Structural heterogeneity, thermal spring distribution, and geothermal energy potential along the Southern Rocky Mountain Trench

UNIVERSITY OF ALBERTA FUTURE ENERGY SYSTEMS

CANADA FIRST RESEARCH EXCELLENCE FUND

Theron Finley, Cedar Hanneson, Ben Lee, Martyn J. Unsworth, Stephen T. Johnston, Jonathan Banks

Department of Earth & Atmospheric Sciences, University of Alberta

Abstract

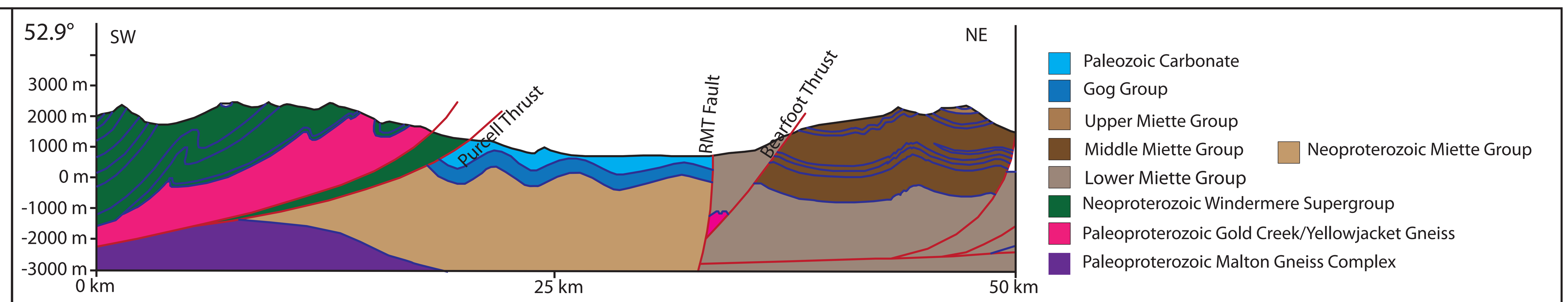
In the Canadian Cordillera, thermal springs tend to occur in association with major faults. Several thermal springs occur along the Southern Rocky Mountain Trench (SRMT), indicating the possibility of a fault-hosted geothermal system. Here, we compile structural and geophysical data from the vicinity of the SRMT to provide a synthesis of the interpreted subsurface. Locations and estimated circulation depths of thermal spring systems along the SRMT are compared against mapped geological structures, and simple hydrogeological models are proposed for each spring. We evaluate the broad relations between fault kinematics and spring occurrence, and consider possible reasons for the notable lack of thermal springs between the latitudes of 51°N and 52.5°N. There is much uncertainty regarding the kinematic history and subsurface geometry of several faults, and further targeted structural and geophysical mapping is required.

Thermal Springs and Geothermal Potential

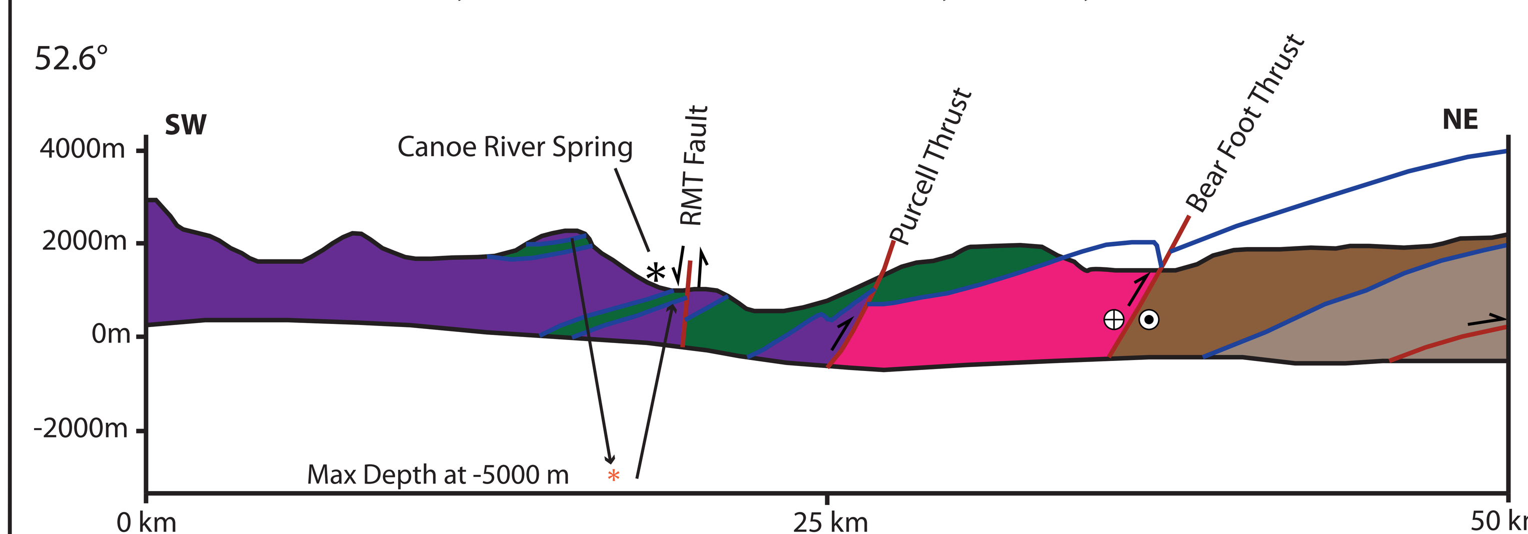
- Several thermal springs occur along the RMT (Fig. 1; Woodsworth & Woodsworth, 2014), which is suggestive of high heat flow and geothermal energy potential (Grasby and Hutcheon, 2001).
- Ferguson and Grasby (2011) argued that determining flow system geometry through geothermometry and structural geology are critical when using thermal springs as geothermal exploration tools.
- There is a notable lack of springs between 51°N and 52.5°N (see Fig. 1). Grasby & Hutcheon (2001) suggested that this gap may be due to a transition from faults with significant normal offset (e.g., Rocky Mountain Trench Fault) in the south, to diffuse displacement on several smaller normal faults whereas north of 51°N.
- To test the hypothesis of along-strike heterogeneity, and to aid in constraining flow system geometries, we have compiled existing structural interpretations along the SRMT.

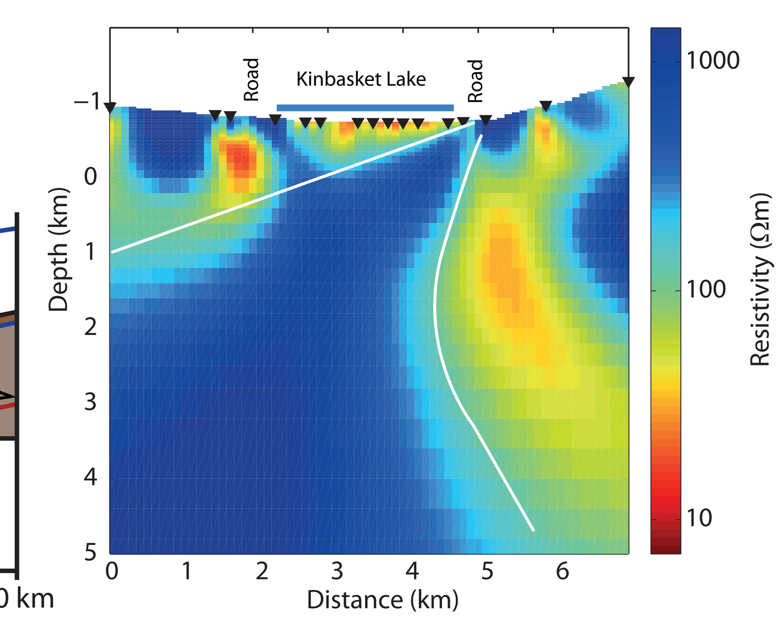
Geological Setting

- The Southern Rocky Mountain Trench (SRMT) is a major fault-controlled valley stretching from northern Montana to central-eastern British Columbia (van der Velden & Cook, 1996).
- The SRMT parallels the structural grain of the Canadian Rocky Mountains and appears to approximately parallel the edge of the North American cratonic basement, which tapers to the west (Monger et al., 1972).
- Stratigraphic units of Proterozoic to Mesosoic age appear continuous across the the SRMT (e.g., van der Velden and Cook, 1996) and it is therefore not generally considered to be a major terrane boundary.
- Highly metamorphosed rocks of the Kootenay and Omineca core complexes outcrop only to the west of the SRMT. Near Valemount, a small block of metamorphic rocks - the Malton Gneiss Complex - occurs within the SRMT (Murphy, 2007).
- Rocks on both sides of the SRMT are affected by eastward-verging thrusts (e.g., Purcell Thrust) and folds developed during the Cretaceous-Paleocene Cordilleran Orogeny.
- In the mid-Cenozoic, extensional faulting occurred in the SRMT on the Rocky Mountain Trench (RMT) Fault, which runs along much of the length of the trench, cross-cutting the Cretaceous-paleocene thrust faults and folds (van der Velden and Cook, 1996).
- There is evidence for dextral shear near Valemount (Murphy, 1990), which may be a zone of transition into large-scale Eocene dextral displacement along the Northern Rocky Mountain Trench and Tintina Trench to the north (e.g., Gabrielse et al., 2006).

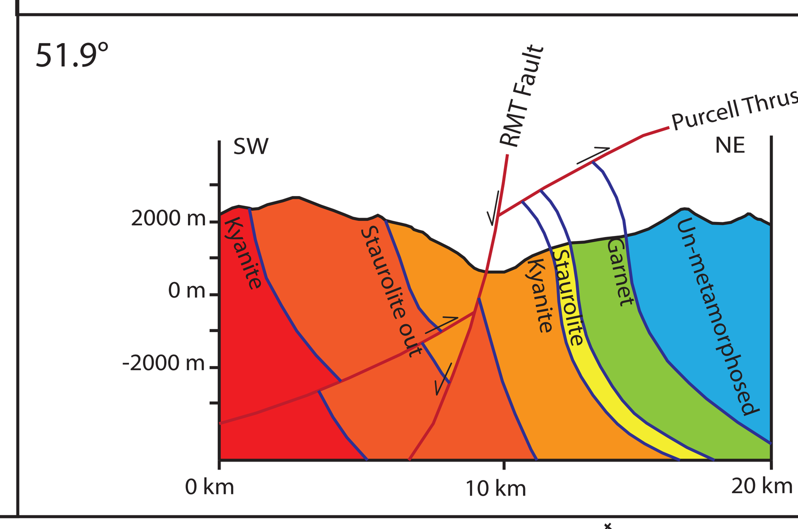


Section 1. Geological cross section of the SRMT at Valemount, BC, after McDonough and Murphy (1994). RMT is bounded to the SW by the Purcell Thrust, and to the NE by the Rocky Mountain Trench Fault.





Section 2. Geological cross section of the SRMT at Kinbasket lake after Murphy (2007). RMT is bounded to the SW by the RMTF, and to the NE by an unamed thrust fault. Note location of the Canoe River Spring coincident with the RMT normal fault. The source of this spring is far below the constrained part of the cross-section. Section 1A: Resistivity cross section from magnetotelluric survey across Kinbasket Lake. Conductors (warm colours) may indicated the presence of fluids.



Section 3. Simplified geological cross-section after Gal and Ghent across Kinbasket lake, with metamorphic zones illustrated. Note that at this locality the Purcell Thrust does not appear at the surface. Geology is poorly constrained in this region, and no detailed cross sections exist.

Table 1. Outlet temperatures and max temperatures derived from geothermometry of each spring (Grasby and Hutcheon, 2001; Fairbank and Faulkner, 1992). Depths are estimated based on a geothermal gradient of ~21 °C/km.

Spring Name	Temp. (°C)	Max. Temp (°C)	Est. Depth (km)
Canoe River	50	129	6.1`
Wolfenden	27.7	35.6	1.7
Radium	44	69	3.3
Fairmont	46.7	62	3
Red Rock	19	?	?
Lussier	43.2	67	3.2
Buhl Creek	37	?	?
Ram Creek	36.5	42	2
Wildhorse	31	58	2.8

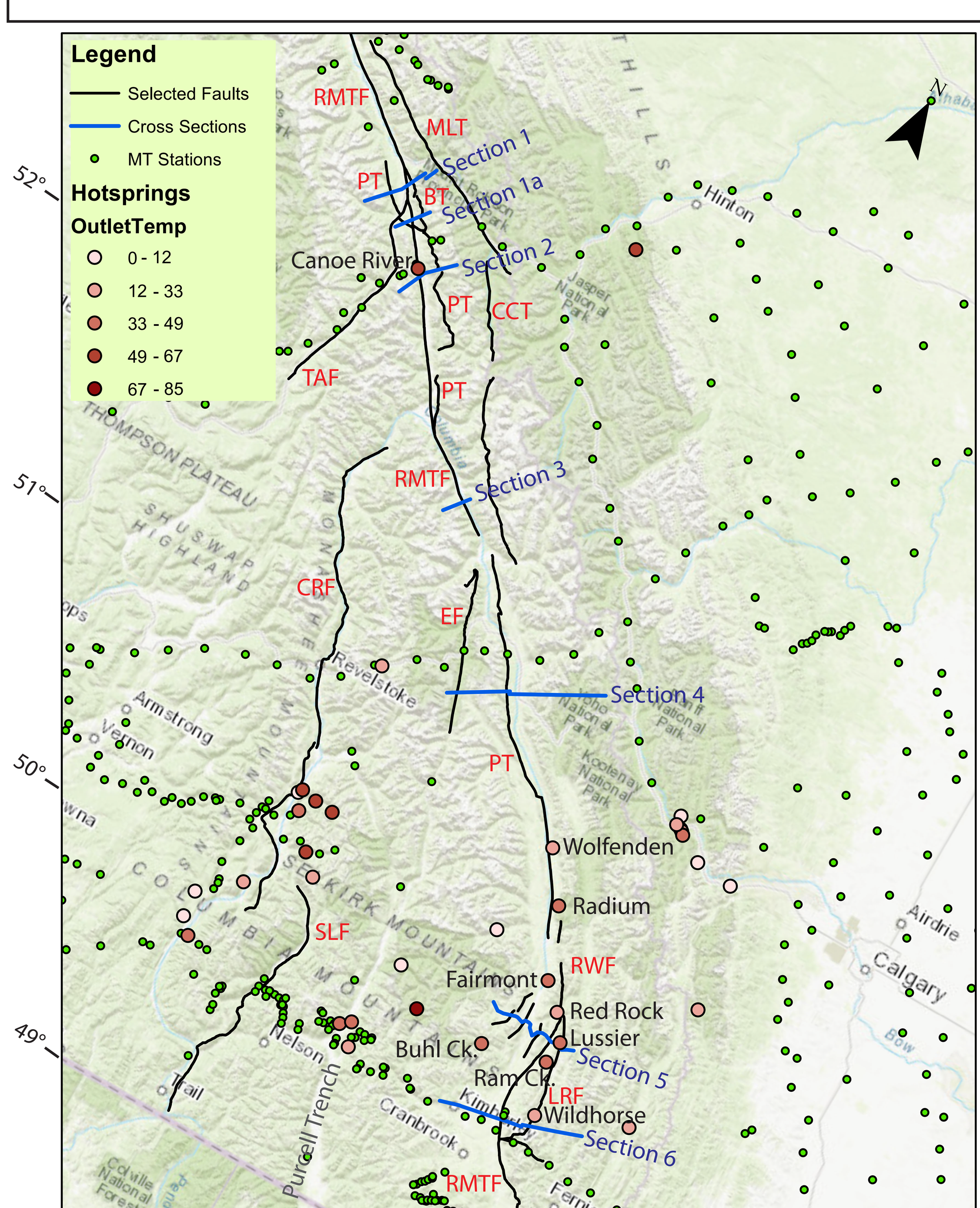
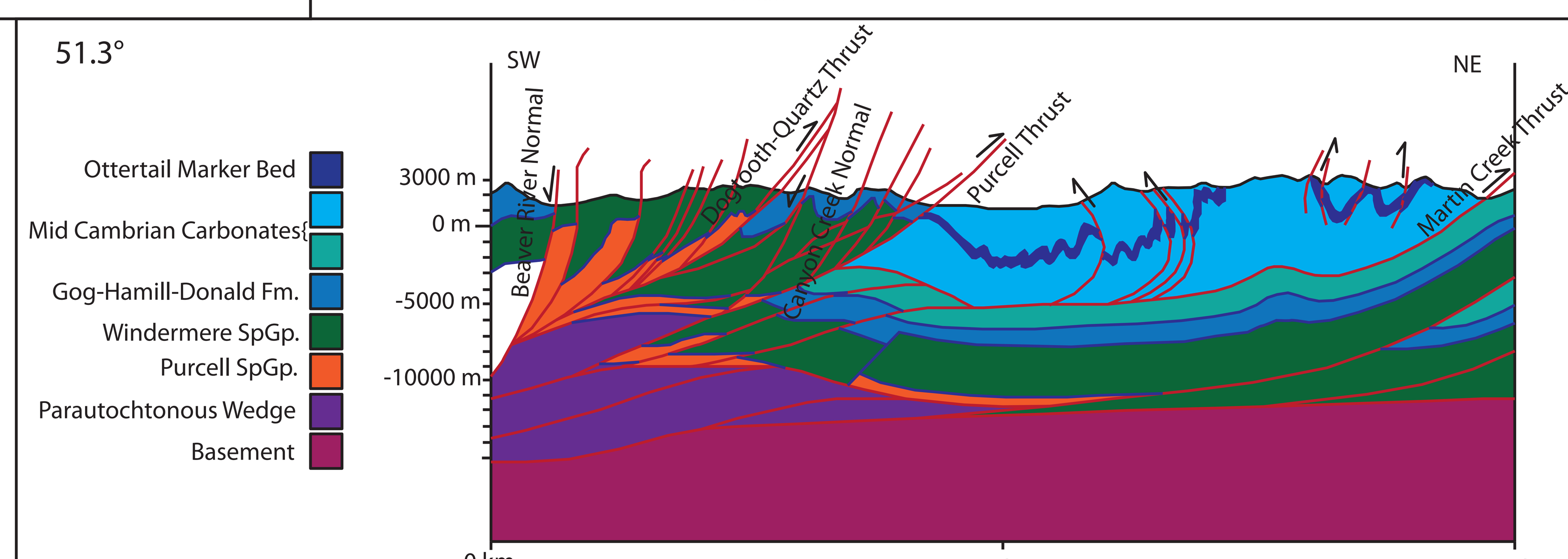
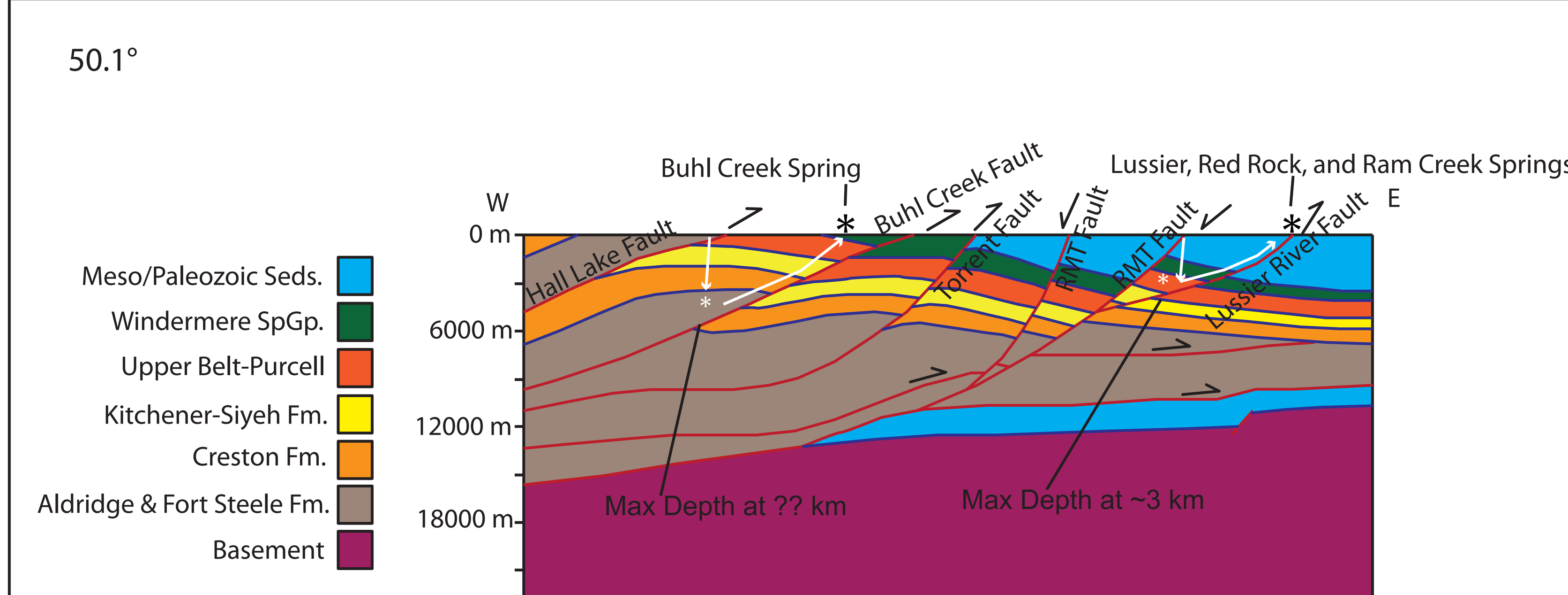


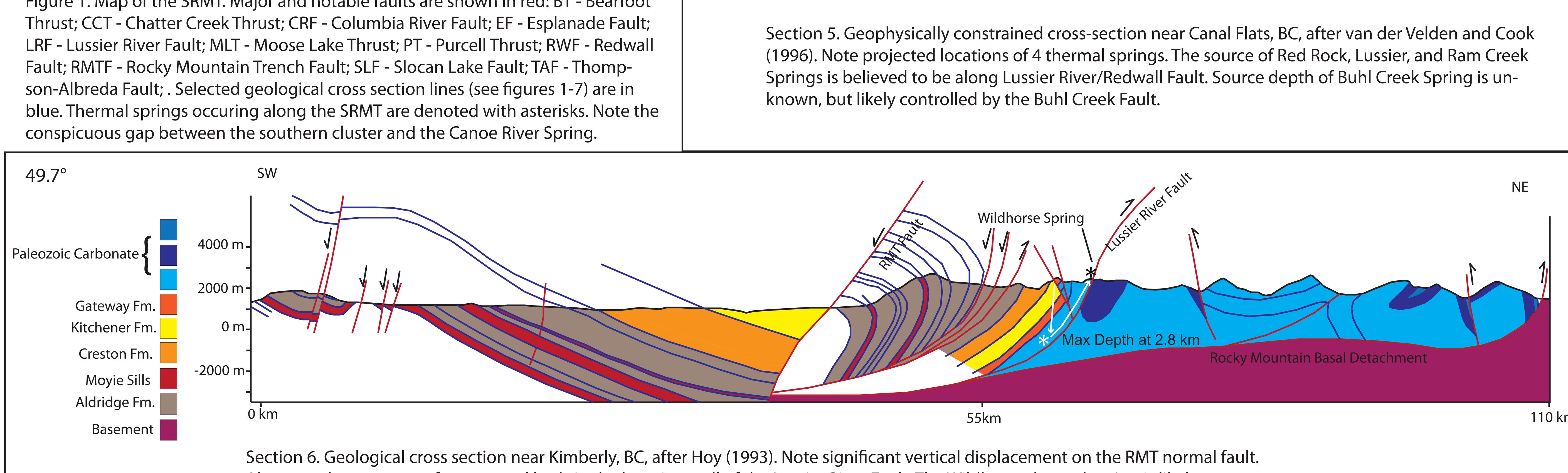
Figure 1. Map of the SRMT. Major and notable faults are shown in red: BT - Bearfoot Thrust; CCT - Chatter Creek Thrust; CRF - Columbia River Fault; EF - Esplanade Fault; LRF - Lussier River Fault; MLT - Moose Lake Thrust; PT - Purcell Thrust; RWF - Redwall Fault; RMTF - Rocky Mountain Trench Fault; SLF - Slocan Lake Fault; TAF - Thompson-Albreda Fault; . Selected geological cross section lines (see figures 1-7) are in blue. Thermal springs occuring along the SRMT are denoted with asterisks. Note the conspicuous gap between the southern cluster and the Canoe River Spring.



Section 4. Geological cross section of the SRMT at Golden, BC, after Kubli and Simony (1994). RMT is bounded to the SW by the Purcell Thrust, and to the NE by an unamed overturned thrust fault. At this part of the SRMT there are no large normal fault offsets, and no thermal springs.



Section 5. Geophysically constrained cross-section near Canal Flats, BC, after van der Velden and Cook (1996). Note projected locations of 4 thermal springs. The source of Red Rock, Lussier, and Ram Creek Springs is believed to be along Lussier River/Redwall Fault. Source depth of Buhl Creek Spring is unknown, but likely controlled by the Buhl Creek Fault.



Section 6. Geological cross section near Kimberly, BC, after Hoy (1993). Note significant vertical displacement on the RMT normal fault. Also note the presence of overturned beds in the hanging wall of the Lussier River Fault. The Wildhorse thermal spring is likely controlled by the Lussier River Fault, and has an estimated source depth of 2.8km

Discussion

- In general, locations of thermal springs appear to be associated with fault structures, although this could simply be a coincidence of topography: both springs and faults tend to occur in valleys.
- No distinct relation between fault kinematics and spring occurence is immediately apparent.
- As suggested by Grasby and Hutcheon (2001), cross-sections show significant normal displacement on the RMT Fault south of 51°N (Sections 5 and 6), and very little to no displacement near Golden (Section 4).
- However, the locations of several springs appear to be related to the Redwall/Lussier River Fault (mapped as a thrust), rather than the RMT Fault (normal).
- Extensional faults are generally better conduits for water due to their inherent stress regime (Bense et al., 2013). Perhaps the Redwall/Lussier Fault has been reactivated as a normal structure?
- With the exception of the Wolfenden spring at its southern end, the Purcell Thrust hosts no thermal springs. It may be impermeable to fluid flow.
- Fault age and activity are important factors in determining fault permeability and may be more important than kinematics. Older faults (e.g., Purcell Thrust) eventually become clogged with mineral precipitate (Bense et al., 2013; Curewitz and Karson, 1997).
- In Section 3, the Purcell Thrust is blind, and intersects the RMT fault in the upper 1000m. Circulating groundwater might intersect the Purcell Thrust first and not reach the RMT fault.
- The Canoe River spring appears to be associated with the RMT fault, which reappears north of 52°N. It is unclear why significant extension occurs here after dwindling between 51°N and 52°N.
- Geothermometry data (Table 1) for the Canoe River spring suggest a much deeper and hotter source than all the springs to the south. It is unclear why these spring waters reach such a great depth, though it must be noted that a different chemical geothermometer is used (Fairbank and Faulkner, 1992); it would be worth re-examining this analysis.

Future Work

- Constraints on geological structure are limited and not harmonized along the SRMT. Cross sections are based on different assumptions about regional tectonics.
- Modernization of historical geological cross-sections would be helpful in understanding this structure and its relation to thermal spring distribution.
- Future work will be focussed on re-drafting geological cross-sections for selected locations along the SRMT. Further constraints should be imposed via geological mapping and geophysical surveying.

REFERENCES

Bense, V. F., Gleeson, T., Loveless, S. E., Bour, O., & Scibek, J. (2013). Fault zone hydrogeology. Earth-Science Reviews, 127, 171–192. https://doi.org/10.1016/j.earscirev.2013.09.008

Curewitz, D., & Karson, J. A. (1997). Structural settings of hydrothermal outflow: Fracture permeability maintained by fault propagation and interaction. Journal of Volcanology and Geothermal Research, 79(3–4), 149–168. https://doi.org/10.1016/S0377-0273(97)00027-9

Fairbank, B.P., and Faulkner, R.L., 1992, Geothermal resources of British Columbia: Geological Survey of Canada, Open File 2526.

Ferguson, G., & Grasby, S. E. (2011). Thermal springs and heat flow in North America. Geofluids, 11(3), 294–301. https://doi.org/10.1111/j.1468-8123.2011.00339.x

Gabrielse, H., Murphy, D. C., & Mortensen, J. K. (2006). Cretaceous and Cenozoic dextral orogen-parallel displacements, magmatism, and paleogeography, north-central Canadian Cordillera. Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements, (December 2016), 255–276.

Gabrielse, H, and Yorath, C., 1991, Geology of the Cordilleran Orogen in Canada: Geological Society of America, Geology of North America Series G-2.

Gal, L.P., and Ghent, E.D., 1990, Metamorphism of the Solitude Range, southwestern Rocky Mountains, British Columbia: comparison with adjacent Omineca Belt rocks and tectonometamorphic implications for the Purcell Thrust: Canadian Journal of Earth Sciences, v. 27, p. 1511-1520.

Grasby, S.E., Hutcheon, I, 2001, Controls on the distribution of thermal springs in the southern Canadian Cordillera: Canadian Journal of Earth Sciences, v. 38, p. 427-440.

Hoy, T., 1993, Geology of the Purcell Supergroup in the Fernie West-half Map Area, Southeastern British Columbia: BC Geological Survey Bulletin 84.

Kubli, T.E., and Simony, P.S., 1994, The Dogtooth Duplex, a model for the structural development of the northern Purcell Mountains: Canadian Journal of Earth Sciences, v. 31., p. 1672-1686.

McDonough, M.R., and Murphy, D.C., 1994, Geology and structure cross sections, Valemount, British Columbia: Geological Survey of Canada, Map 1843A.

Monger, J. W., Souther, J. G., & Gabrielse, H. (1972). Evolution of the Canadian Cordillera: A Plate Tectonic Model. American Journal of Science. https://doi.org/10.2475/ajs.272.7.577

Murphy, D.C., 1990, Direct evidence for dextral strike-slip displacement from mylonites in the southern Rocky Mountain Trench near Valemount, British Columbia: Geological Survey of Canada Current Research, Paper 90-1E, p. 71.

Murphy, D.C. (comp), 2007, Geology, Canoe River, British Columbia - Alberta: Geological Survey of Canada, Map 2110A.

van der Velden, A.J., and Cook, F.A., 1996, Structure and tectonic development of the southern Rocky Mountain Trench: Tectonics, v. 15, p. 517-544.

Woodsworth, G., and Woodsworth D., 2014, Hot springs of Western Canada: a complete guide: West Vancouver, Gordon Soules Book Publishers Ltd., 304 p. bb