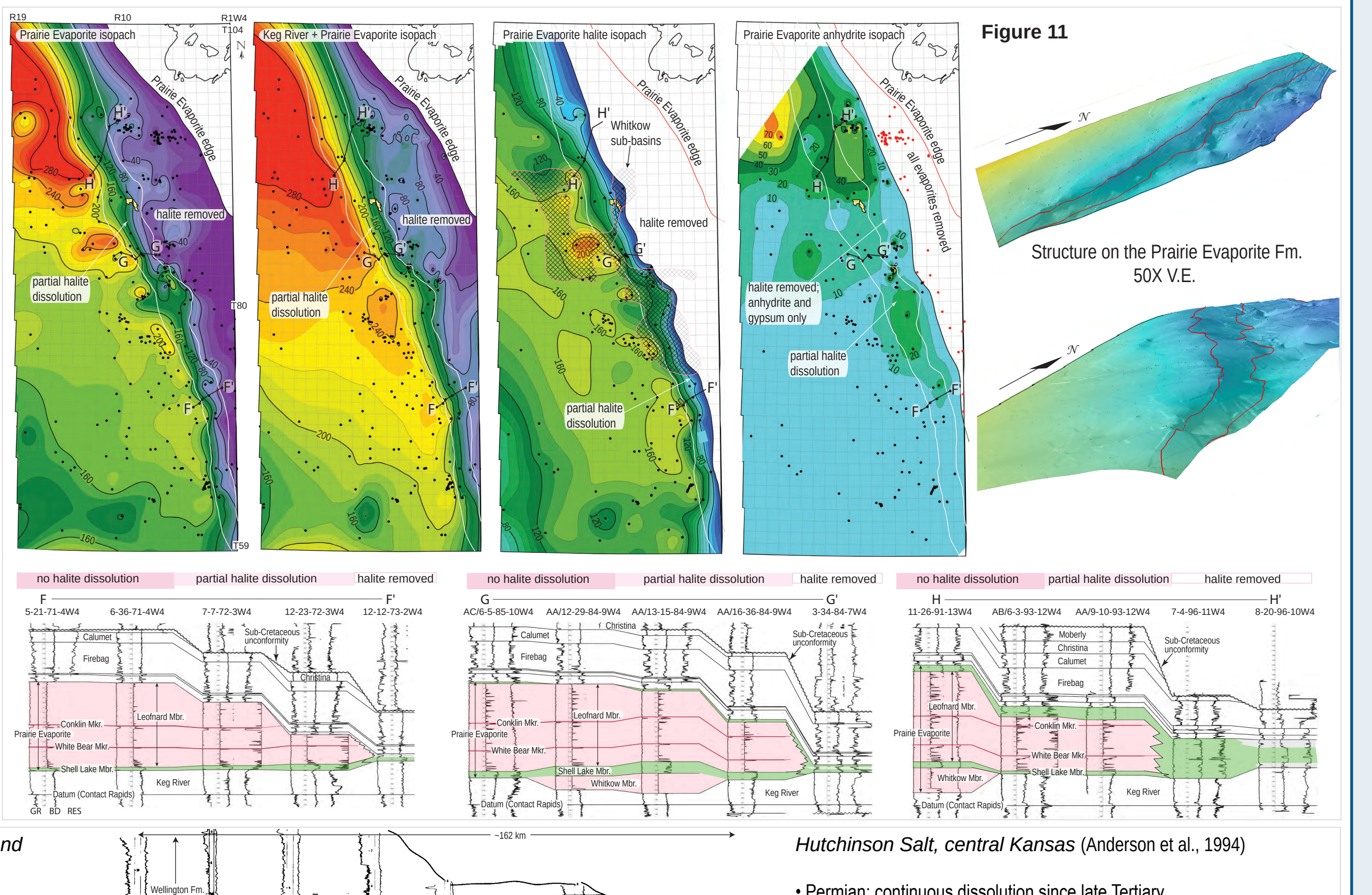
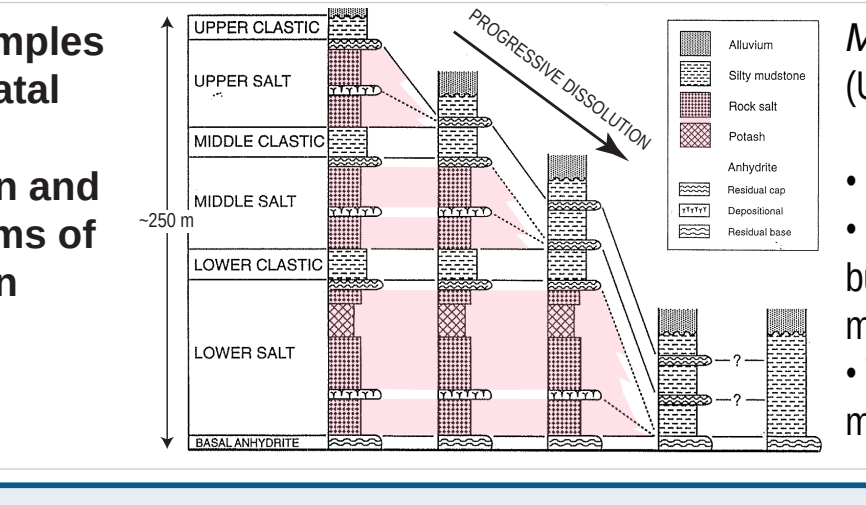

Prairie Evaporite isopach
Keg River + Prairie Evaporite isopach
Prairie Evaporite halite isopach
Prairie Evaporite anhydrite isopach
Prairie Evaporite edge
halite removed
partial halite dissolution
Whitkow sub-basins
halite removed; anhydrite and gypsum only
all evaporites removed
Structure on the Prairie Evaporite Fm. 50X V.E.
no halite dissolution
partial halite dissolution
halite removed
F
F'
G
G'
H
H'
Calumet
Firebag
Sub-Cretaceous unconformity
Christina
Moberly
Conklin Mkr.
Leofnard Mbr.
White Bear Mkr.
Shell Lake Mbr.
Whitkow Mbr.
Keg River
Datum (Contact Rapids)

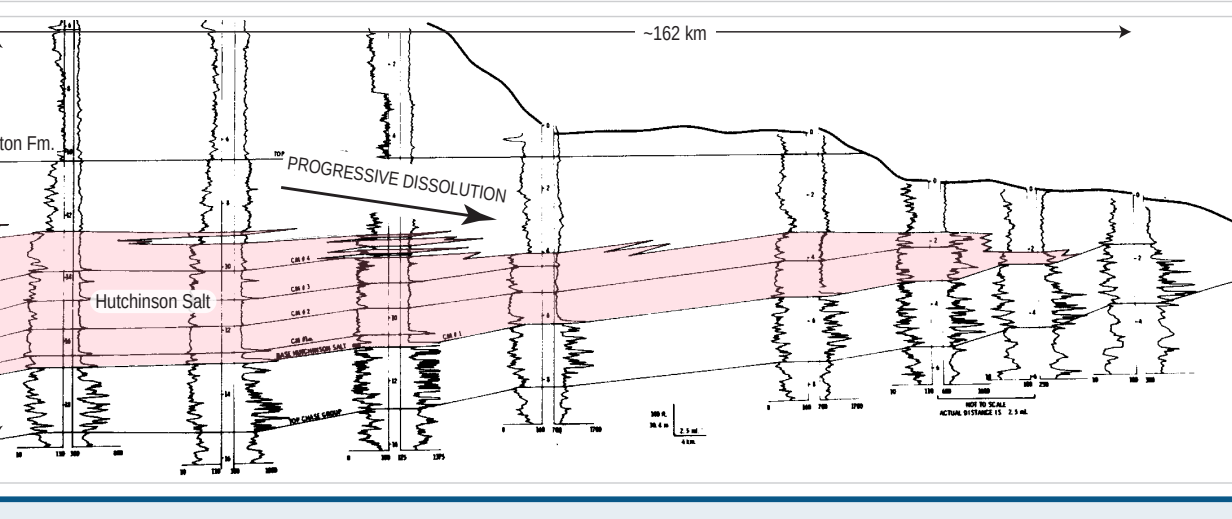
Figure 11

Other examples of intrastratal top-down dissolution and mechanisms of dissolution


Upper clastic
Upper salt
Middle clastic
Middle salt
Lower clastic
Lower salt
Basal anhydrite
Progressive dissolution
~250 m

Maha Sarakham Formation, NE Thailand (Utha-aroon et al., 1995)

- Upper-middle to late Cretaceous
- Dissolution of halite occured during shallow to deep burial; undersaturated waters flowing through the clastic marker beds dissolved halite along bed boundaries.
- This process occured top-down adjacent to the basin margin.


~162 km
Wellington Fm.
Progressive dissolution
Hutchinson Salt
90

Hutchinson Salt, central Kansas (Anderson et al., 1994)

- Permian; continuous dissolution since late Tertiary
- Halite-dominated marine cycles (cyclic carbonate, sulphate, and halite)
- Top-down dissolution of halite occurs through infiltration of undersaturated waters along the top of the halite.
- Leaching of salt causes subsidence and fracturing in overlying strata, which enhances permeability and further access to undersaturated waters from above through the fractures.

Paleogeographic Reconstruction of the Sub-Cretaceous Unconformity

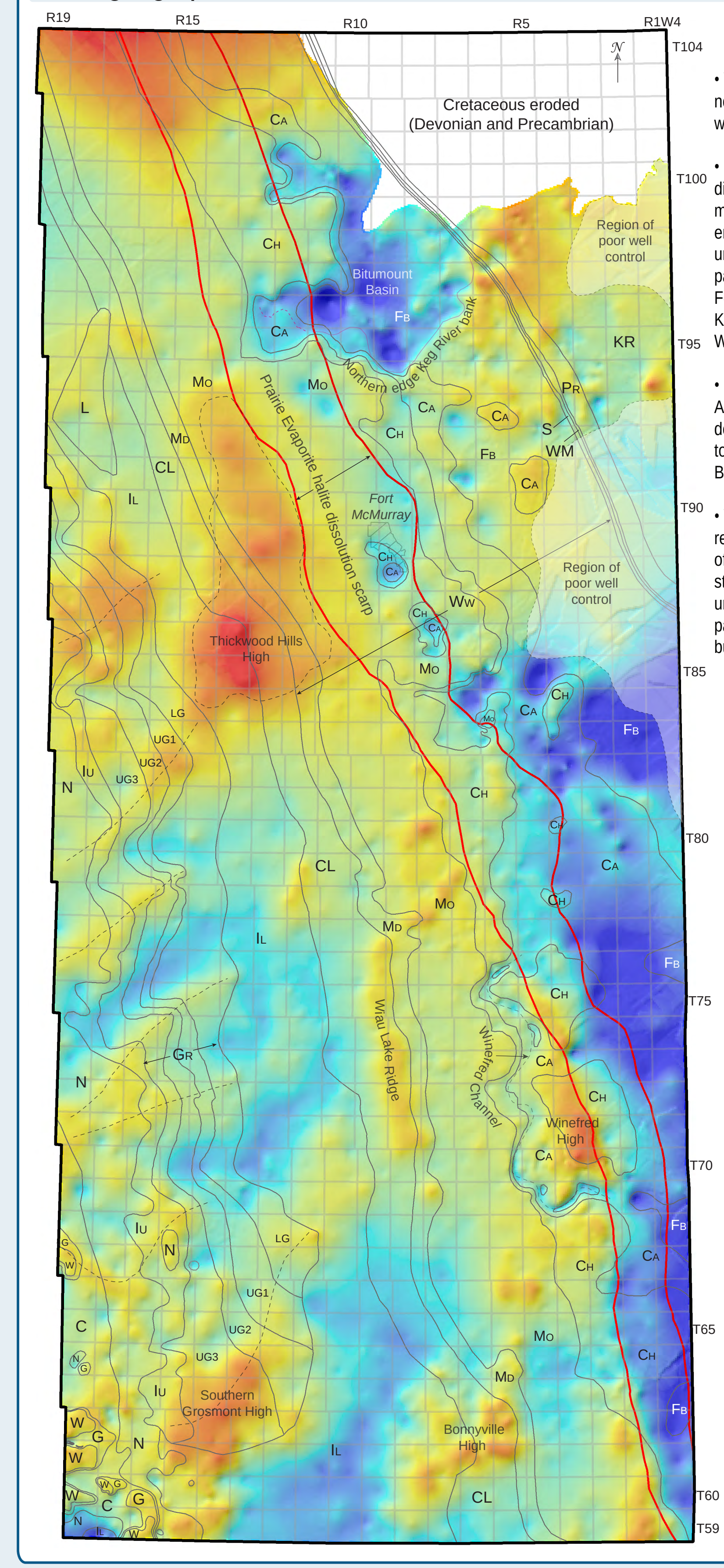

R19
R15
R10
R5
R1W4
T104
T100
T95
T90
T85
T80
T75
T70
T65
T60
T59
Cretaceous eroded (Devonian and Precambrian)
Region of poor well control
Bitumount Basin
Northern edge Keg River bank
Prairie Evaporite halite dissolution scarp
Fort McMurray
Thickwood Hills High
Wiau Lake Ridge
Winefred Channel
Winefred High
Southern Grosmont High
Bonnyville High

Figure 12

- We identify and name a number of notable features on the unconformity west of the dissolution scarp.
- East of the Prairie Evaporite dissolution scarp the Waterways members subcrops are complex; enhanced structuring on the unconformity here is a result of paleotopography on the Keg River Formation (removal of halite above the Keg River results in the draping of Waterways over Keg River buildups.
- Keg River buildups along the Athabasca Arch cause an eastward deflection of Waterways subcrops up to the southern margin of the Bitumount Basin.
- We interpret the Bitumount Basin to represent a combination of faulted offset, coupled with enhanced structuring of the sub-Cretaceous unconformity over the underlying paleotopography on Keg River buildups.

Wabamun Group
W - Wabamun (undifferentiated)
Winterburn Group
G - Graminia
C - Calmar
N - Nisku
Woodbend Group
Iu - Upper Ireton
Gr - Grosmont
UG3 - Upper Grosmont 3
UG2 - Upper Grosmont 2
UG1 - Upper Grosmont 1
LG - Lower Grosmont
L - Leduc
Il - Lower Ireton
CL - Cooking Lake
Beaverhill Lake Group
Ww - Waterways
Md - Mildred
Mo - Moberly
Ch - Christina
Ca - Calumet
Fb - Firebag
S - Slave Point
Elk Point Group
WM - Watt Mountain
Pr - Prairie Evaporite (remnant)
KR - Keg River

Sub-Cretaceous paleotopography (relative height in metres)
92
-145
50 km

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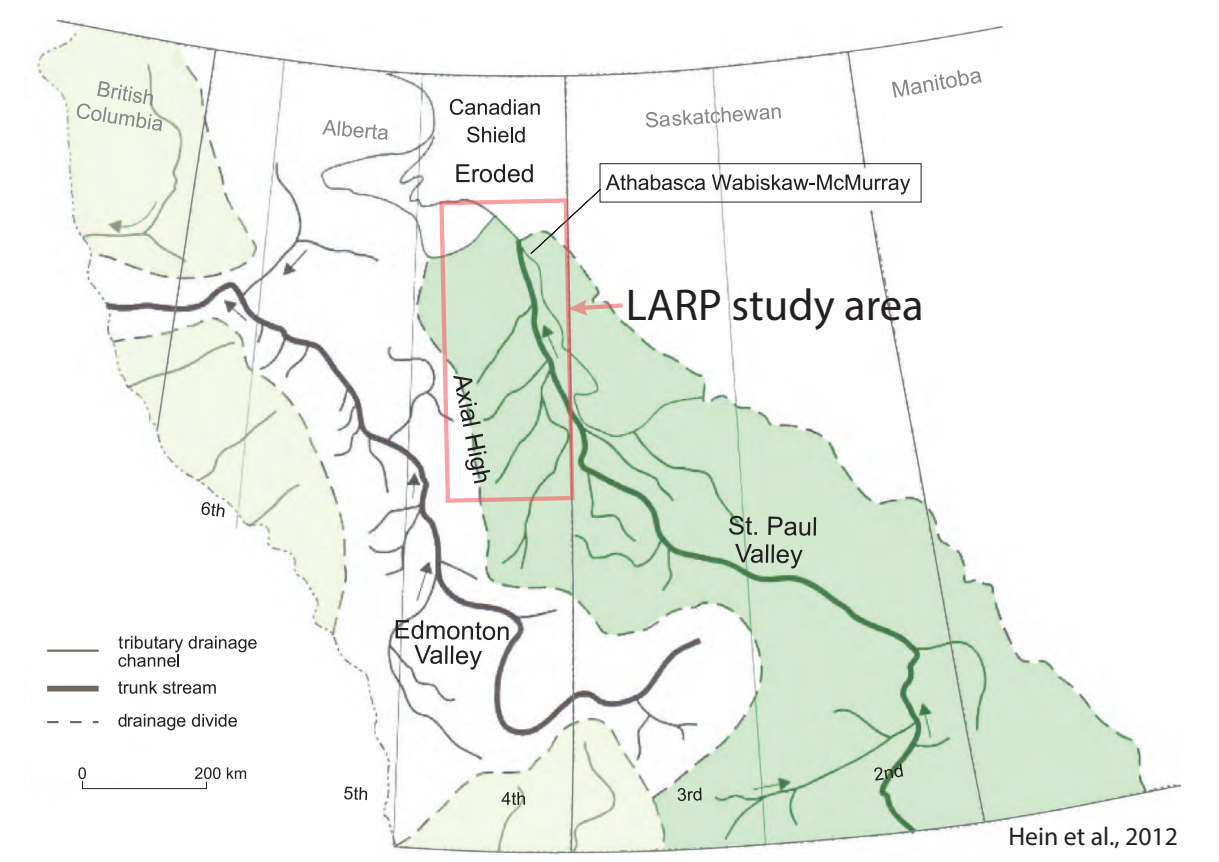
Mannville Group Accommodation Trends on the Sub-Cretaceous Unconformity


British Columbia
Alberta
Canadian Shield Eroded
Saskatchewan
Manitoba
Athabasca Wabiskaw-McMurray
LARP study area
Axial High
St. Paul Valley
Edmonton Valley
tributary drainage channel
trunk stream
drainage divide
200 km
6th
5th
4th
3rd
2nd
Hein et al., 2012

- The LARP study area falls within one of a few main, northward-flowing paleovalleys that developed on the sub-Cretaceous unconformity during the Cretaceous.
- The northern extent of the St. Paul paleovalley (Saskatchewan) is known as the Athabasca Trunk Valley (Ranger, 2006); the principal structural control on the location of this main depositional fairway was the elongate subsidence valley that was created through the dissolution of halite and sulphates in the Prairie Evaporite Formation, and the subsequent collapse of the overlying Devonian strata.
- An axial high separated the Athabasca Trunk Valley from the Edmonton Valley to the west.
- A number of tributaries oriented obliquely to the main paleovalleys formed across the axial high.

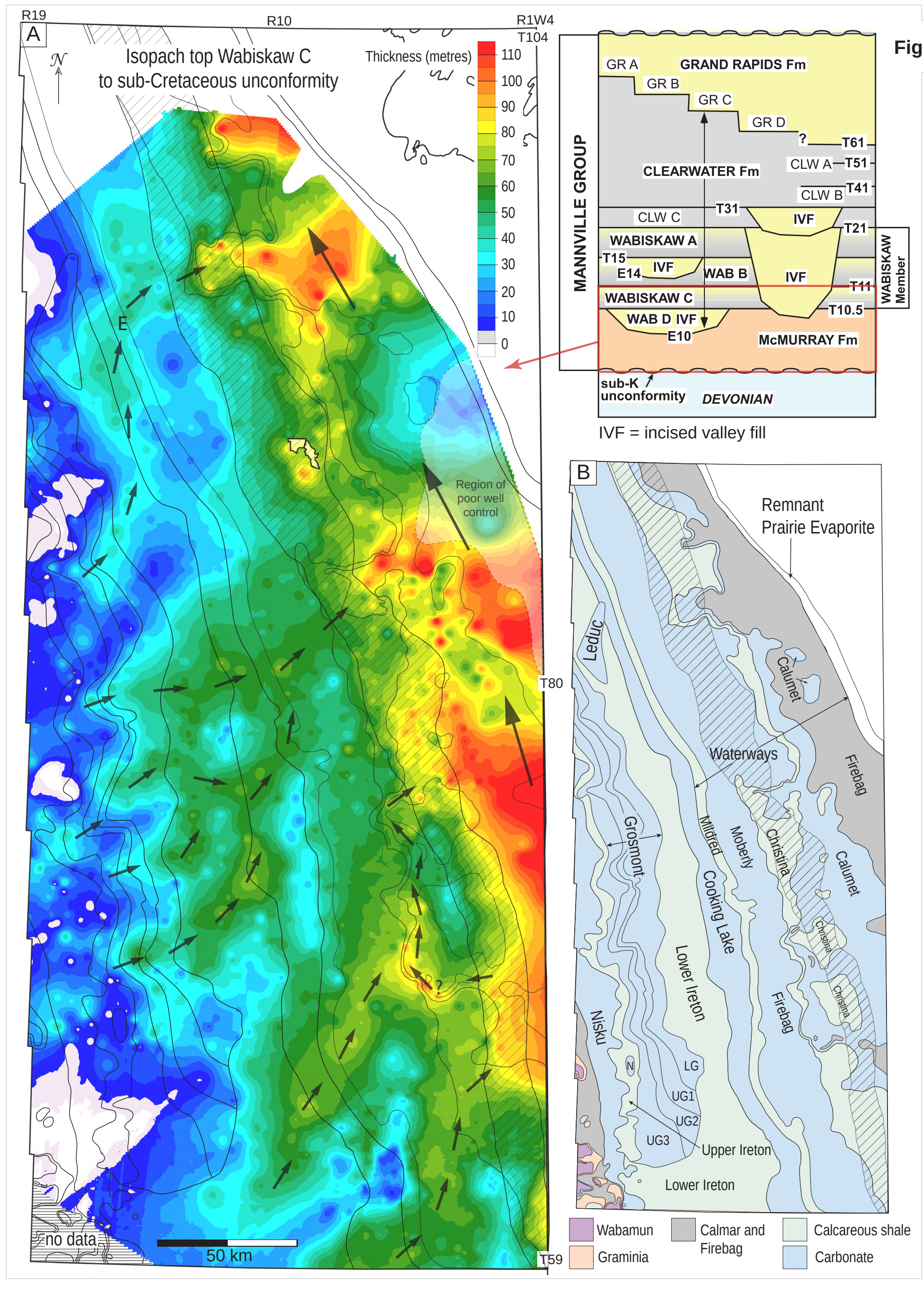

R19
R10
R1W4
T104
T80
T59
A
Isopach top Wabiskaw C to sub-Cretaceous unconformity
Thickness (metres)
110
100
90
80
70
60
50
40
30
20
10
0
Region of poor well control
no data
50 km
GR A
GRAND RAPIDS Fm
GR B
GR C
GR D
CLEARWATER Fm
CLW A
CLW B
CLW C
WABISKAW A
WABISKAW C
WAB B
WAB D IVF
IVF
McMURRAY Fm
MANNVILLE GROUP
WABISKAW Member
T61
T51
T41
T31
T21
T15
E14
T11
T10.5
E10
sub-K unconformity
DEVONIAN
IVF = incised valley fill
B
Remnant Prairie Evaporite
Leduc
Calumet
Waterways
Firebag
Grosmont
Mildred
Moberly
Christina
Cooking Lake
Lower Ireton
Upper Ireton
Nisku
LG
UG1
UG2
UG3
Wabamun
Graminia
Calmar and Firebag
Calcareous shale
Carbonate

Figure 13

- The primary control that evaporite dissolution played in loer Mannville Group regional depositional patterns is illustrated by an isopach of the combined McMurray Formation and partial Wabiskaw Member succession (Fig. 13).
- The thickest parts of this interval correspond to locations within and east of the Prairie Evaporite halite dissolution scarp–this is the location of the main Athabasca Trunk Valley–and correlate well with the updated extent of the dissolution scarp as mapped in this study.
- The western margin of the Athabasca Trunk Valley is bordered by the face of the Prairie Evaporite halite dissolution scarp (see also model images from Fig. 11).
- The Winefred Channel (an incised meandering channel form; see Fig. 12) contains the thickest McMurray deposits west of the dissolution scarp.
- West of the dissolution scarp, lower Mannville accommodation is controlled by a series of paleotopographic highs formed of Devonian carbonate (Fig. 13B).
- On a regional scale, the axial high of Hein et al. (2012) can be seen as resistant carbonate of the Grosmont and Nisku formations; this axial high continues westward into the thick, resistant carbonate of the Wabamun Group.
- Tributaries flowing eastward toward the Athabasca Trunk Valley cross this axial high and occupy a series of erosional lows separated by well-defined intervening highs—re-entrants and headlands, respectively—on the carbonate (see dashed lines on the paleohighs on Fig. 12).

Summary

Paleozoic strata have been reassessed regionally in northeastern Alberta in an area that accounts for approximately 12% of the province. Detailed lithostratigraphic correlation, mapping, and modelling provide the basis to interpret the Paleozoic geology of the LARP area in the broader context of the Alberta Basin. Important findings are summarized below.

Precambrian Athabasca Arch and it's Influence on Elk Point Strata

- Precambrian paleotopography on the Athabasca Arch was an important control on broad depositional patterns throughout deposition of the Elk Point Group.
- Differential compaction of Contact Rapids Formation shale around Precambrian basement highs, during and after lower Keg River Formation deposition, resulted in antecedent topography that became the locus for upper Keg River buildups.
- In a reciprocal pattern, evaporites of the Whitkow Member of the Prairie Evaporite Formation accumulated preferentially within a series of inter-buildup sub-basins that correspond to Precambrian basement lows.
- A contiguous Keg River bank formed along the northern margin of the Athabasca Arch, which acted to restrict normal-marine water access to southerly sub-basins (Keg River interbuildup areas); north or this barrier, comparable thicknesses of anhydrite accumulated at similar stratigraphic levels as the Whitkow Member, ostensibly due to proximity to the Presqu'ile Barrier and less intense evaporitic drawdown.

Prairie Evaporite Halite Dissolution Scarp

- Isopach mapping of halite and anhydrite within the Prairie Evaporite Formation, using modern well control, allows for a substantial update to the location and extent of the halite dissolution scarp, and the region within which all sulphates have been removed.
- Detailed correlation of members and marker beds within the Prairie Evaporite illustrate that intrastratal halite dissolution occured top-down–a common theme within other basin-margin settings where evaporite dissolution has occured.

Structure and Accommodation Trends on the Sub-Cretaceous Unconformity

- The location of the Prairie Evaporite halite dissolution scarp is the primary structural control on the position of the sub-Cretaceous unconformity surface, forming a large subsidence trough that was the locus for thick accumulations of overlying lower Mannville Group strata.
- East of the dissolution scarp, Keg River Formation buildups along the Athabasca Arch influenced structure at the sub-Cretaceous unconformity, an example being the southern boundary of the Bitumount Basin correlating to the northern margin of a potentially contiguous Keg River bank.
- West of the dissolution scarp, NW–SE trending subcrop belts of Beaverhill Lake to Wabamun Group carbonates and intervening shales influenced structure on the unconformity surface through differential erosion.
- A series of ridges and paleovalleys perpendicular to the subcrop belts formed on the Grosmont and younger formations; the valleys were the location of eastward-flowing tributaries of the Athabasca Trunk Valley.

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