In Search of a Cordilleran Point Source to the McMurray Sub-Basin*

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Abstract

The sub-Cretaceous Unconformity (SCU) comprises a complex drainage pattern that controlled the delivery of sediments to the oilsands-hosting McMurray sub-basin. On its western margin, the McMurray sub-basin is constrained by Red Earth and Wainwright Highlands, and the Grosmont Ridge as well as others. Recent work has shown that the majority of sediments delivered to the McMurray sub-basin are derived from the southeastern United States and the Canada Shield. However, the highlands on the western flank of the sub-basin are periodically intersected by valleys that may have acted as sediment delivery conduits for Cordilleran sourced sediments. A combination of isopach mapping and petrographic analysis of 54 thin section from the southern end of the McMurray sub-basin (Twps. 50 to 70, Ranges 5 to 17 W4) are studied to identify if, and to what extent, Cordilleran sediments reached the McMurray sub-basin. Preliminary results demonstrate that the vast majority of sediments consist of detrital quartz, of which approximately 92% of grains are monocrystalline and 3% are polycrystalline. Some detrital quartz grains also have sillimanite, rutile, or vacoule inclusions, which reflects the granitic (sillimanite and rutile) or hydrothermal (vacuole) origin of the quatz. Moreover, the presence of detrital feldspar and polycrystalline quartz support a Canadian Shield and/or Appalachian provenance for the sediment. Evidence of a Cordilleran point source at the south-end of the McMurray sub-basin is not evident based on the mineralogy of the sediments. The mineralogical work presented herein confirms interpretations that McMurray Formation sediments are derived almost exclusively from the Canadian Shield and southeast United States, and that western highlands effectively blocked Cordilleran sediments from reaching the sub-basin. Moreover, the rivers that fed into the McMurray sub-basin from the west were likely small, and hence are unlikely to contain significant quantities of bitumen or other hydrocarbons.

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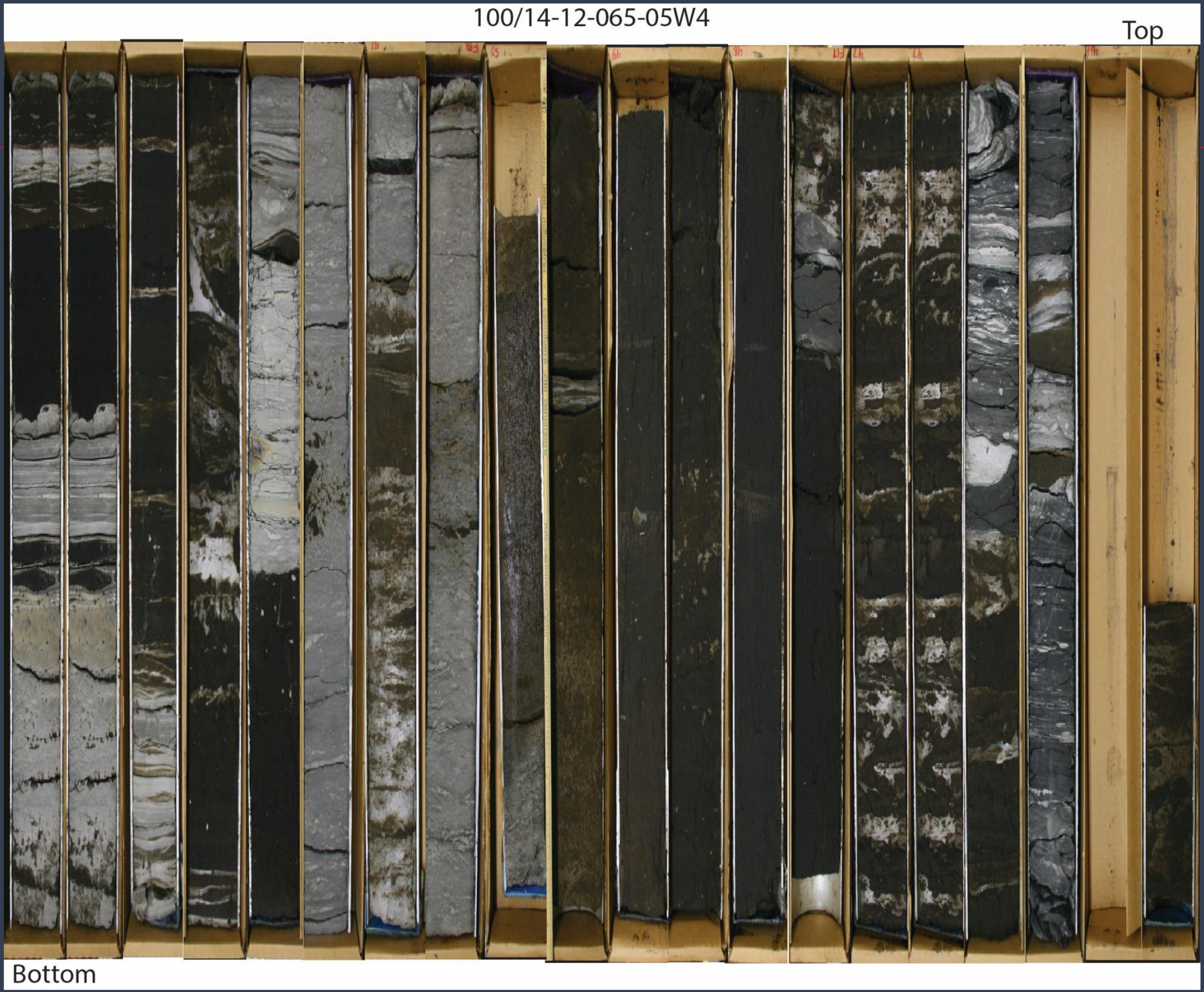
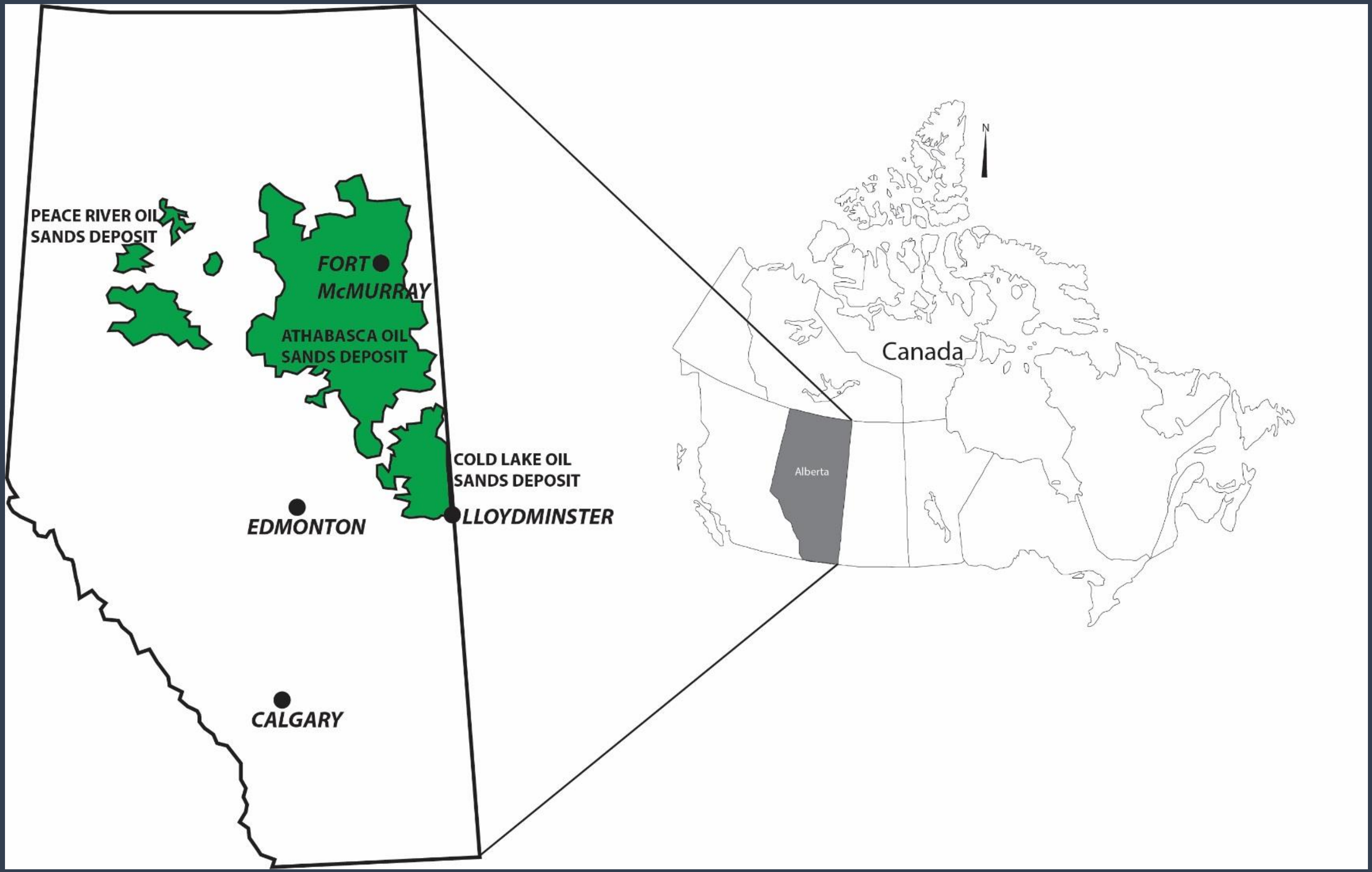
Outline



- Introduction
- Objectives
- Stratigraphy
- Study Area
- Methodology
- Results
- Conclusions

Introduction

- Contains largest proven reserves of oil sands in the world (~168 billion barrels)
- Reserves hosted mainly in the McMurray Formation
- Grosmont-Wainwright Highlands prevented Cordilleran sediments from reaching the McMurray Sub-Basin
- Sediment Sources:
    1. Canadian Shield
    2. SW or SE USA



Modified from Einstein, 2006

Objectives

1) Ascertain if the Grosmont-Wainwright Highlands prevented Cordilleran sediments from reaching the McMurray Sub-Basin from the south and southwest.

2) Quantify the percentage of Cordilleran sediments that reached the McMurray Sub-Basin

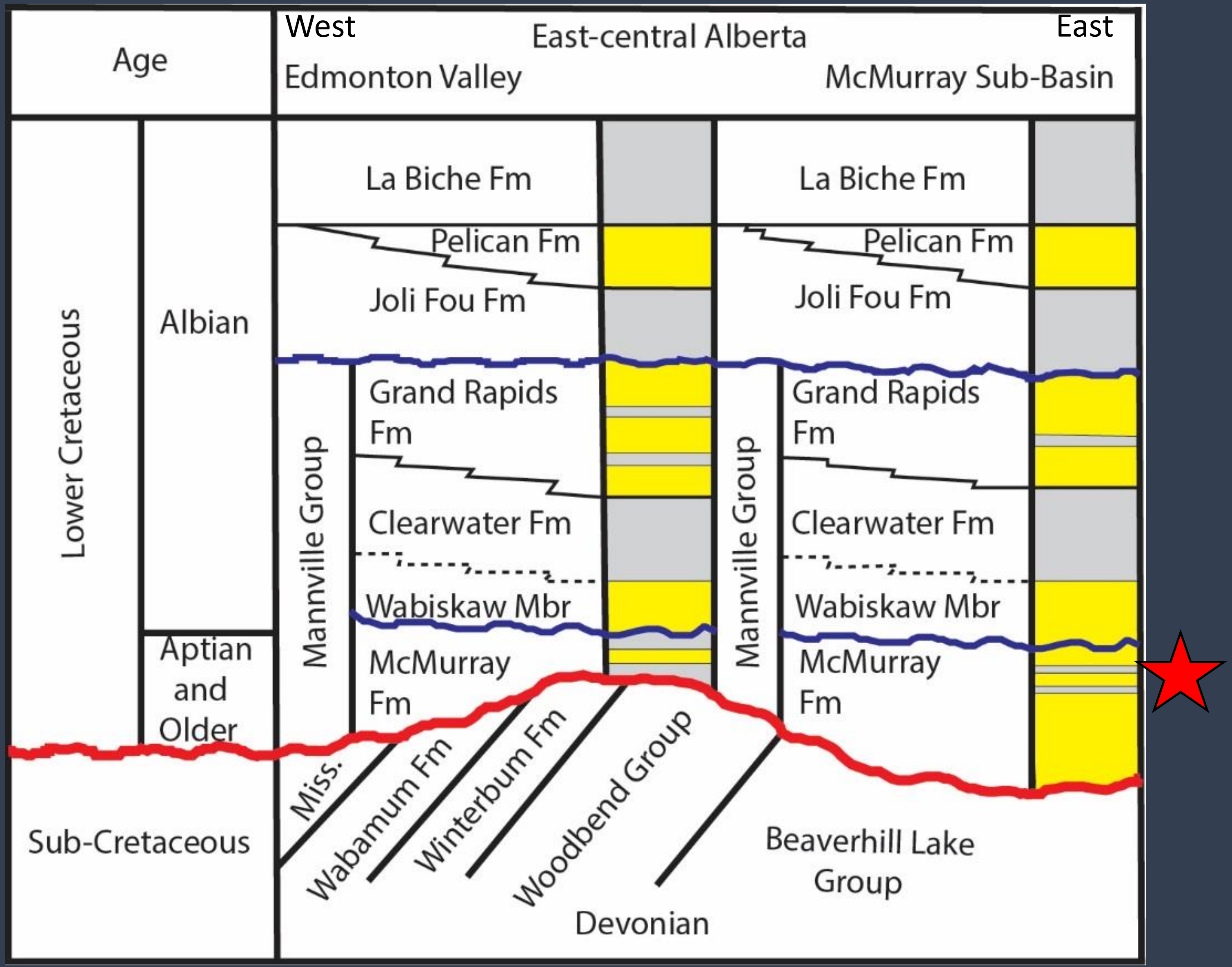
3) Identify any variation in mineralogical composition of the McMurray Formation among paleo-valleys carved into the Wainwright Highland (southern McMurray Sub-Basin)

4) Demonstrate the impact of mineralogical composition on porosity and permeability of McMurray Formation sandstones

Stratigraphy of McMurray Formation

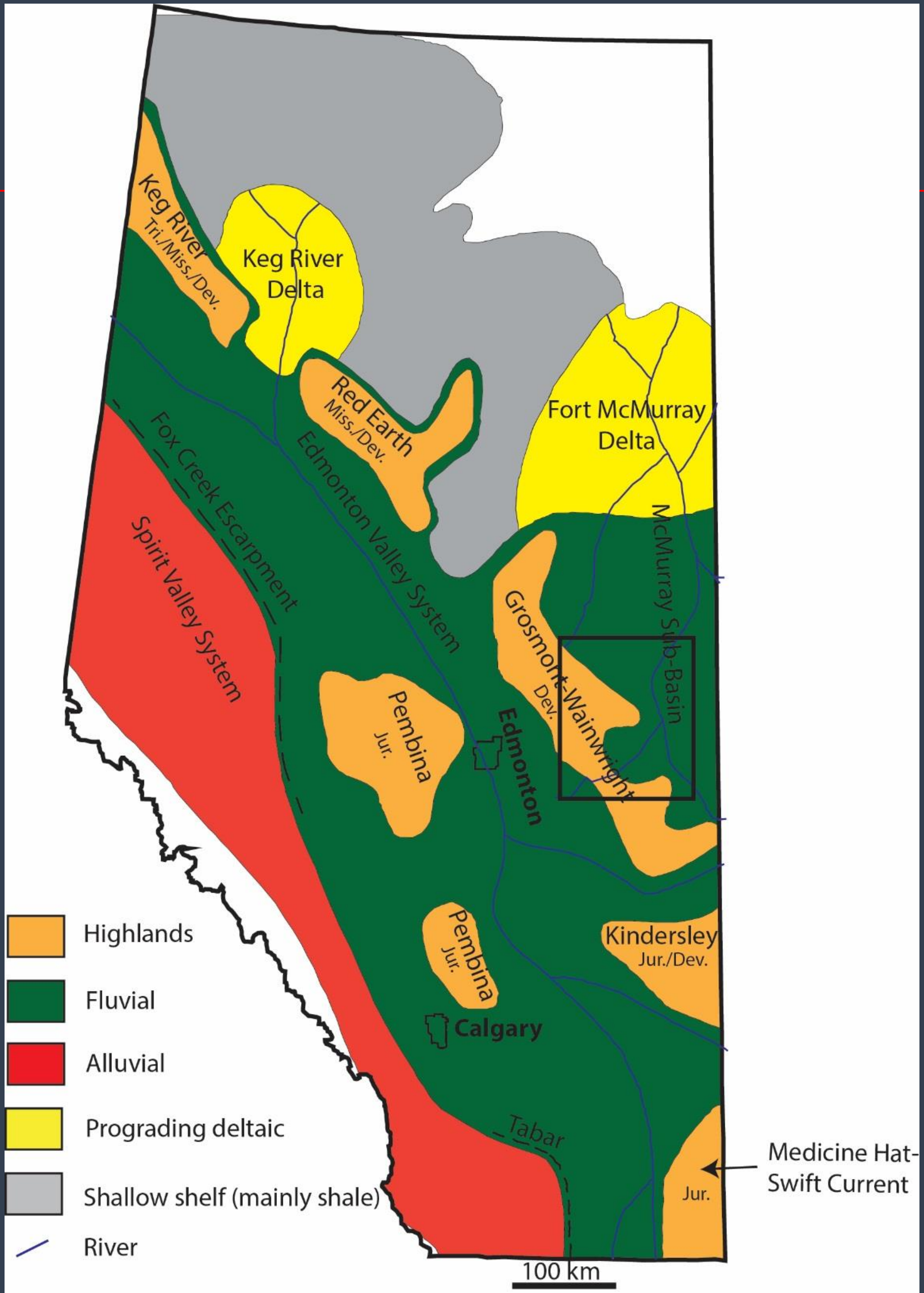
Unconformably overlies Paleozoic carbonates, and is overlain by Wabiskaw Mbr

Subdivided into lower, middle and upper McMurray



Modified from Wightman et al., 1995

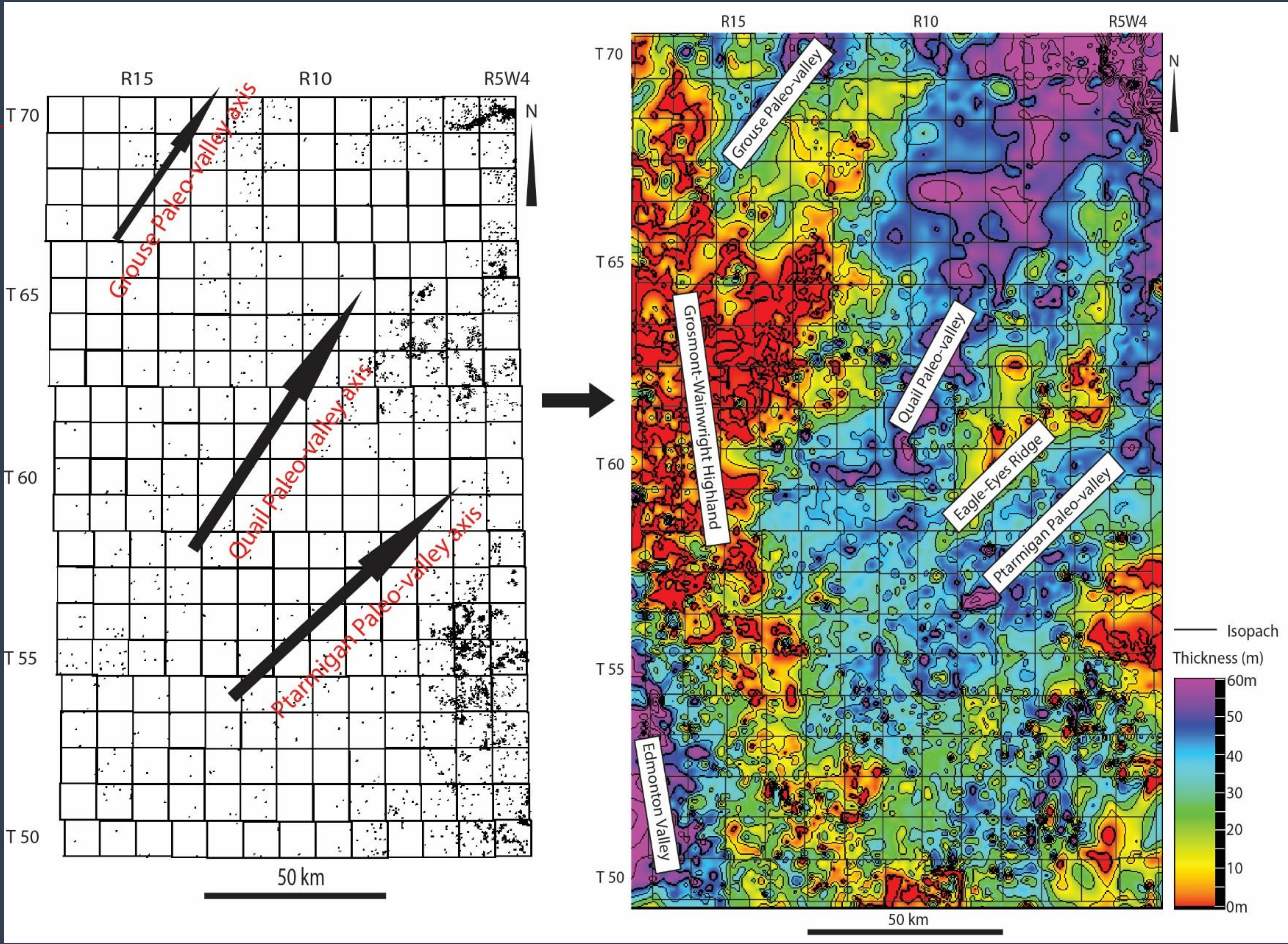
Study Area



- Location: east-central Alberta
- Number of wells: 7228
- Wainwright-Grosmont Highlands, McMurray Sub-Basin and Edmonton Valleys are intercepted
- The SCU comprises three NE-trending paleo-valleys

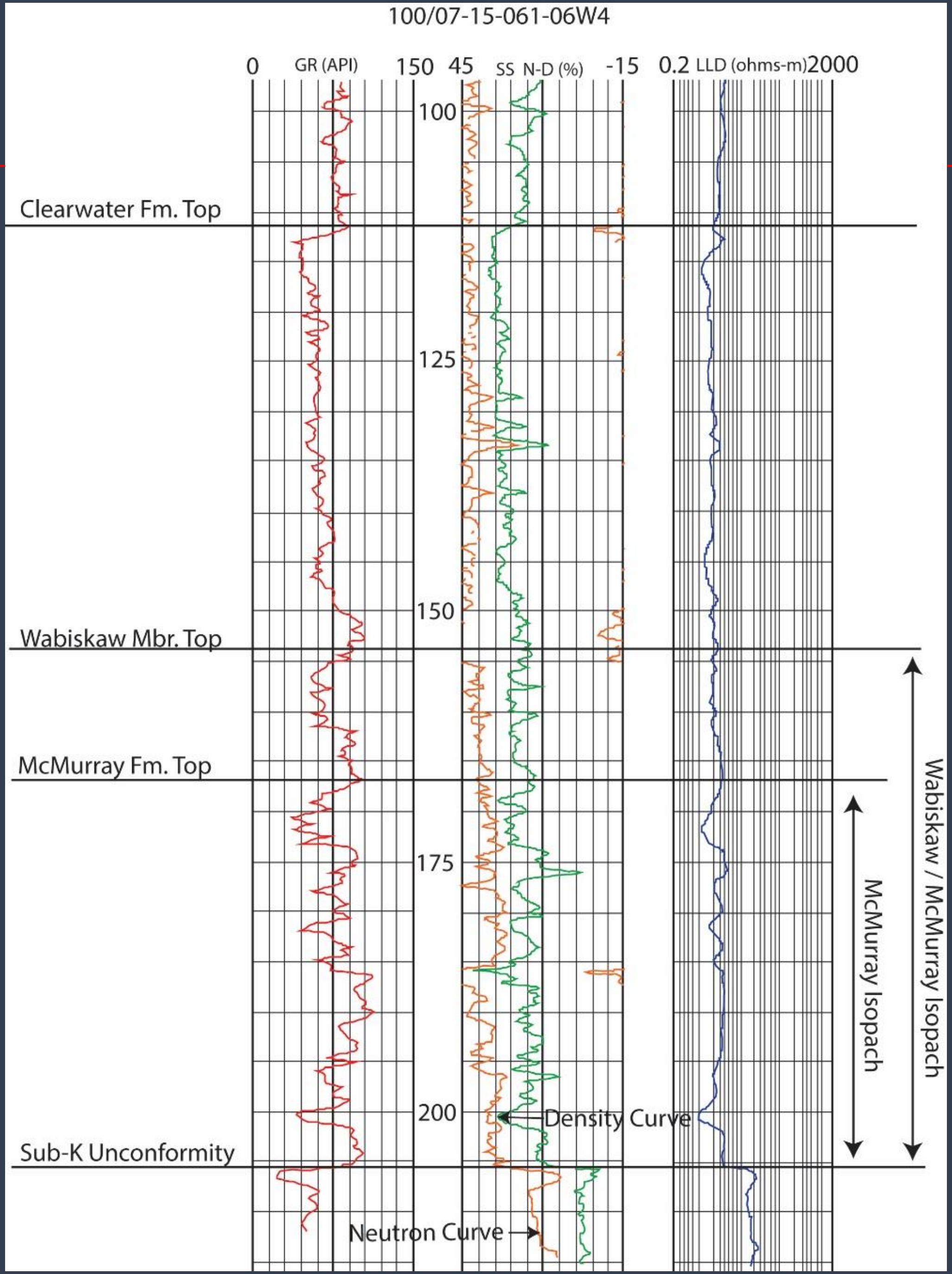
Modified from Smith, 1994

Study Area



Wainwright-Grosmont Highlands, McMurray Sub-Basin and Edmonton Valleys are intercepted

The SCU comprises three NE-trending paleo-valleys: Grouse, Quail, and Ptarmigan Paleo-valleys



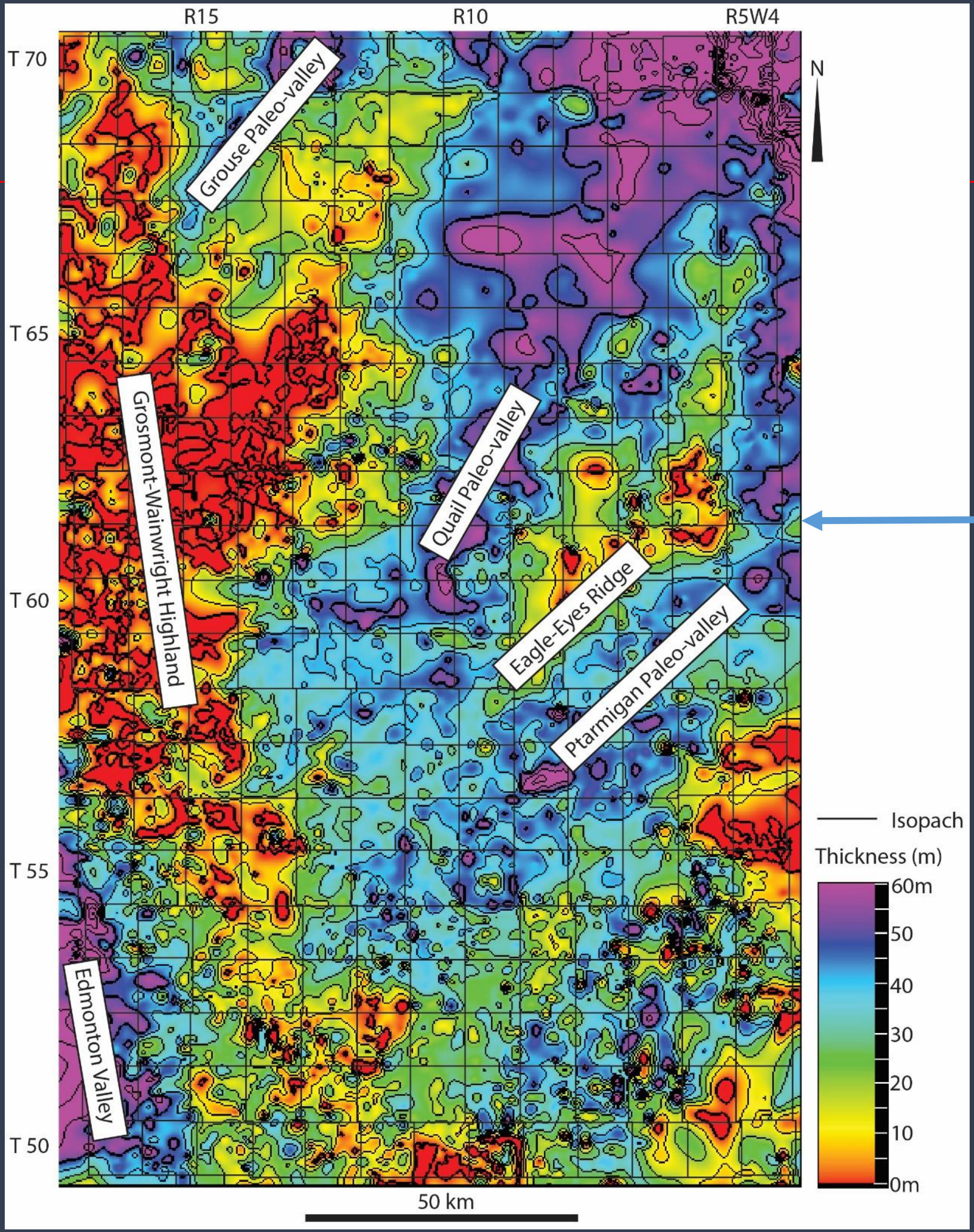
Isopach Mapping

Surfaces picked in 7228 wells:

Wabiskaw Mbr Top

Top McMurray Fm

Sub-K Unconformity



Isopach Mapping

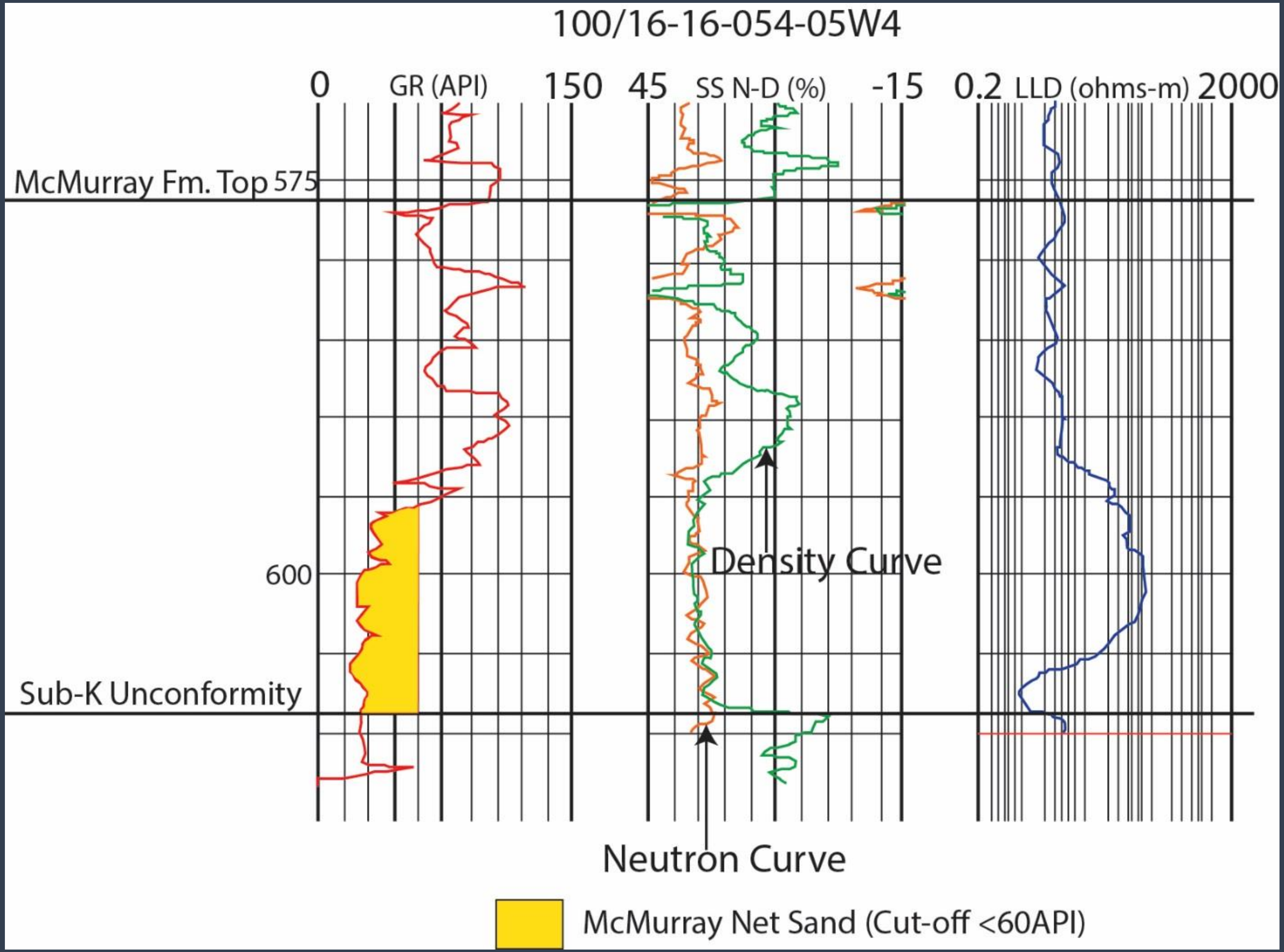
Maps generated:

McMurray Isopach

Wabiskaw-McMurray Isopach

Net-sand Mapping

Used a sandstone cutoff of <60 API on gamma ray curve



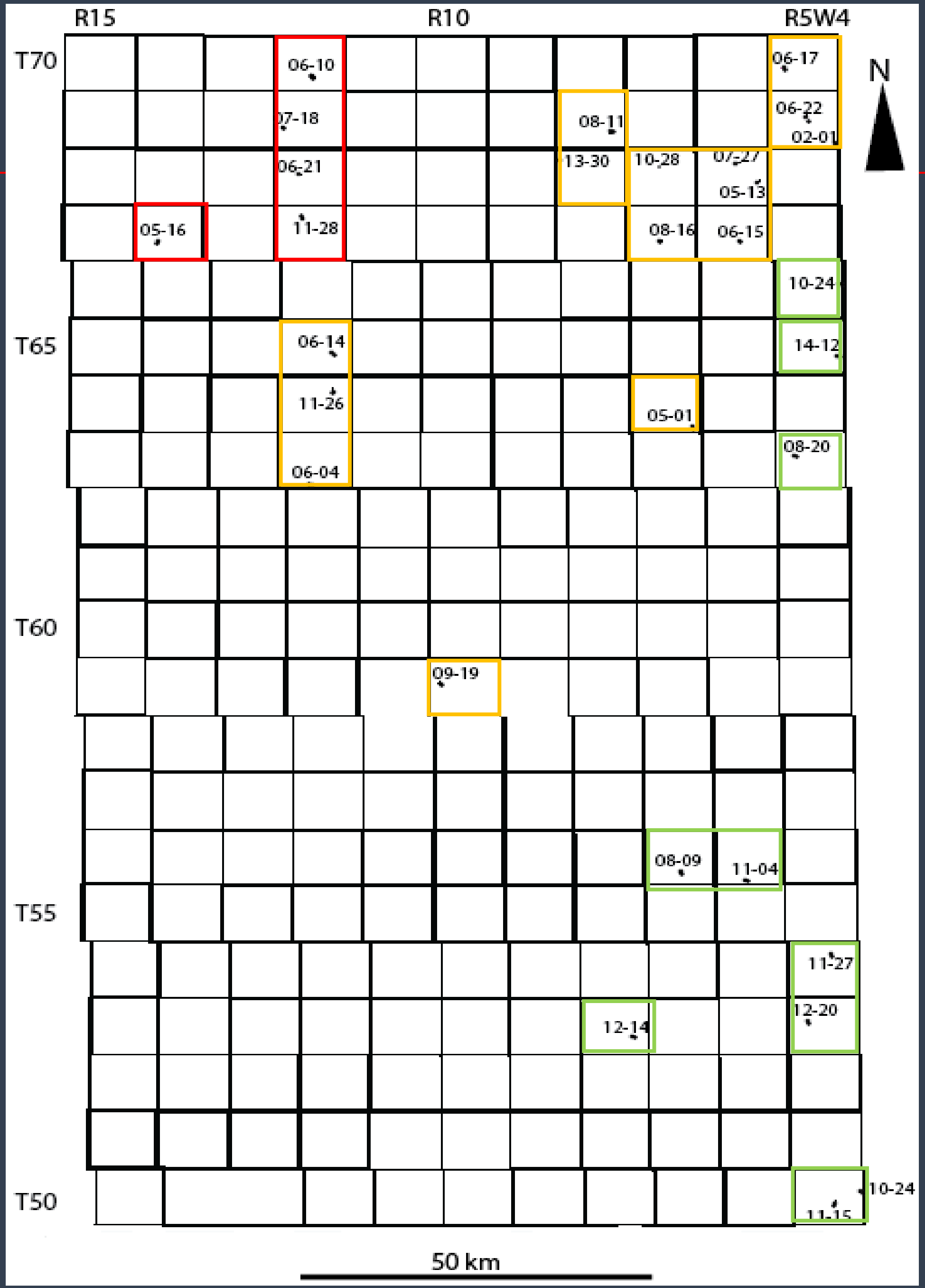
Thin Section Analysis

Dataset: 55 samples (26 cores)

Point count method: average 508 grains counted per thin section

Chert and quartzite are counted as lithic fragments

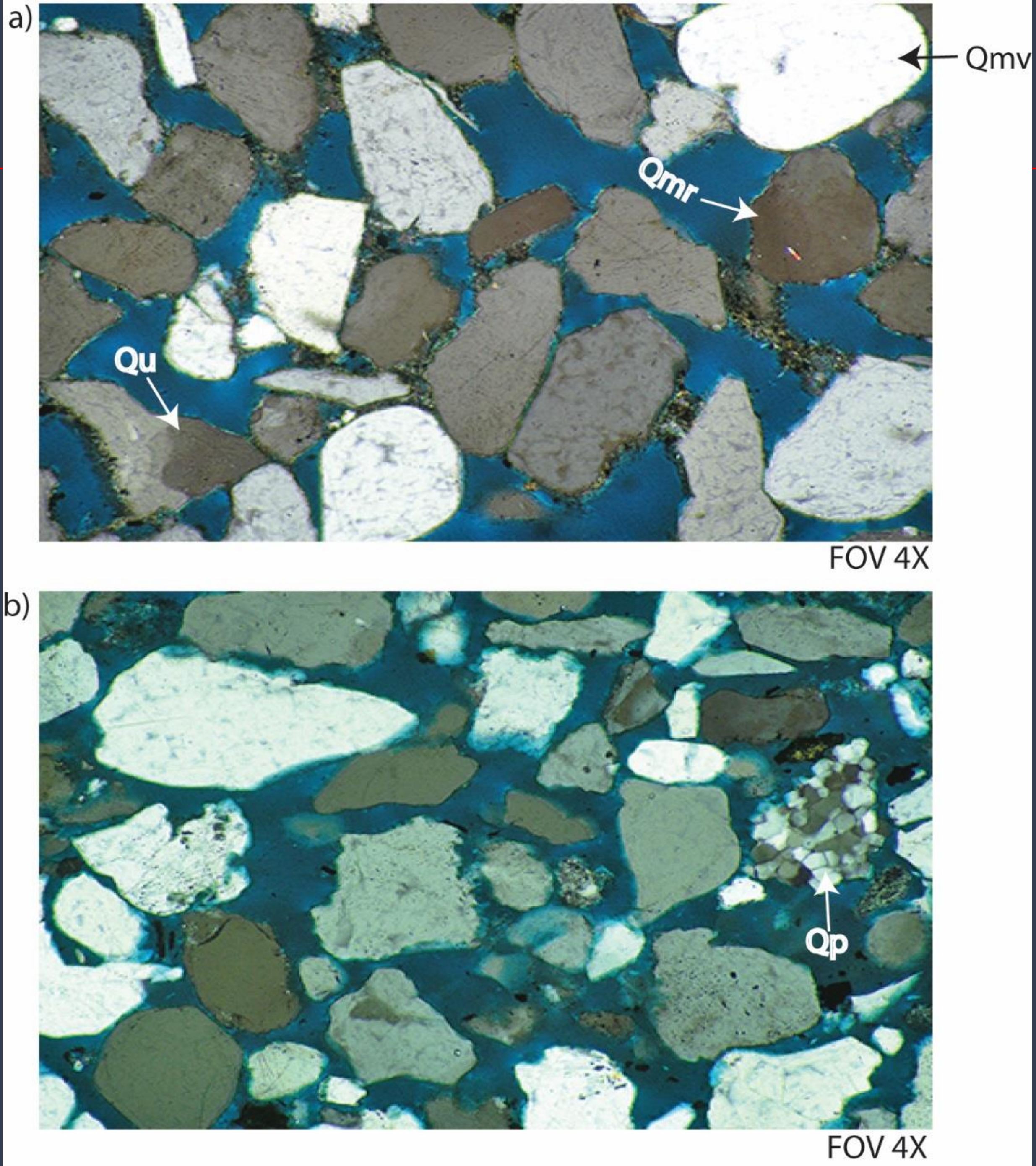
Folk (1974) sandstone classification scheme used to name sandstones



Cores sampled from Ptarmigan

Cores sampled from Quail

Cores sampled from Grouse

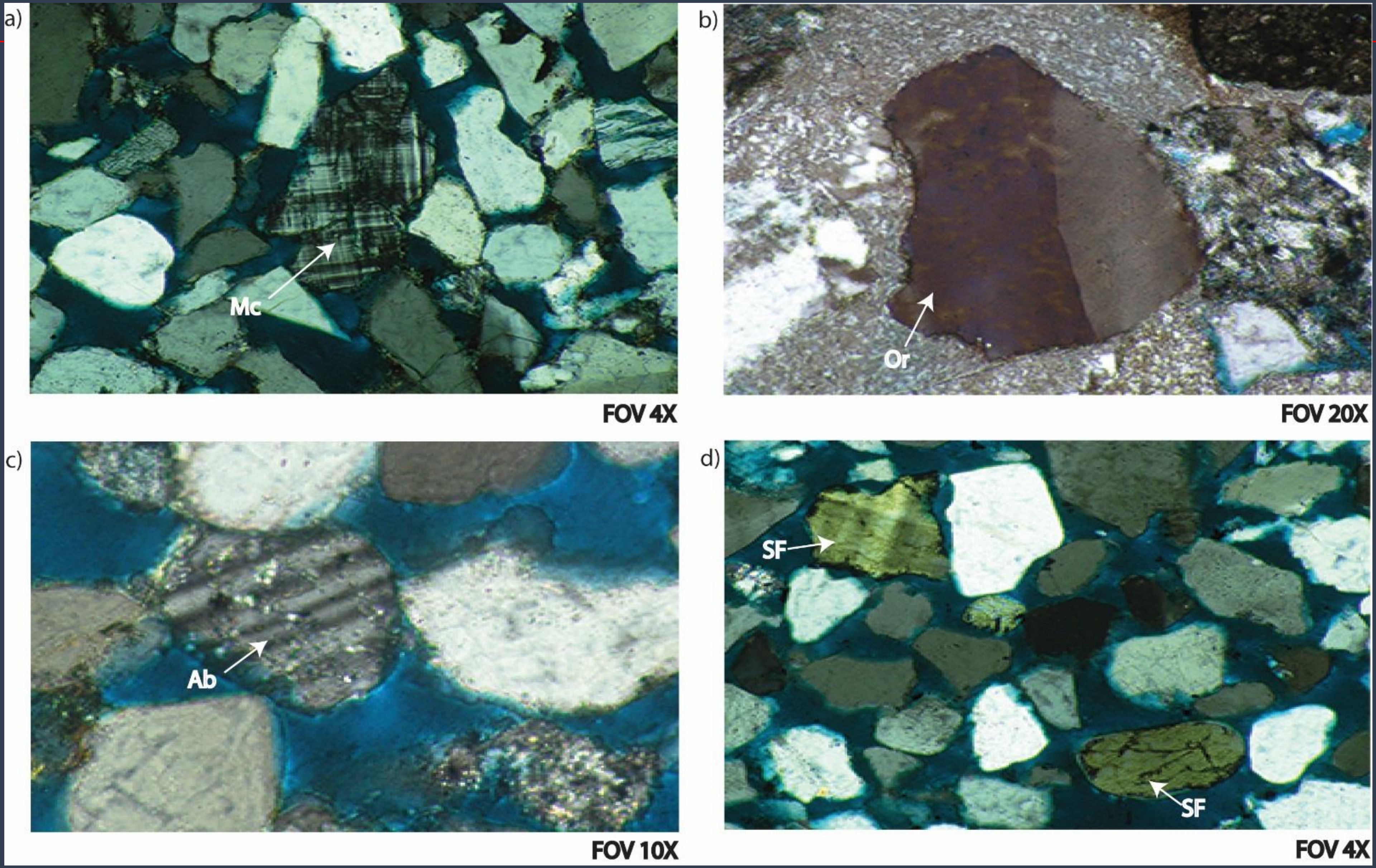


Bulk Mineralogy

Quartz:

- Monocrystalline (99%) vs polycrystalline (1%)
- Texture
- Inclusion: vacuole vs needle like

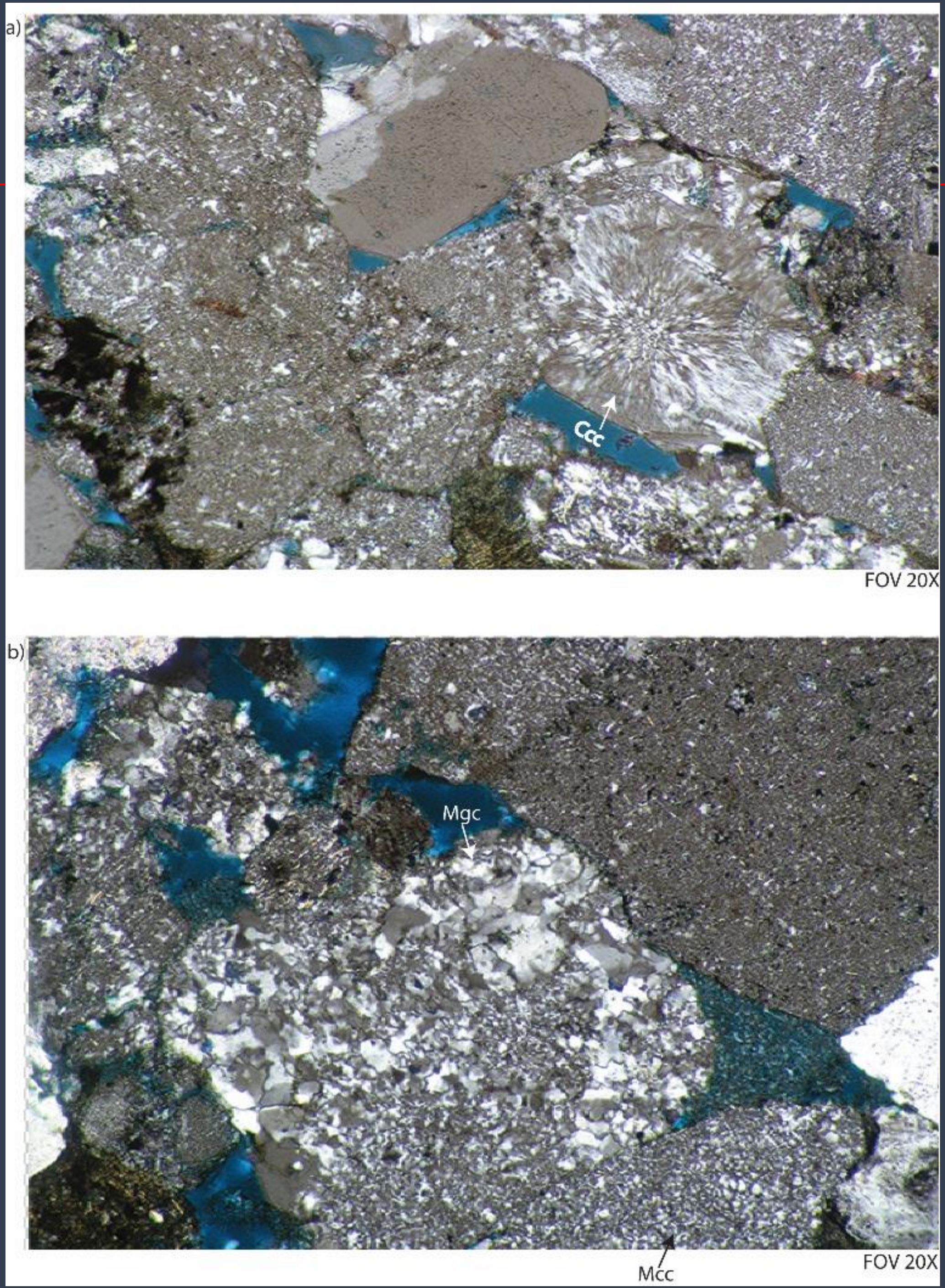
Results



Bulk Mineralogy

Feldspar

- Consists of 87% orthoclase, 10% albite and 3% microcline
- Texture
- Appearance

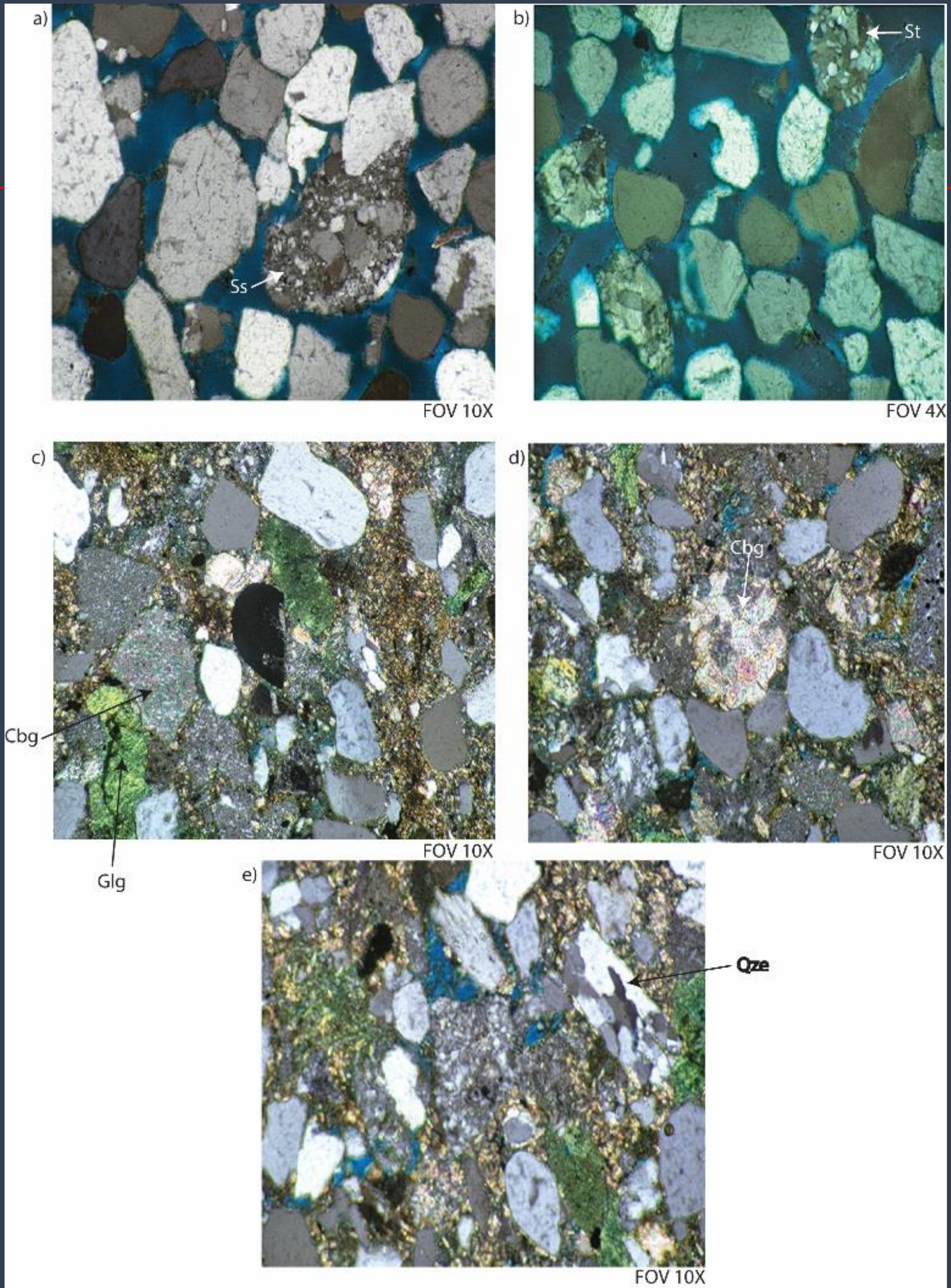


Bulk Mineralogy

Lithic Fragments

- Consist of 90% chert (micro vs mega) and 10% others
- Texture

Results



Bulk Mineralogy

Lithic Fragments (others)

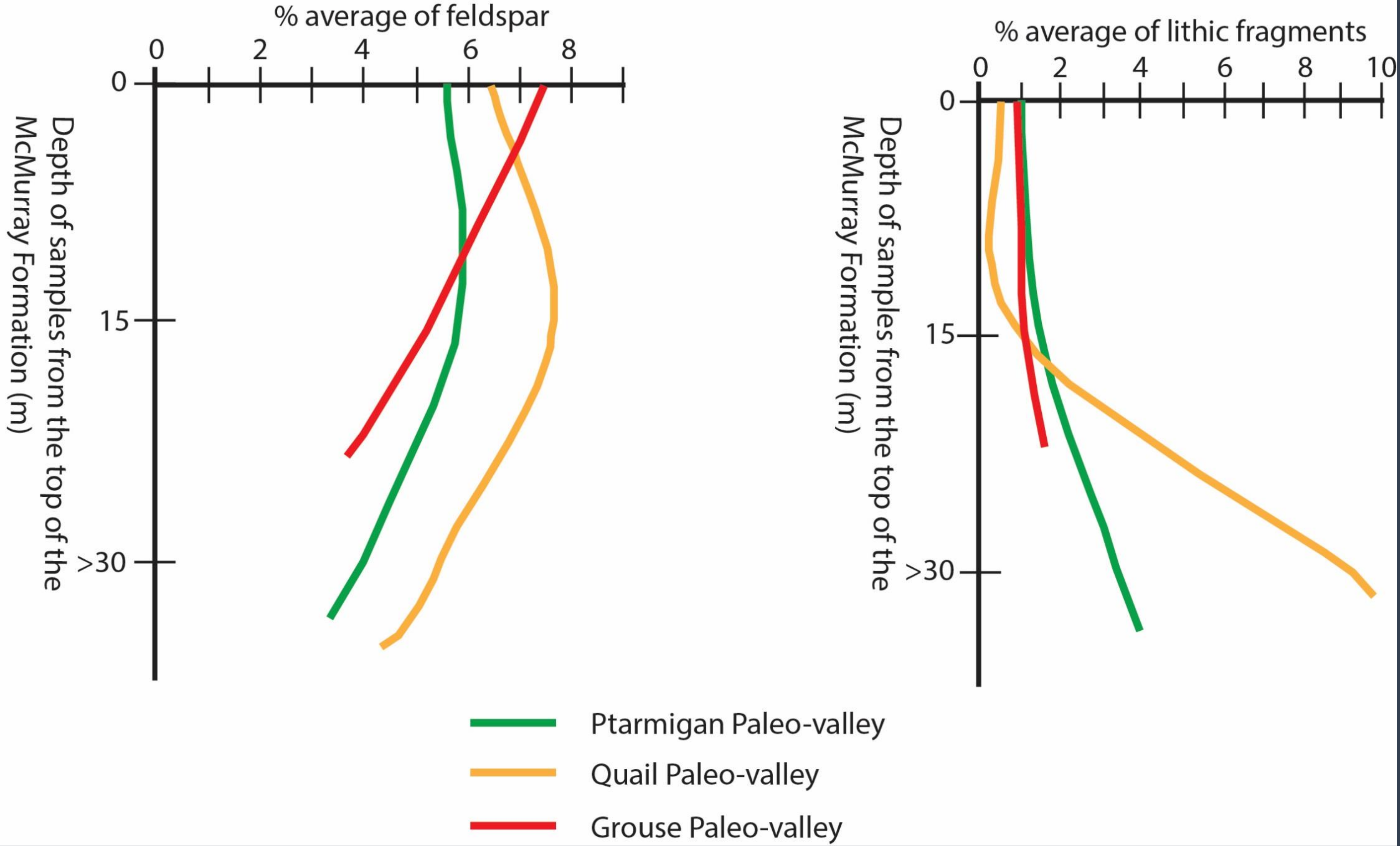
- Consist of 90% chert (micro vs mega) and 10% others
- Texture

Results

Vertical Variation in Mineralogy by Channels

Paleo-valleys	Number of samples	Ranges of depth of samples from the top of the McMurray Formation (m)	Quartz		Feldspar		Lithic Fragments	
			Ranges (m)	Averages (%)	Ranges (%)	Averages (%)	Ranges (%)	Averages (%)
Ptarmigan	9	Within 0-14.99	80.00-95.51	91.01	3.29-11.25	5.62	0.00-2.07	0.93
	10	Within 15-29.99	83.51-96.25	91.20	1.87-9.77	5.85	0.08-4.92	1.50
	2	Greater than 30	85.25-92.91	89.10	3.69-4.45	4.07	0.56-5.55	3.48
Quail	9	Within 0-14.99	76.28-94.30	89.46	3.6-14.13	6.43	0.20-1.03	0.41
	9	Within 15-29.99	74.34-91.60	86.10	4.20-14.14	7.67	0.00-2.13	1.01
	7	Greater than 30	49.70-94.62	82.88	2.57-8.88	5.50	0.10-36.51	9.36
Grouse	4	Within 0-14.99	76.15-92.15	85.69	2.31-16.33	7.47	0.46-1.71	0.88
	5	Within 15-29.99	88.83-94.24	91.64	3.32-6.83	5.31	0.07-1.39	1.05

Vertical Variation in Mineralogy by Channels

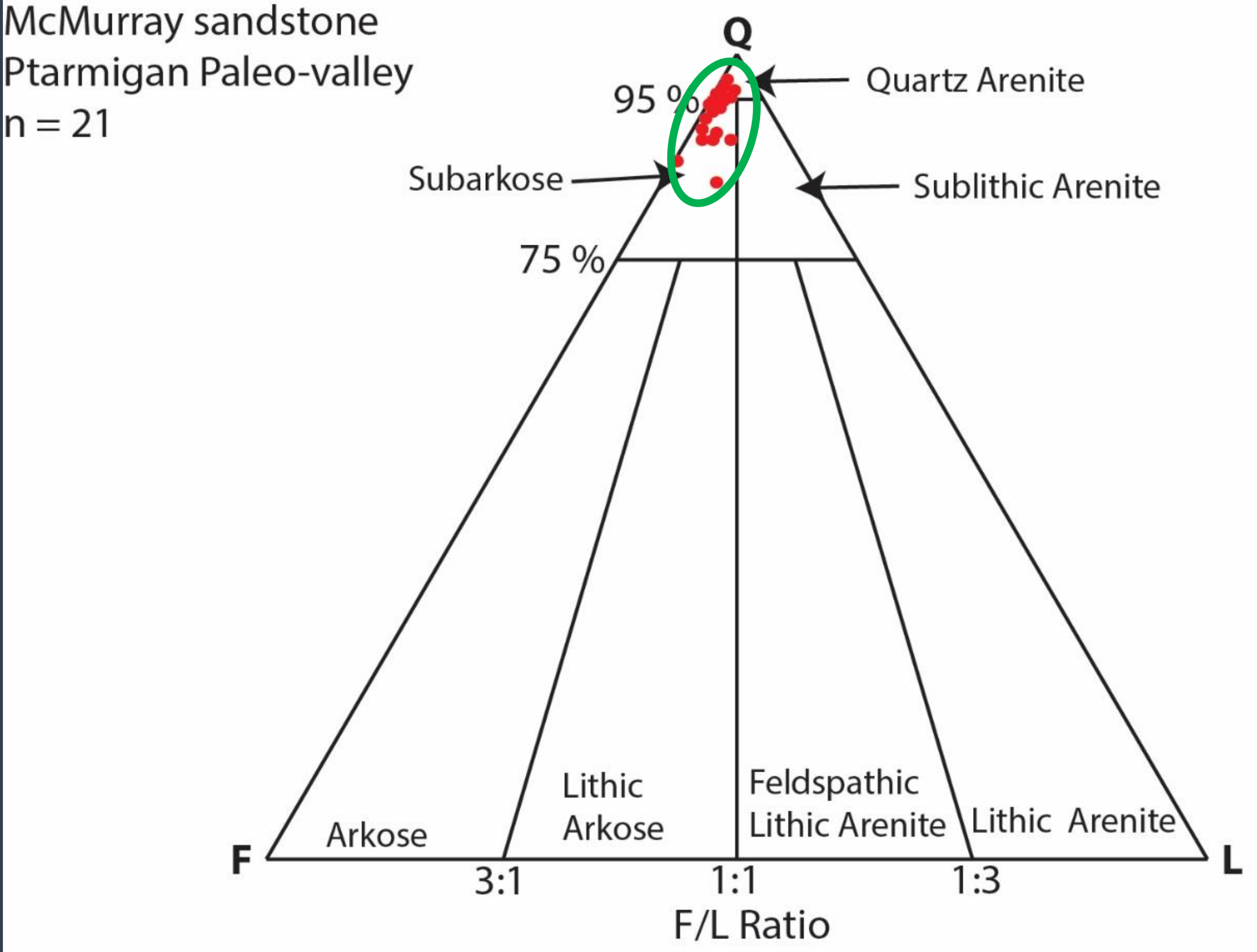


- Feldspar decrease with depth
- Lithic Fragments increase with depth

Comparison of published mineralogical data with present study

Formation (Area/valley)	Quartz (%)	Feldspar (%)	Lithic Fragments (%)	Authors
McMurray Fm. (Athabasca)	89-95	5-7	2-4	Hein et al. (2012)
Dina Fm. (Lloydminster)	56-95	0-23	0-8	Bayliss and Levison (1976)
McMurray Formation (Athabasca)	41-97	0-16	0-28	Bayliss and Levinson (1976)
Ellerslie Fm. (Edmonton Valley)	45-70	0-6	1-20	Williams (1963)
McMurray Fm. (Ptarmigan)	80-97	2-11	1-6	Present study
McMurray Fm. (Quail)	49-94	3-14	0-39	Present study
McMurray Fm. (Grouse)	76-94	2-16	0-2	Present study

Variation in Mineralogy by Channels- Ptarmigan

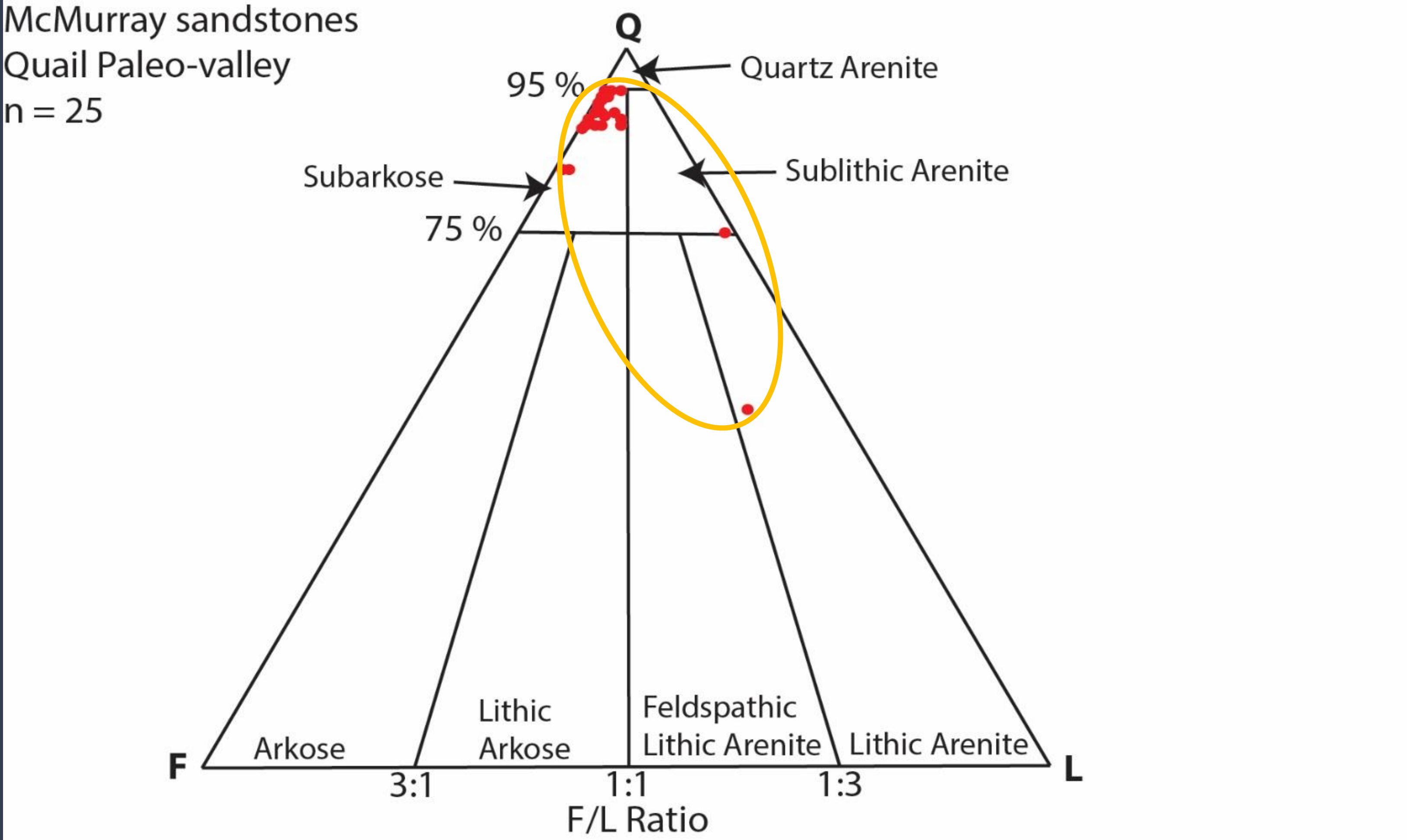


Q = Monocrystalline and polycrystalline quartz.

F = Orthoclase, microcline and albite.

L = Microcrystalline chert, megacrystalline chert , sandstones/siltstones and quartzite.

Variation in Mineralogy by Channels- Quail

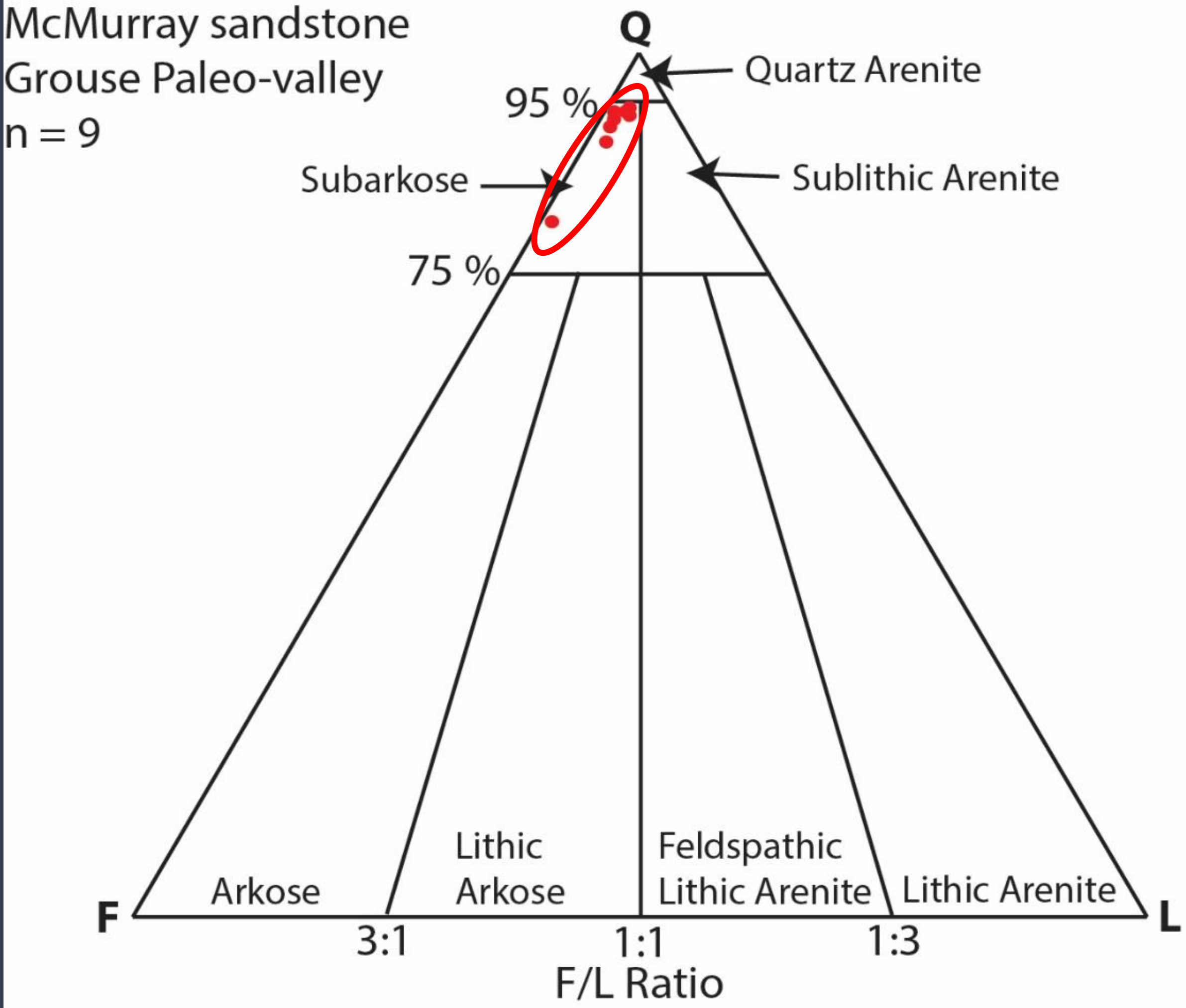


Q = Monocrystalline and polycrystalline quartz

F = Orthoclase, microcline and albite

L = Cryptocrystalline chert, microcrystalline chert, megacrystalline chert, carbonate, sandstones/siltstones, and glauconite grains.

Variation in Mineralogy by Channels- Grouse



Q = Monocrystalline and polycrystalline quartz.

F = Orthoclase, microcline and Albite

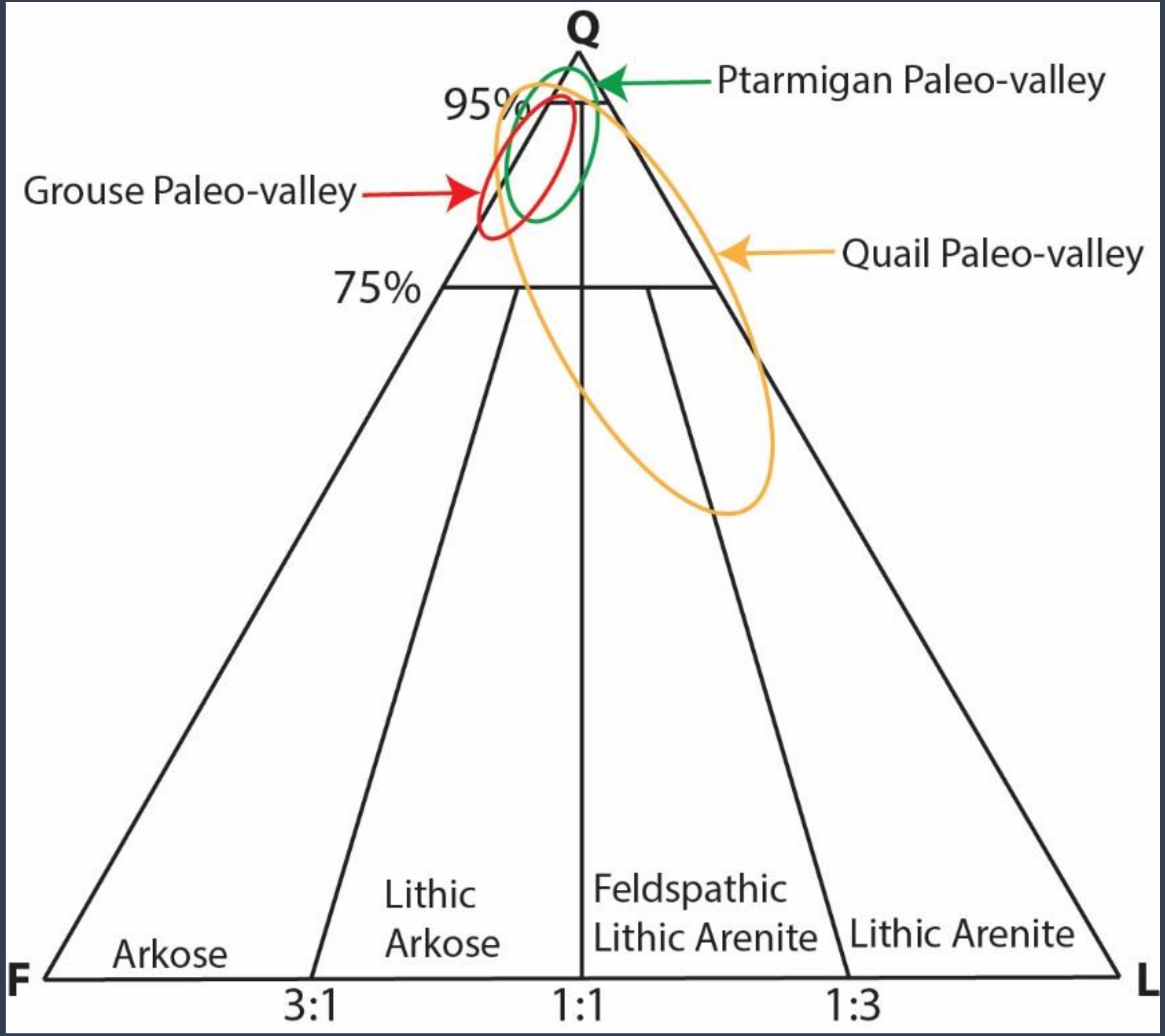
★ **L** = Monocrystalline chert, megacrystalline chert, sandstone/siltstone and carbonate

Variation in Mineralogy by Channels

Type of Sandstones

- Ptarmigan- subarkose-quartz arenites
- Quail- subarkose-lithic arenites
- Grouse- subarkose arenites

Paleo-valleys	Lithic Fragments			
	Chert	Sandstones / siltstones	Carbonates	Quartzite
Ptarmigan	✖	✖		✖
Quail	✖	✖	✖	
Grouse	✖	✖	✖	



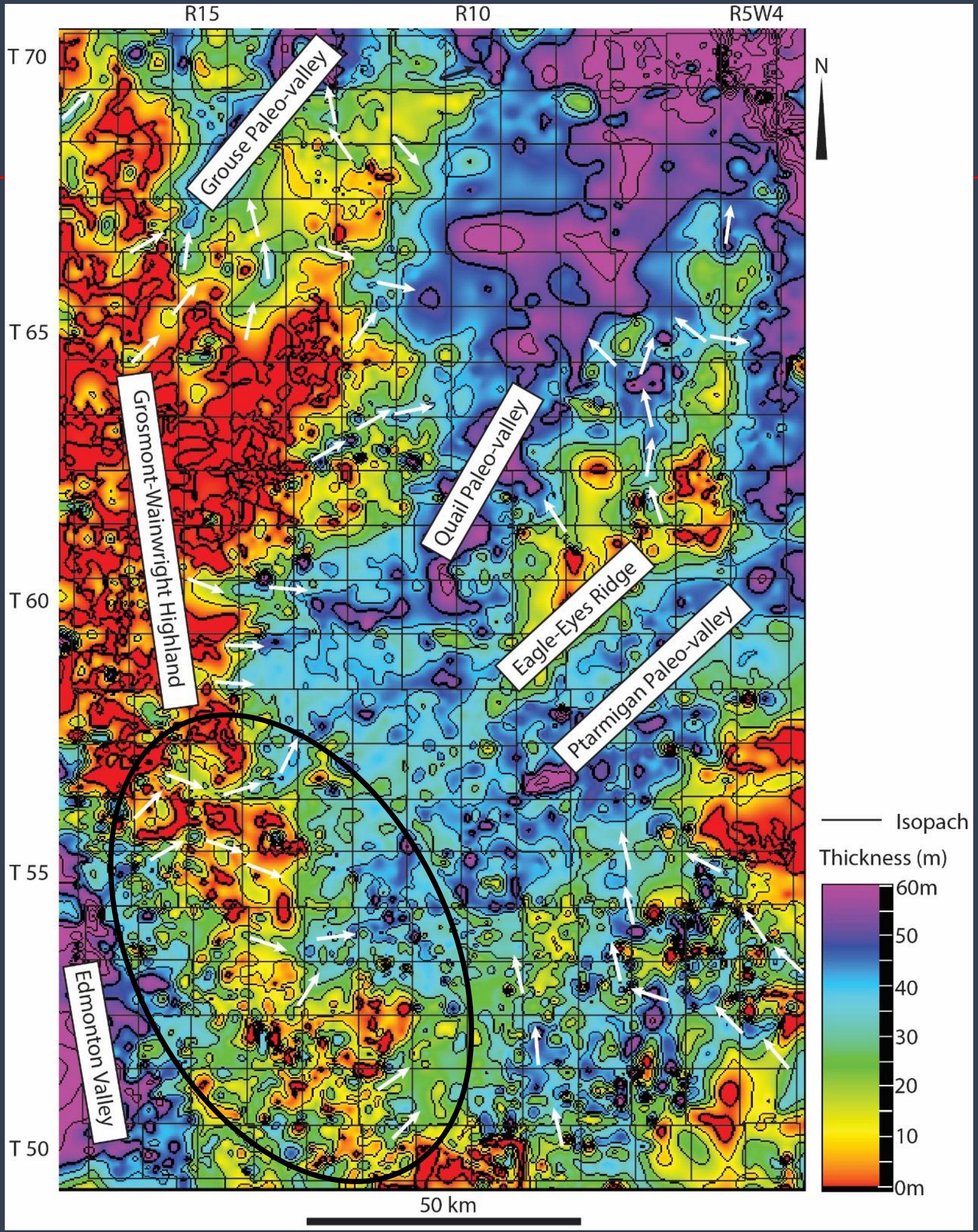
Correlation between Variation in Mineralogy by Channels with their Porosity and Permeability

Data sets

- Ptarmigan: 56 wells
- Quail: 70 wells
- Grouse: 13 wells

Paleo-valleys	Type of Sandstone	Range of Porosity (%)	Average Porosity (%)	Range of Permeability (mD)	Average Permeability (mD)
Ptarmigan	Subarkose to quartz arenites	25.2-47.1	36.9	0-13500	3440.8
Quail	Subarkose to lithic arenites	25-62.5	37.9	0-10208	1626.2
Grouse	Subarkose	21.2-41.5	33.1	0-3166	995.5

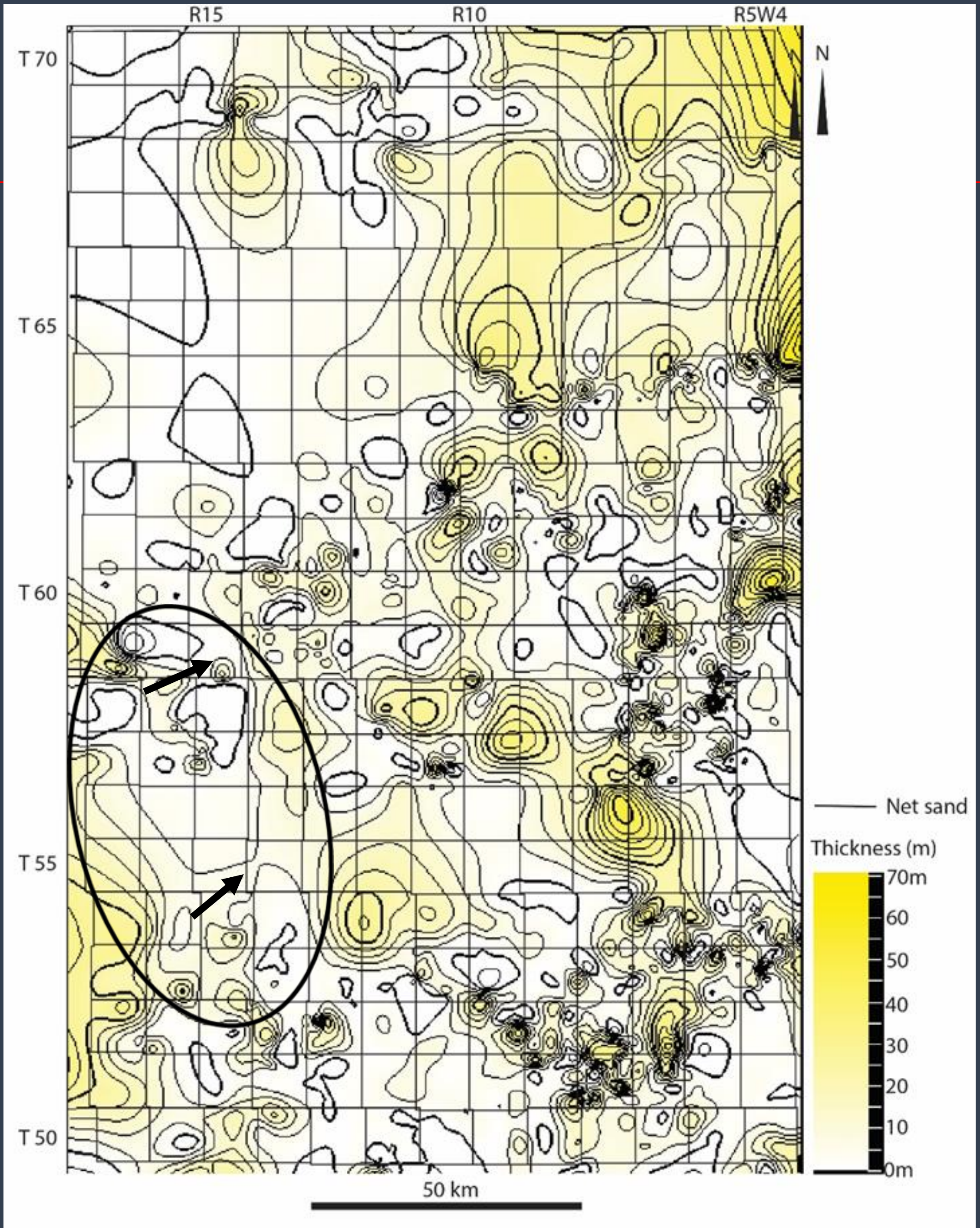
Percentages of Sediments Received



Paleo-flow map

- Arrows represent paleo-flow directions
- Paleo-flow from south-southwest and southeast

Percentages of Sediments received



Net-sand map

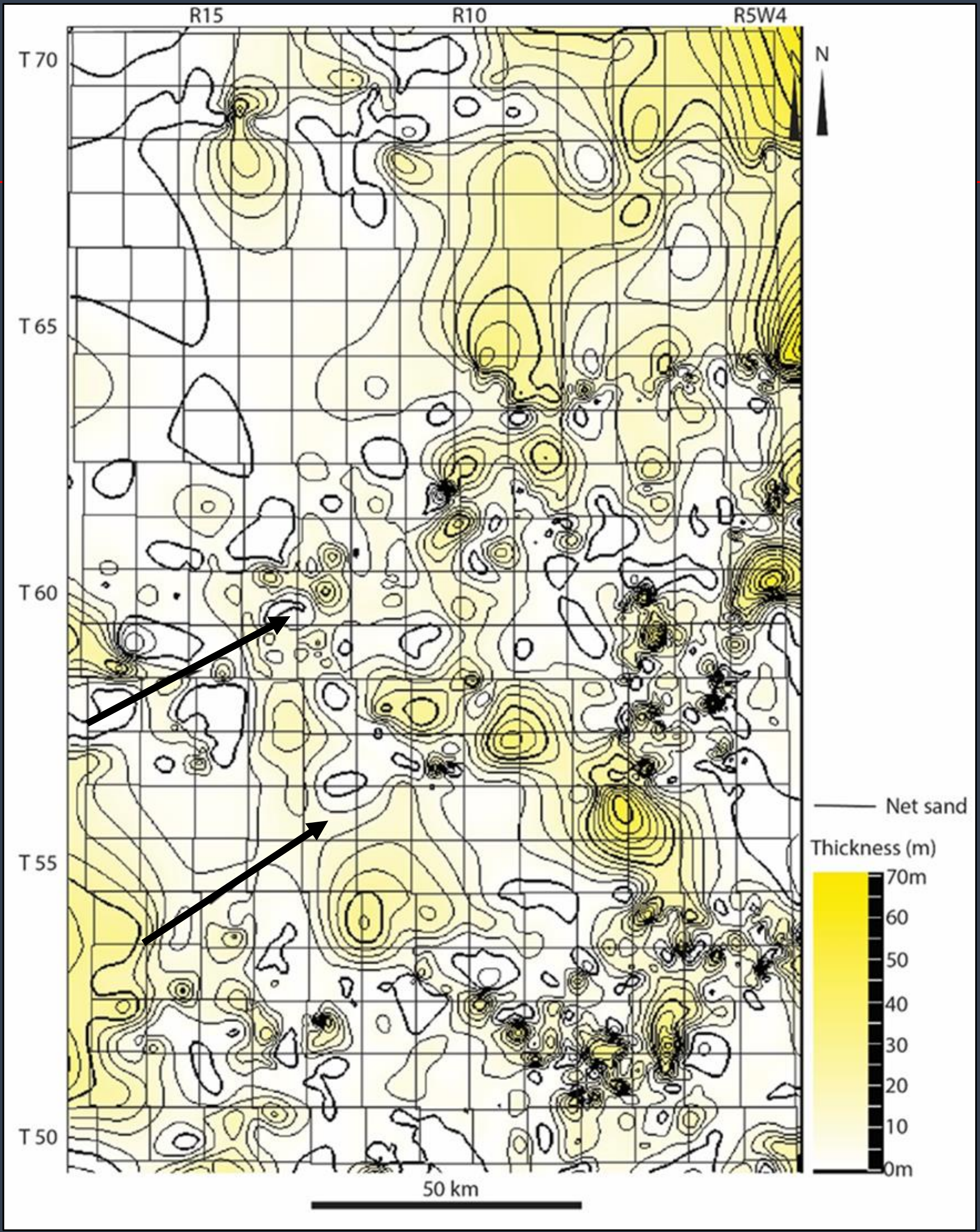
- Arrow represent point of connection between the McMurray Sub-Basin and Edmonton Valley
- Sediments coming-into the basin and the resultant sediments in the basin are vector quantities
- Relationship: linear combination

Percentages of Sediments Received

- $(S_{Q1}, S_{Q2}) = (E_{Q1}, E_{Q2})x + (D_{Q1}, D_{Q2})y$
- x and y are linear combinations (proportion)
- X=(x/(x+y))*100
- Y= (y/(x+y))*100
- X= percentages of sediment derived from the south-southwest
- Y= percentages of sediments derived from southeast

Paleo-valley/ Formation	Dina Fm.	Ellerslie Fm.	Ptarmigan McMurray Sandstone	Quail McMurray Sandstones
% Range of Quartz	56-95	45-70	80-96	50-94

Paleo-valley	% of sediments derived from the south-southwest (Cordilleran materials)	% of sediments derived from the southeast
Ptarmigan	41.1	58.9
Quail	41.2	58.8

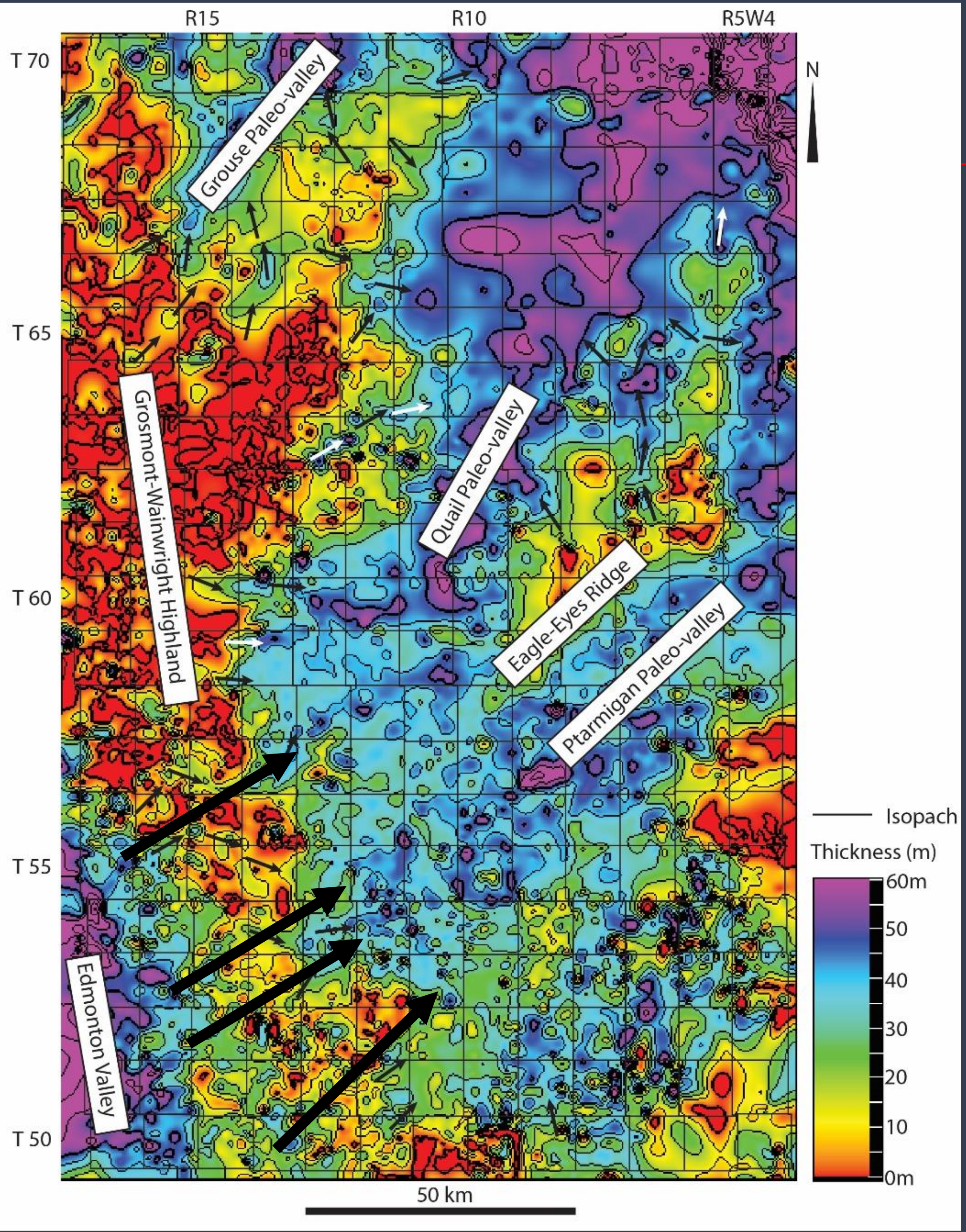


Conclusions

- Completed net-sand mapping and mineralogical analysis of the southwest McMuray Sub-basin: looking for a Cordilleran point source

Detrital grains	Sources
High Proportion of mono vs poly quartz and strained vs unstrained quartz	Product of multiple recycle
Unaltered feldspar mostly orthoclase	Suggests continental basement source (Canadian Shield)
Sandstone/siltstone, carbonate and quartzite	Recycle Precambrian sandstones, Paleozoic carbonates and clastics apron on Canadian Shield
Chert ★	Chert nodules within the Paleozoic carbonates of WSCB (Cordilleran materials)

Conclusions



Completed isopach mapping and mineralogical analysis of the southwest McMuray Sub-basin: looking for a Cordilleran point source

ID 3 paleo-valleys carved into the Wainwright Highland: Grouse, Quail, and Ptarmigan Paleo-valleys

Paleo-valleys appear to be stratigraphically equivalent to the Middle McMurray

Quail and Ptarmigan Paleo-valleys receive ~40% of their sediment from the Cordillera