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2014 GSA Annual Meeting in Vancouver, British Columbia (19–22 October 2014)

Paper No. 339-9
Presentation Time: 3:35 PM

IMPACT OF PALEOZOIC KARST UPON GROUNDWATER FLOW IN THE VICINITY OF THE ATHABASCA OIL SANDS

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Extracting oil from the Athabasca Oil Sands requires abundant water supply, much of it from groundwater, and geological layers capable of receiving large amounts of injected waste water. Hence good understanding of geological structures and knowledge of the dynamics of existing regional groundwater flow systems and their response to the imposed stresses of water production and waste water injection is of paramount importance to successfully determine and manage any changes to the pattern of groundwater flow.

The presentation outlines the existing groundwater flow systems affected by the ubiquitous karst in Paleozoic layers. The Paleozoic karst causes the low flow potential drain found by Hitchon (1969). This drain collects groundwater flow from the Cretaceous layers above and from deeper Paleozoic layers to discharge into the Athabasca River.

The Devonian Grosmont Formation underlies the southwestern and northwestern part of the Cretaceous Athabasca Oil Sands. Permeabilities as high as 250 Darcy ($2.5*10^{-3}$ m/sec) were measured in boreholes within this formation, which acts as a regional collector and transmitter of groundwater in the area of its occurrence. Heavy oil is already being extracted from the Cretaceous layers above the Paleozoic, creating a noticeable effect on the pattern of groundwater flow in the Grosmont Formation by water extraction and injection. In the future additional extraction operations will target the Grosmont Formation itself. Pronounced effects on the regional and local groundwater flow systems are anticipated for the area of the Wabasca Oil Sands, located between the Wabasca and Athabasca Rivers.

To the east of the occurrence of the Grosmont Formation, karst in lower Paleozoic layers also collects and transmits groundwater flow from the Cretaceous and Paleozoic layers into the Athabasca and the Clearwater Rivers. Due to the geometrical configuration of these two main rivers there exist three additional major regional groundwater flow systems, one to the south of Ft. McMurray in the area of the Stony Mountain Uplands and two more to the north of Fort McMurray east and west of this stretch of the Athabasca River. All of these systems have already been subjected to substantial water extraction and waste water injection.

Session No. 339

T160. Environmental Effects of Oil and Gas Development on Water Quality: Toward Sustainability and Stewardship
Wednesday, 22 October 2014: 1:00 PM-5:00 PM

Vancouver Convention Centre-West 109

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Impact of Paleozoic Karst upon Groundwater and Surface Water Flow in the Vicinity of the Athabasca Oil Sands

by
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Location of Athabasca oil sands, Alberta, Canada

Norman Einstein, 2006. http://en.wikipedia.org/wiki/Athabasca_oil_sands#mediaviewer/File:Athabasca_Oil_Sands_map.png

2



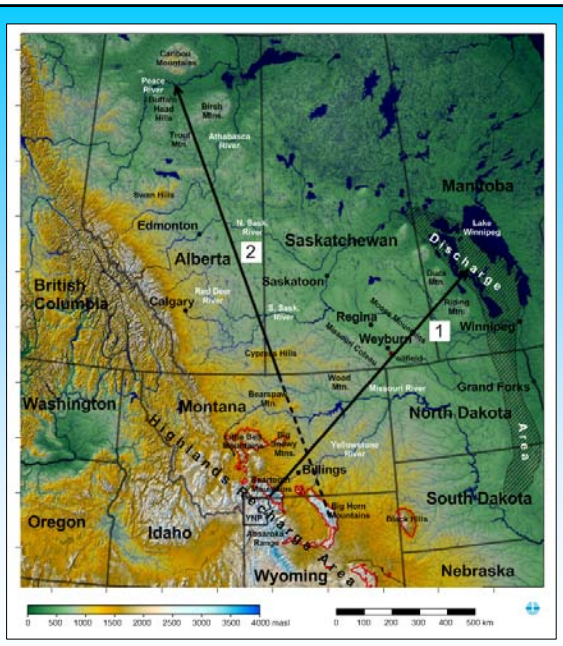
Previously postulated long-range deep groundwater flow systems from Montana to

(1) Manitoba (~ 1100 km)

(2) NE Alberta (~ 1600 km)

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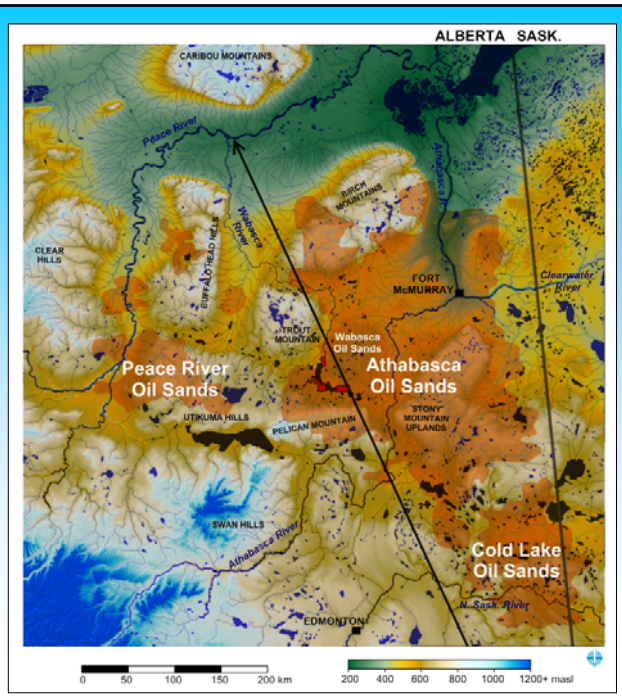
Postulates of a long range groundwater flow systems in the Northern Great Plains of North America.

(1) From area close to Yellowstone National Park to Manitoba over 1100 km (Downey et al., 1987)

(2) over 1600 km from the Big Horn Mountains in Montana to the Peace River in NE Alberta supposedly under-flowing the Athabasca oil sands [Bachu, 1999]. Dashed extension added by us.

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Relationship of the long-range flow system Montana to Peace River postulated by Bachu (1999) to the position of the Alberta oil sands .

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Recharge/discharge of deep aquifers

Legacy concept of regional groundwater flow

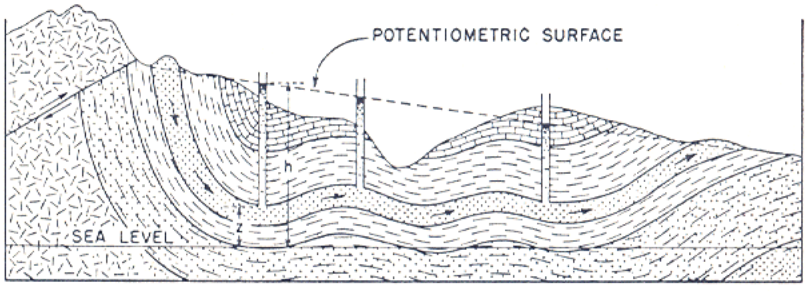
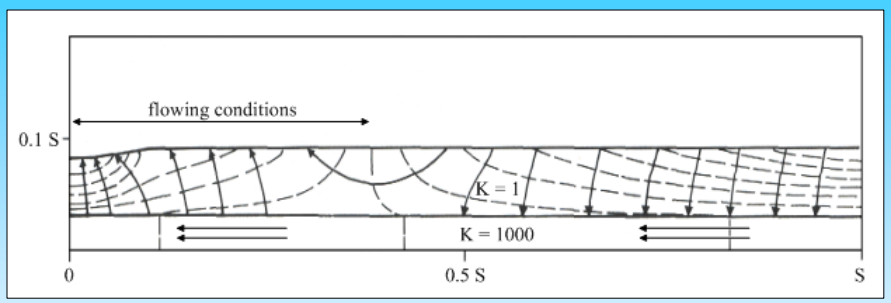


FIG. 11.—Regional flow of water through sand from higher to lower outcrop, showing continuous drop in potential.

Hubbert, 1953

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Freeze and Witherspoon, 1967, Figure 2C. Flow lines added.

Minimizing the total energy consumption.

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Continuity of flow between aquitard and aquifer
(under natural hydraulic conditions)

Flow volume (entering aquifer) = $-\text{grad}\,\Phi * A * \sigma$

= hydraulic force * area * fluid conductivity

and given that:

Flow leaving aquitard = Flow entering aquifer

therefore flow is balanced by:

(1) $\sigma_{aquitard} << \sigma_{aquifer}$

(2) $A_{aquitard} >> A_{aquifer}$

(3) $\text{grad}\,\Phi_{aquitard} >> \text{grad}\,\Phi_{aquifer}$

after Weyer, 1996

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Groundwater flow does not take the path of least resistance

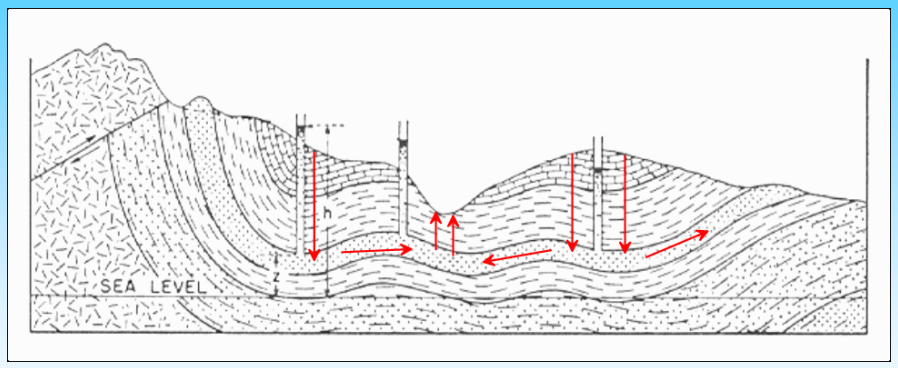
instead

the multitude of pathways are arranged such that the energy consumption in the entire flow field is minimized

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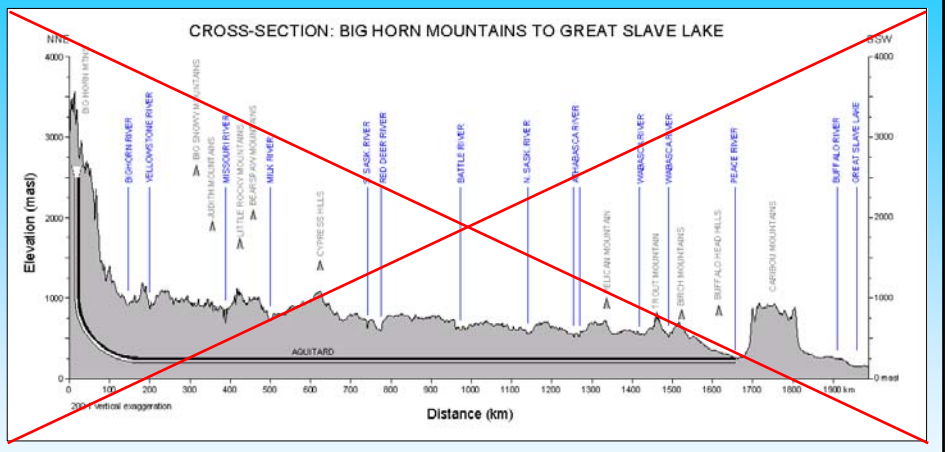


Revised concept of regional groundwater flow



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Schematic representation of the long range flow system Montana to Peace River postulated by Bachu (1999)

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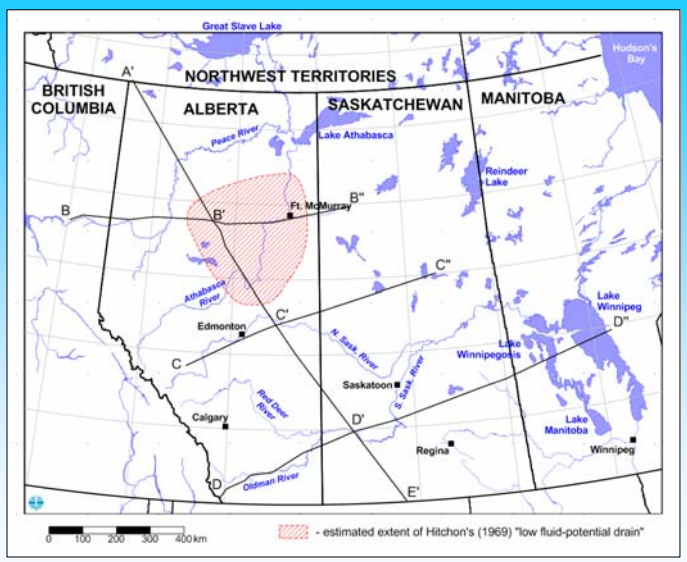


Groundwater flow systems in the vicinity of the Athabasca Oil sands

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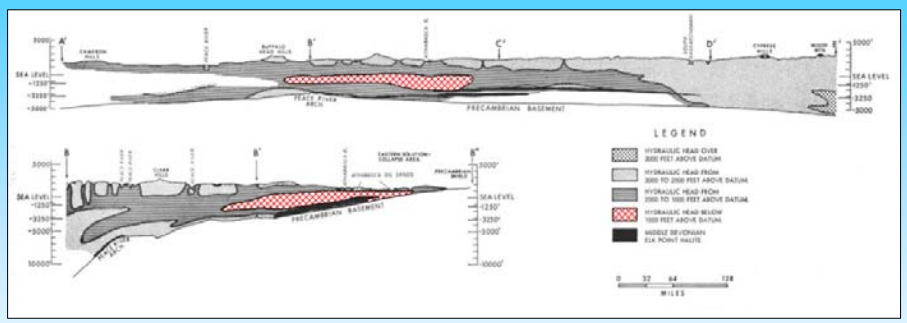




Red hatched area: estimated extent of Hitchon's (1969, Fig 3) low fluid-potential drain.

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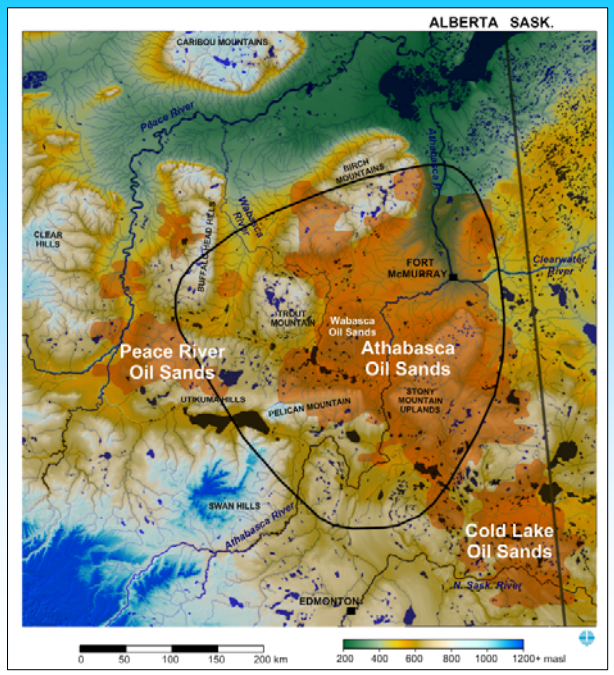
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Red hatched area: Hitchon's (1969, Fig 8) low fluid-potential drain.

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Schematically-estimated extent of Hitchon's (1969) "low fluid potential drain"

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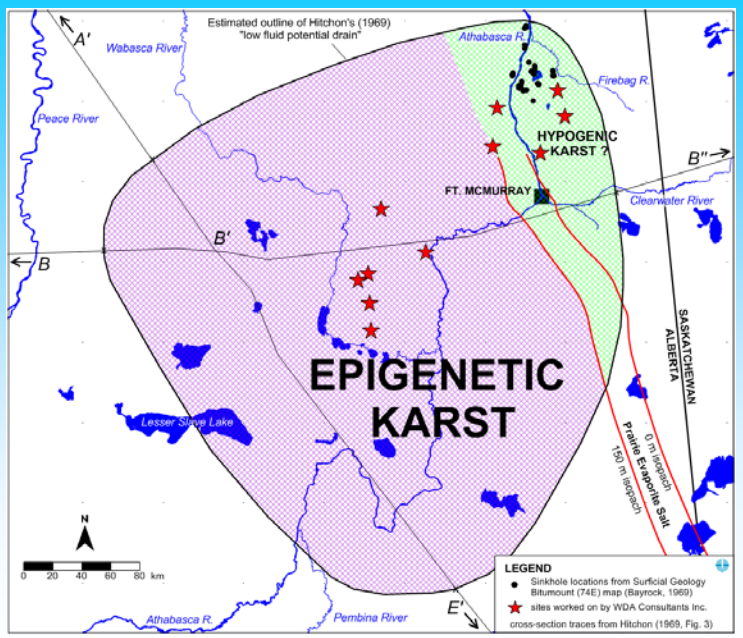


Paleozoic Karst

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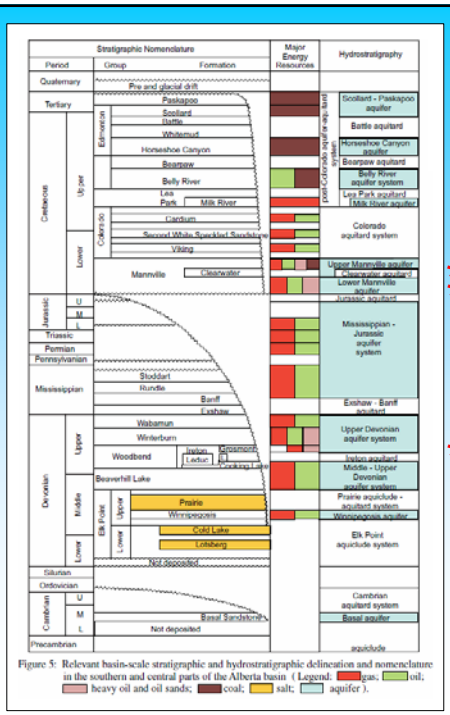


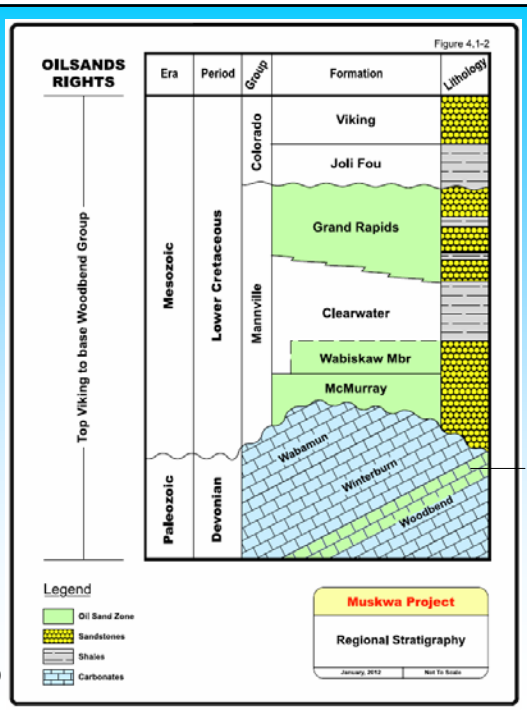
Figure 5: Relevant basin-scale stratigraphic and hydrostratigraphic delineation and nomenclature in the southern and central parts of the Alberta basin (Legend: gas; oil; heavy oil and oil sands; coal; salt; aquifer).

Regional stratigraphy column with hydrocarbon occurrence and hydrostratigraphy from Bachu et al. (2000).

* bitumen

* bitumen

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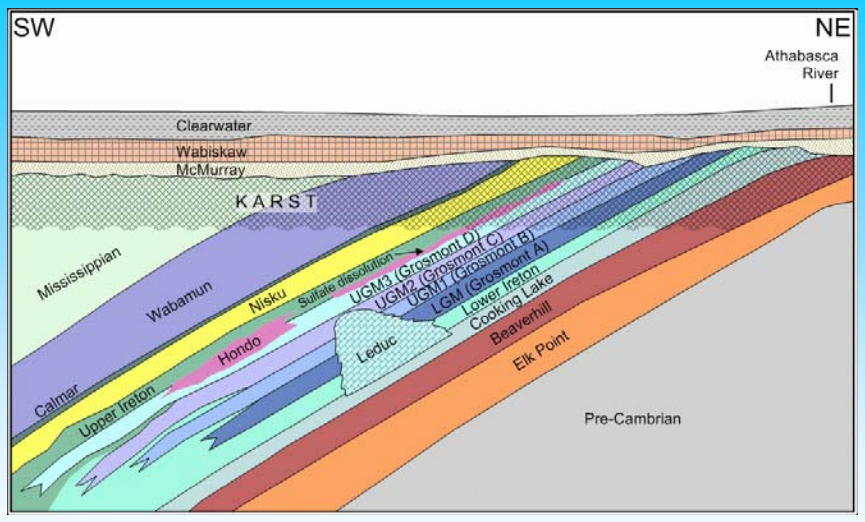


Grosmont

Regional stratigraphy showing the occurrence of bitumen in the Mesozoic and the Devonian Grosmont, as well as the Paleozoic unconformity.

Modified after Koch Exploration Canada LP, 2012, Application for Approval of the Muskwa Oil Sands Project. Submitted February, 2012, 263 p., Fig. 4.1-2

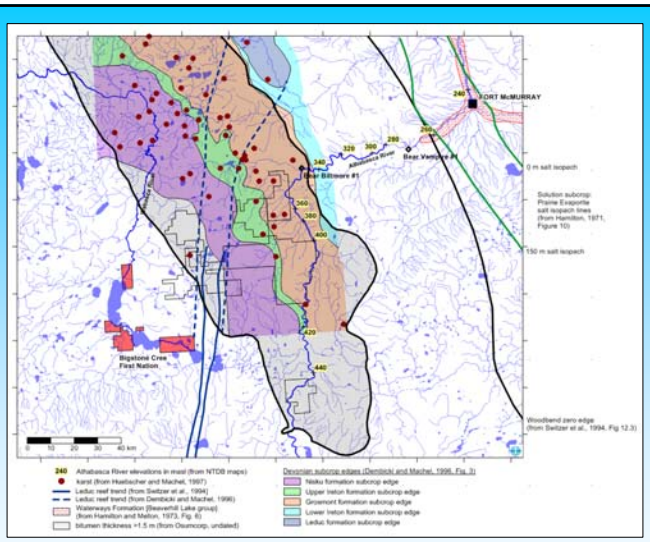
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Schematic SW-NE stratigraphic section (Weyer et al., 2013, Fig. 15). Actual SW-dip about 1°. Grosmont subdivided into A, B, C, D from the bottom up.

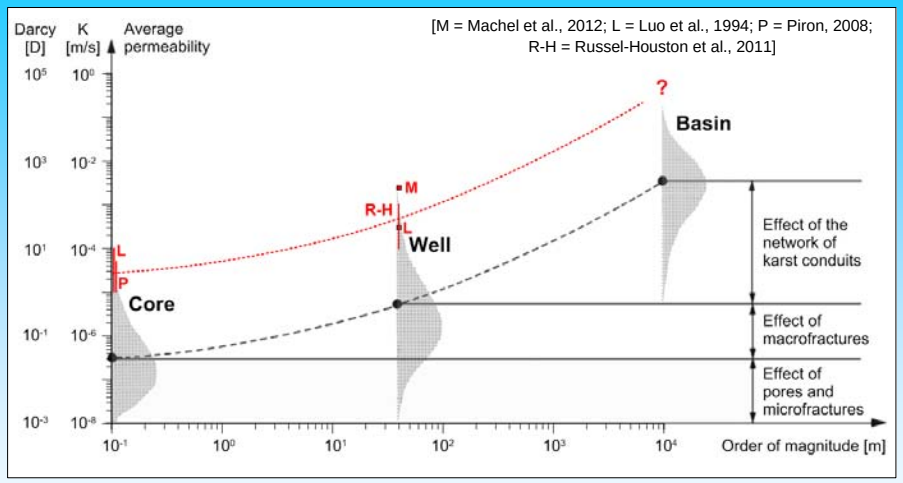
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Bitumen in the Grosmont platform, karst in boreholes within the Grosmont Formation, and river water elevations in the Athabasca Canyon, the regional discharge area [From Weyer et al., 2013, Figure 11.]

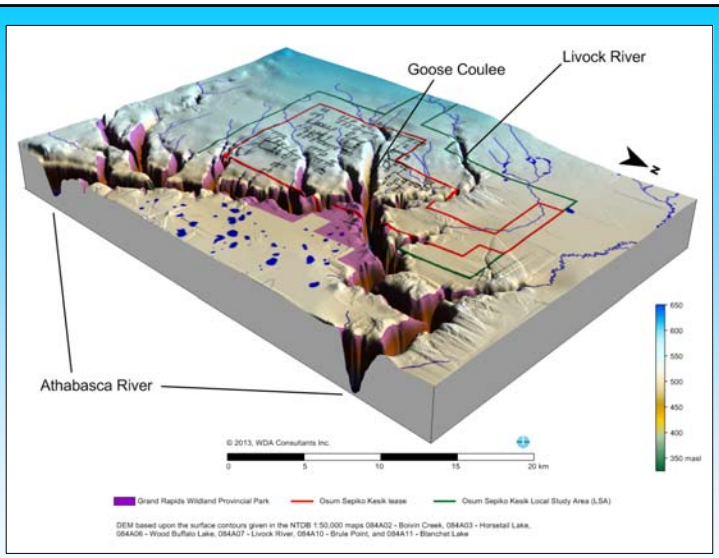
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Effect of scale on permeability in karst. Literature data for the Grosmont reservoir added.
Hundreds of Darcies at the well scale.
Speculation of possibly thousands of Darcies in a basin-scale network of karst conduits.

From Weyer et al., 2013, Figure 17 (black curve and framework from Kiraly, 1975, Fig 19)

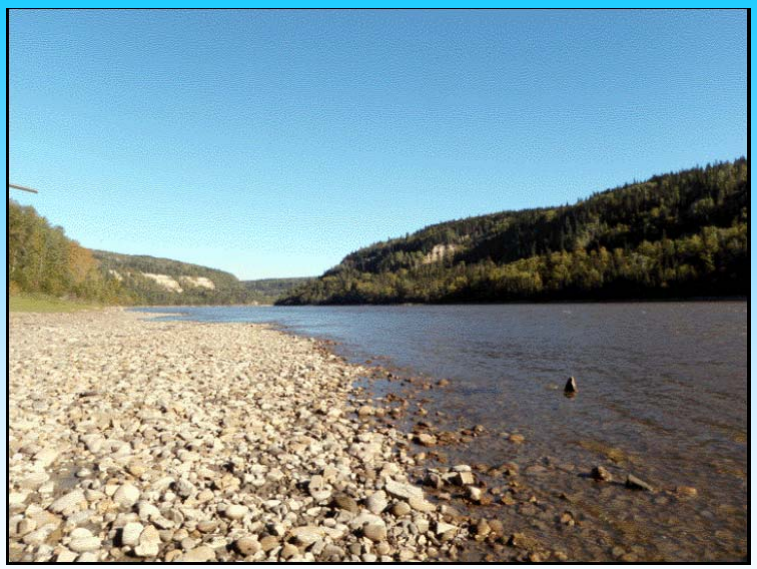
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DEM of the Sepiko Kesik lease site (site plan taken from Osum, 2013) with the incised Athabasca River canyon.

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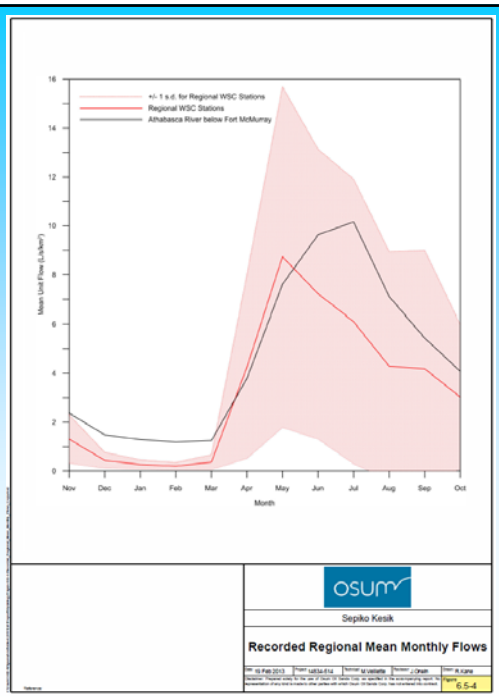
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Canyon of the Athabasca River viewing downstream. Picture from Osum, 2013, Fig. 8.5-9.

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Recorded Regional Mean Monthly Flows. From Osum, 2013, Fig 6.5-4.

Winter flow of the Athabasca River suggests substantial groundwater discharge from the Upper Devonian karst.

One l/sec km^2 is equivalent to 32 mm annual precipitation.

Athabasca River below Ft. McMurray gaging station 07DA001
Gross drainage area: 132,585 km^2

25

Recorded mean monthly flows in January in the Athabasca River at Station 07DA001 near Ft. Mc Murray downstream of confluence with the Clearwater River

	catchment area	area	January			recharge
			normalized discharge	river flow		
		km^2	l/s km^2	l/s	m^3/s	mm/a
	A	B	C	D		E
	measured normalized flow: (from hydrographs)					
1	Regional WSC stations (red hydrograph)	--	0.3	--	--	10
2	Athabasca/Clearwater basin (black hydrograph)	132,000	1.3	171,600	171.6 [1]	42
3	Non-karstic part within A/C basin	86,900	0.3	26,100	26.1 [2]	10
	calculated flow from karst:			145,500	145.5 [3]	
4	Total LFPD - Hitchon drain (Paleozoic karst)	102,000	1.4 [4]	--	--	**46**
5	Karst within the A/C basin	45,100	3.2 [5]	--	--	**103**
6	Karst within A/C basin + assumed subsurface drain	67,900	2.1 [6]	--	--	**69**

Notes:
- 1 l/s km^2 is equivalent to approximately 32 mm/a of precipitation
- LFPD = Low Fluid Potential Drain (Hitchon, 1969)
- [1] B2 x C2 [2] B3 x C3 [3] D2 - D3 [4] D5 / B4 [5] D5 / B5 [6] D5/B6

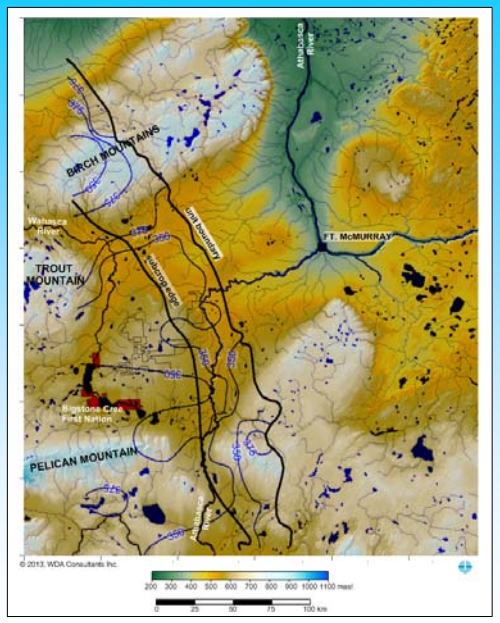
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Regional groundwater flow: Wabasca oil sands

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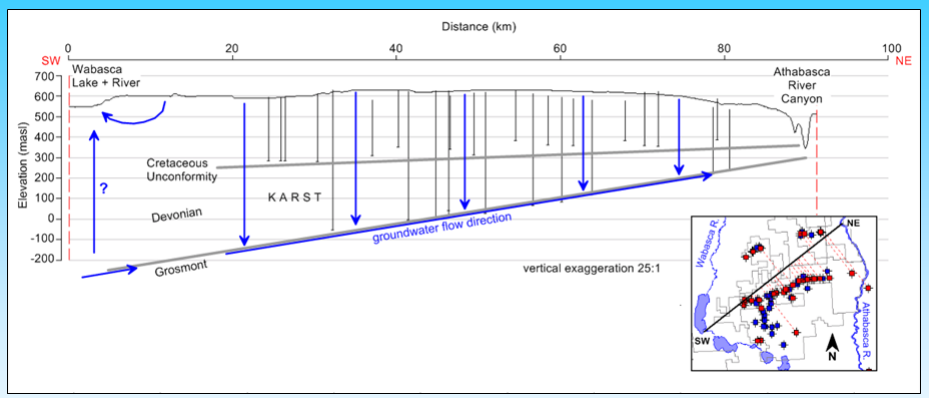


Pre-industrial hydraulic heads in the Grosmont aquifer system.

From Bachu et al. (1993, Figure 20b) with topography added indicating the elevation of the groundwater table.

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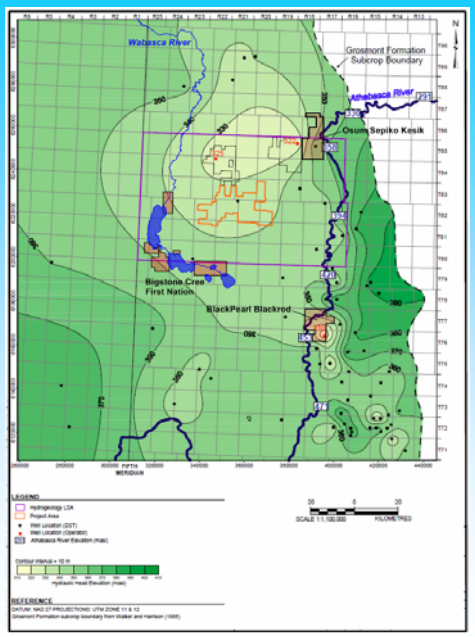
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Schematic SW-NE cross-section from the town of Wabasca-Desmarais (SW) to the east bend of the Athabasca Canyon (NE) with deduced pre-industrial groundwater flow directions.

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Hydraulic head distribution in the undifferentiated Grosmont formation.

Modified from Cenovus (2011, Figure 44).
Prepared by Westwater

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Summary

1. The postulated groundwater ‘pipeline’ from Montana to the Peace River in NE Alberta does not exist.
2. In the area of the Athabasca Oils sands the Paleozoic karst at the unconformity between Mesozoic and Paleozoic layers collects groundwater flow from the surface and from greater depth and delivers nearly all of it towards the Athabasca and Clearwater Rivers.
3. Within the Wabasca oil sands recharged groundwater flows vertically downwards into the karstic Paleozoic layers and from there through the highly permeable Grosmont Formation towards the Athabasca River.
4. Waste water injected within the Wabasca oil sands flows towards the Athabasca River.

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