Athabasca Basin, Saskatchewan and Alberta: Structural History, Unconformity Uranium and Cretaceous Heavy Oil

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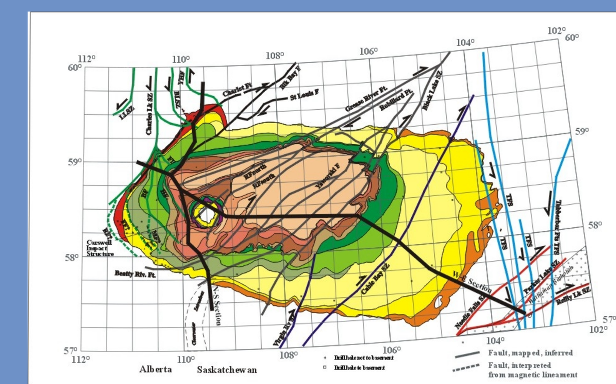
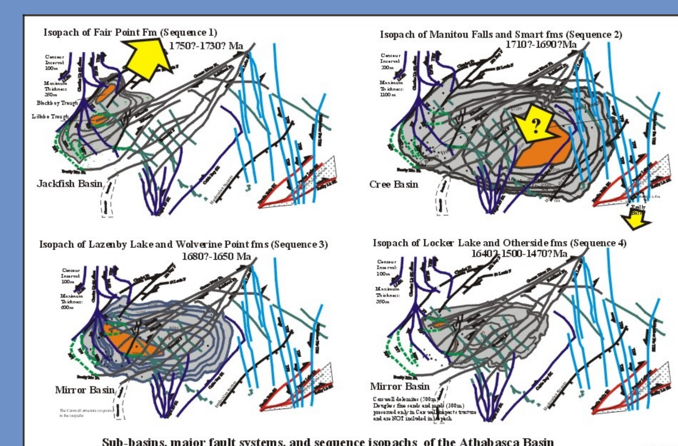
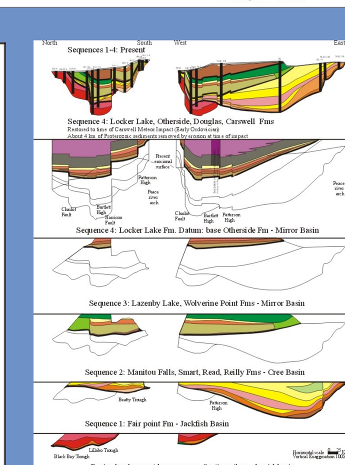
ABSTRACT

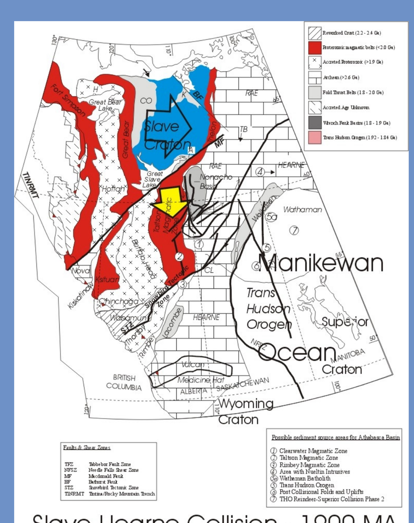
The Athabasca Basin was the third major basin to develop in the northern Saskatchewan-Alberta area as a result of the assembly of the Slave, Rae, Hearne and Superior Provinces into a single continent. It is a complex basin resulting from the superposition of 3 basins emplaced over a period of at least 100 Ma, and possibly as much as 500 Ma. The uranium in the unconformity orebodies is probably largely derived from U rich plutons emplaced at various stages of the continental assembly of Laurentia around and beneath the basin. It was remobilized by deep-basin hydrothermal convection from the plutons directly and/or after they were reworked by erosion into the basin sediments. Increased heatflow near the U rich plutons beneath a sedimentary blanket may also be a factor in development of the hydrothermal systems. Orebodies formed near the basal unconformity of the Athabasca Group sandstones in redox traps during repeated but minor reactivation of either major shear zones crossing the basin, or major structures along basement strike parallel to the basin margin, with the larger orebodies found to date in the latter type. The location of the major orebodies in areas of maximum flexure during basin growth suggests that this was a control on the development of hydrothermal systems. Thus, of particular interest for the development of unconformity orebodies are fault systems associated with the development of the later sequences of the Athabasca Basin. Regional structural controls involved in the formation of these ores include: 1) orogenic processes that formed the U rich plutons, 2) basin forming processes due to continued contraction after the Trans-Hudson Orogen, 3) extensional processes, perhaps basin deepening, that were related to continental breakup of Laurentia. During its unroofing history the Athabasca Basin was covered by Paleozoic and Mesozoic sediments and tilted westward to permit the updip migration of Exshaw-Bakken oils into the Athabasca Group sandstones during the Cretaceous.

Development of Sequences 1-4

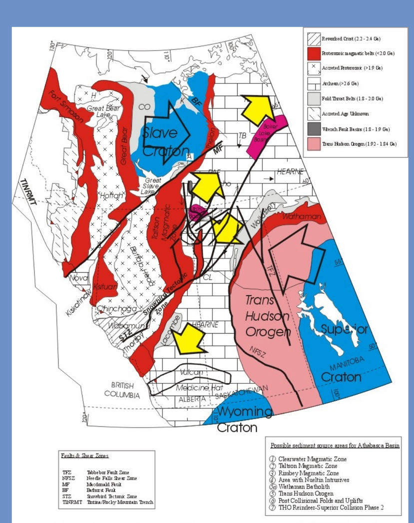




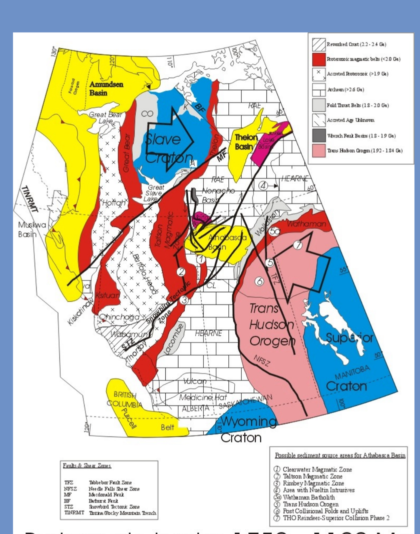




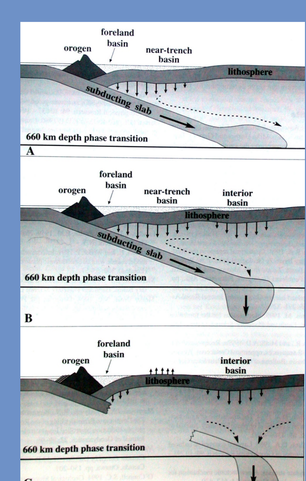
Formation of Nonacho and Thluicho Lake Groups



Formation of Martin and Baker Lake Groups



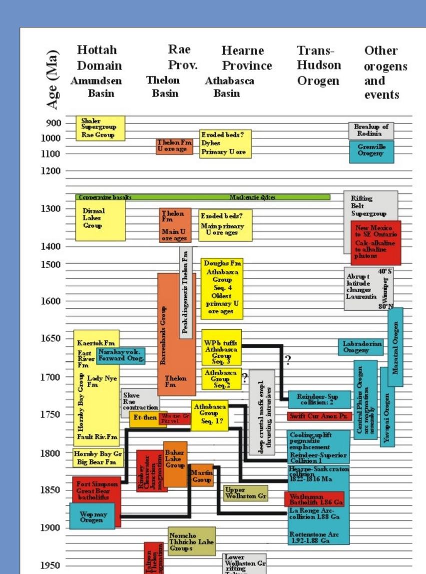
Proterozoic basins 1750 Ma to 1100 Ma



Possible reason for formation of Athabasca Basin Sequences 1 and 2

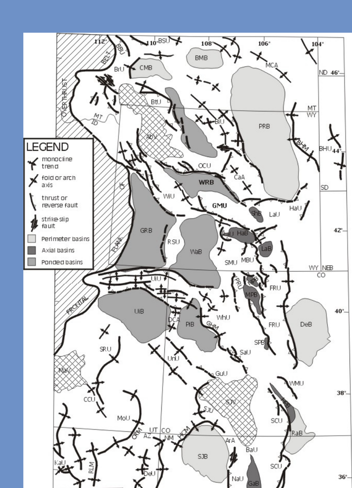
Pysklywec and Mitrovica

Late dynamic loading of the crust occurs about 80 Ma after onset of subduction due to delayed passing of subducting slab through 600 km depth phase transition



Age relationships of Athabasca Basin and related tectonic events

Black lines show possible reasons for Athabasca Basin deepening due to late dynamic loading of crust during passage of subducting slab through mantle boundary



Basin formation as a result of continuing post-orogenic crustal shortening

- Thick skin tectonics subtly comparable to Laramide Orogeny
- Perimeter basins (e.g. Powder River Basin) bordered by monoclines, not boundary faults
- Perimeter basins furthest from orogenic belt
- Athabasca Basin similar to perimeter basin

Unconformity Uranium Orebodies

Requirements for Unconformity Orebodies

- Hydrothermal system emplaced ores
- Requires post-deep burial Athabasca faulting
- Deeply rooted faults provide hotter fluids
- Prolonged activity required for large orebodies
- U rich plutons generate high thermal gradients

Character of late faulting at unconformity

- Faulting usually reactivation of old basement faults
- Faults often reverse
- Faults flatten and splay in sandstone
- Many reactivations
- Total displacement minor

Crustal Thermal Gradient and Heat Flux at 1600 Ma

Amount of U^{235}	5	times present amounts
Amount of U^{238}	1.35	times present amounts
Amount of Th^{232}	1.1	times present amounts
Amount of K^{40}	2	times present amounts

Present amount equivalent to 6 ppm U in upper 8 km of crust

This accounts for 50% of heat flow

Heat flux and thermal gradient around K and U rich intrusives much higher than crustal average

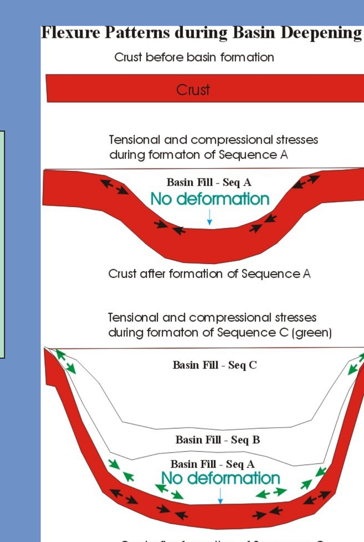
Contrast in heat flow between average crust and U rich batholiths much higher 1600 Ma ago

Burial of enriched radioactive layers beneath thick sediments produces high geothermal gradients in sediments propagating down into enriched layers

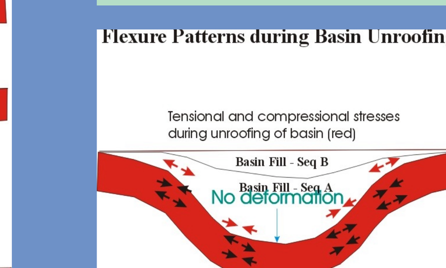
Therefore U rich intrusives focus ascending columns of convecting basin fluids

Data from Dicken, A.P., Radiogenic Isotope geology, 1995; Sandiford et al., 1999, Earth and Planetary Science Letters, v. 163, p. 149-165

- Areas of flexuring migrate as basin develops
- Extensional zones become compressional zones as area of flexure moves from a convex-up to a concave-up area of the basin floor and vice-versa
- Some areas may remain undeformed



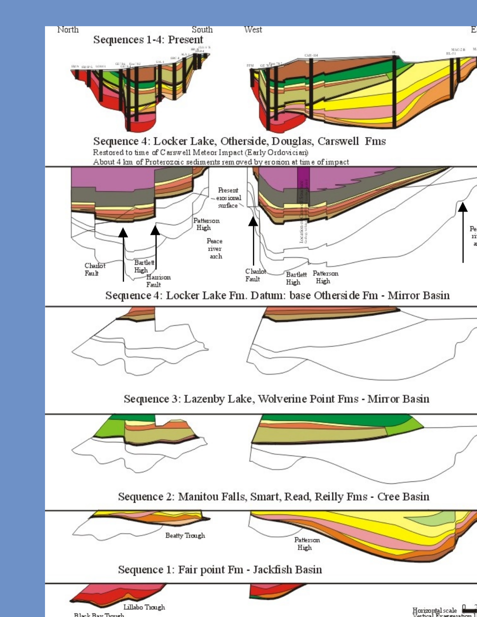
Location of Extensional and Compressional Zones during unroofing

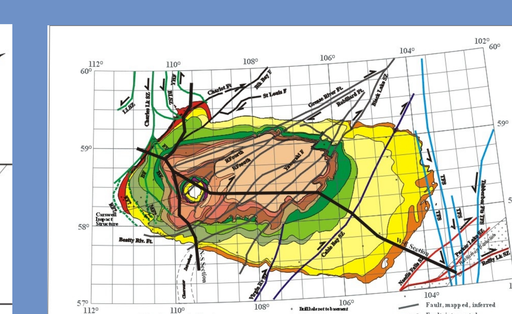


- **Areas of flexuring migrate as basin is unroofed**
- **Extensional zones become compressional zones as area of flexure moves from a convex-up to a concave-up area of the basin floor and vice-versa**
- **Some areas may remain undeformed**

Basin Analysis

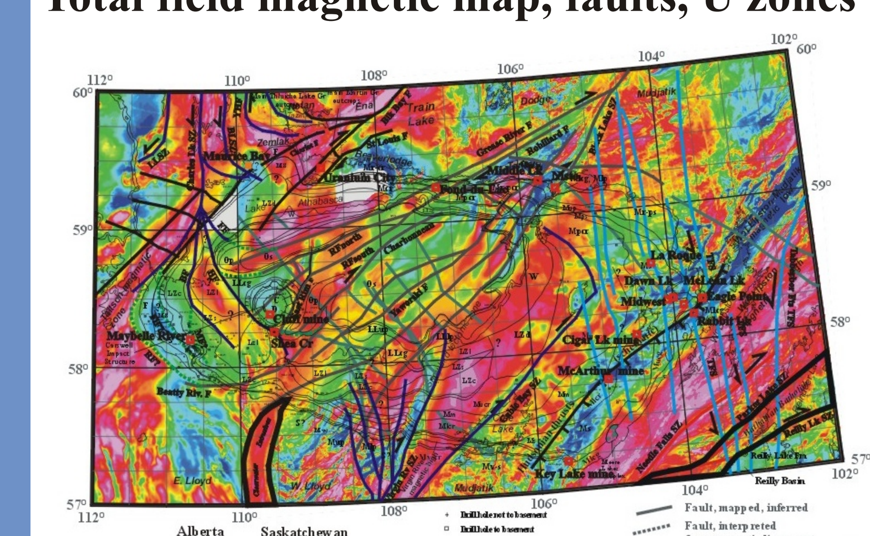
Can identify areas of greatest flexure. Therefore it has the potential to identify areas where favourable structures are best developed. Cross-sections leveled on progressively deeper datums identify areas of greatest flexuring. Uranium mineralization is found in these areas.



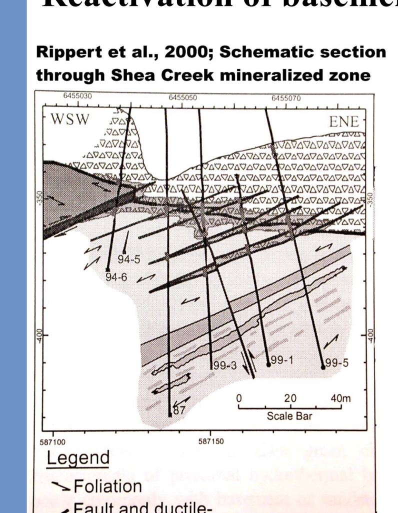


Arrows indicate areas of maximum flexure during deposition of Sequence 4, the time of ore emplacement

Total field magnetic map, faults, U zones



Reactivation of basement faults by basin development



Shea Creek - an example of brittle reactivated faults at the unconformity

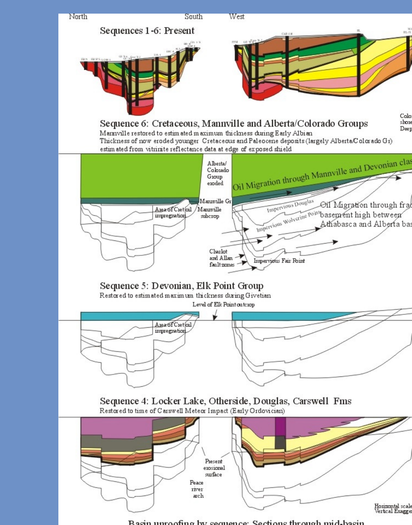
- **Faults reactivated whenever basin shape is modified by loading or rebound**
- **Process lasts as long as basin shape changes**
- **Areas of greatest flexure promote deepest faults**
- **Basement faults parallel to basin margin uplifts are preferentially reactivated**

Implications for Exploration:

Hydrothermal systems for U develop preferentially in:
- Faults parallel to basin margin in zones of maximum flexure during later stages of basin development;
- Faults active in basin development after deep burial;
- Areas of high geothermal gradients over U enriched plutons.

Thus, basin analysis helps identify areas of greater potential

Basin Unroofing

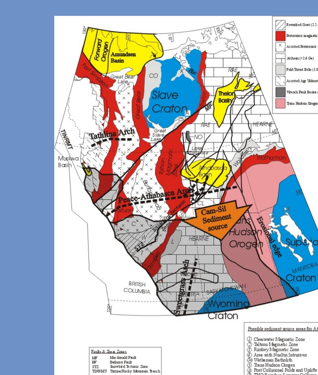


Present

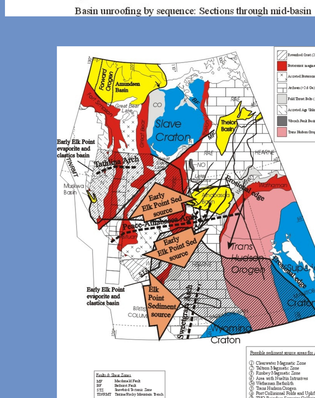
End Cretaceous

Middle Devonian

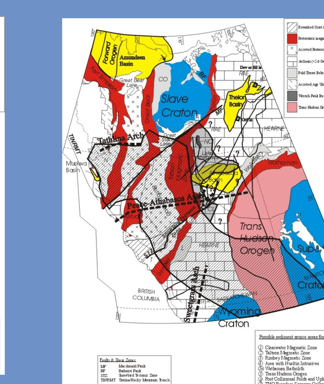
Early Ordovician



Cambro-Ordovician



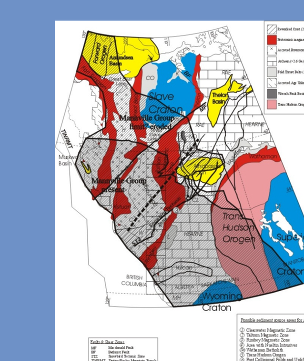
Devonian Lower Elk Pt



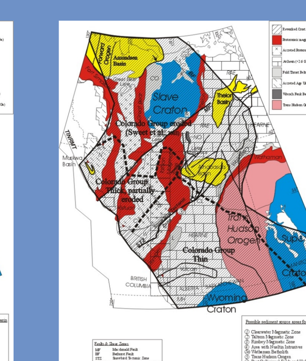
Late Elk Point

Paleozoic unroofing history:

Peace River Arch is southern boundary of Athabasca Basin



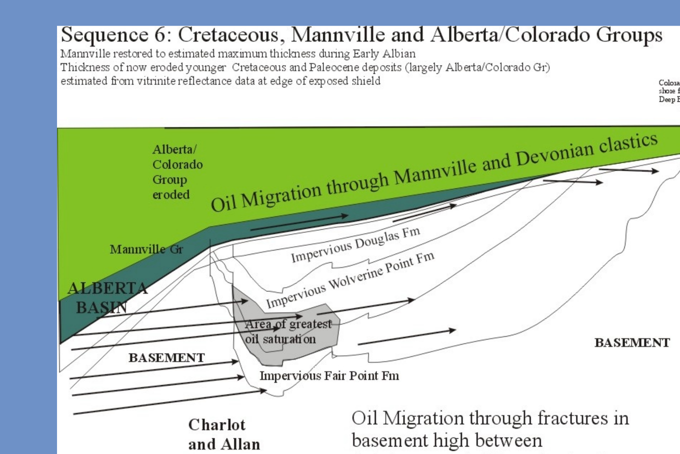
Early Cretaceous Manville



Late Cretaceous, Alberta/Colorado Groups

Cretaceous unroofing history:

Athabasca Basin tilted to west



Cretaceous Oil Migration

Tilting of basin to the west permitted up-dip oil migration into the Athabasca Basin
Note: extreme vertical exaggeration

Summary

1. Uranium was emplaced by long-lasting hydrothermal systems.
2. Focused in reactivations of crustal scale basement faults initiated during fold belt thrusting and escape tectonism during and following Thelon and Hudsonian orogenies.
3. Faults reactivated repeatedly over 500 Ma during development of Athabasca Basin.
4. Hydrothermal systems were optimized near U-enriched plutons with high geothermal gradients.
5. Structural controls were also important in the migration of oil into the Athabasca Basin.

Acknowledgments

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Accessibility to exploration core, especially from Cameco and COGEMA.
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