Going back to basics-building a new tectonic map of the Peace River Arch and the Deep Basin areas of the Western Canadian Sedimentary Basin.

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Summary

This presentation illustrates the processes and data sets that were used to build a new tectonic map of the Peace River Arch and the Deep Basin areas which are located at the center of the Western Canadian Sedimentary Basins (WCSB). The main objective here is to illustrate the benefit of using basic principles of geoscience and integration techniques to improve and update our understanding of the development of different hydrocarbon plays in these areas. The new map also illustrates a direct link between Tectonically Active Fault Zones (TAFZ's) and the presence of induced seismicity evets associated with the development of active resource plays of these areas.

Also included are examples from other parts of the basin, such as Southern Alberta and the Cordova Basin of British Columbia, that are known to be tectonically active and experience induced seismicity events associated with horizontal drilling activities.

Introduction to the new tectonic map of the Peace River Arch and the Deep Basin Area.

The new tectonic map of the Peace River Arch and the Deep Basin area that is shown in figure 1 was built through the integration of 3D and 2D seismic, key isopach and structure maps, production and pressure information, high resolution magnetic data, remote-sensing images, and field observations. The map identifies the major fault system of the study area, their structural style, timing of deformation, and possible ties to the presence of tectonically active fault zones (TAFZ) that often became the focal point of induced seismicity events. Some of the key structural elements that are shown on this map include:

- The outline of the Peace River Arch.
- The Fort St John Graben (FSJG) also known as the Dawson Creek Complex.
- The outline of the inverted western arm of the FSJG also known as the Hudson Hope Embayment.
- A major Hinge-line fault that forms the eastern boundary of the over pressure zone in the Upper Montney formation.
- A buried thrust front that sets up the eastern boundary of the Fore-Foothill area.
- Several reactivated basements involved, strike-slip faults.
- Location of HTD reservoirs associated with reactivated basement faults.

- Major Tectonically Active Fault Zones (TAFZ's) that are known to be the focal point of induced seismicity events.

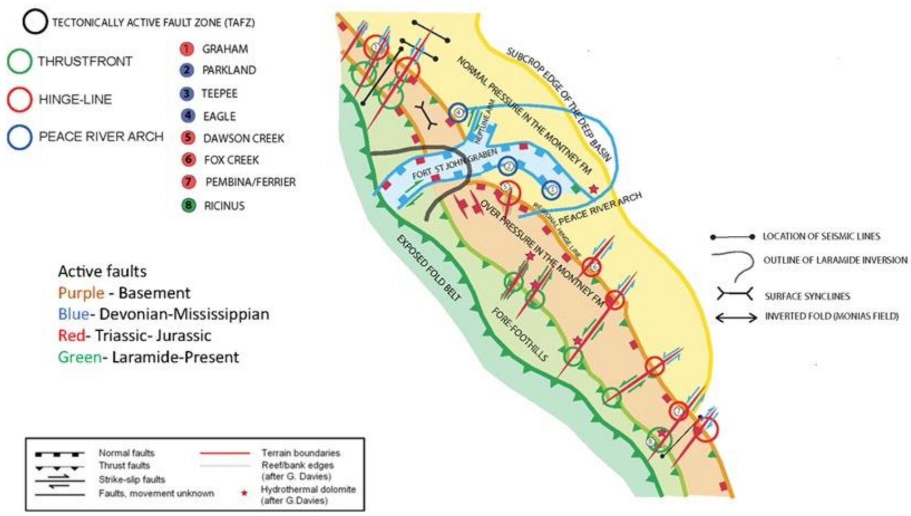

Figure 1. A tectonic map of the Peace River Arch and the Deep Basin Area. Early versions of tectonic maps and data sets used to identify key geological structures in this area with both conventional and reconnaissance exploration tools can be found in (Berger 1994, Berger et al 2010).

Review of the tectono-stratigraphic maps of the study area.

The complex geological history of the Peace River Arch and the northern portion of the Deep Basin area are illustrated here with several tectono-stratigraphic maps that are shown in figure 2.

- The first map of figure 2A illustrates the development of the Fort St John Graben/Dawson Creek Complex during the collapse of the Peace River Arch at early Mississippian time (Barckley et al 1995). The map shows the location of the depo-center of the Kiskatinaw formation that filled this graben during the main rifting event. Also shown are the main oil and gas fields such as Boundary Lake and Pouce Cope that produce from the basal and upper sand units of the Kiskatinaw formation.
- The second map of figure 2B shows the presence of a thick depo-center of the Lower Montney formation that was deposited in this area during a major "sag phase" of the main graben (e.g. Harding 1990). The Upper Montney unit is now being developed with horizontal drilling over and around the old Triassic Mica field (Vermilion 2024).
- The third map of figure 2C shows the shifting of the depo center of the Upper Montney formation to the west during Middle Triassic time. This shift was triggered by the development of a foreland basin during the early development of the Canadian Rockies

fold belt. The key Upper Montney Groundbirch and Dawson Creek Complex pools are positioned along major down to the basin, listirc, normal faults that are typically found in this type of tectonic setting.

- The fourth map of figure 2D illustrate the effect of the continuous building and loading of the fold belt to the west that led to the deposition of a thick Halfway and the newly defined Sunset Prairie formation along the main graben, particularly in the western arm of the graben that is also known as the Hudson Hope Embayment (Furlong et al 2015). The Monias and Wilder gas fields represent some of the key pools of the Halfway formation that were found at the western arm of the graben.
- The final map of figure 2E illustrates the final effect of the late Laramide thrusting events that resulted in the inversion of the Hudson Embayment and other pre-existing faults in this area. This process led to the development of hydrocarbon traps in Monias, Blueberry, Jeddney Bubbles and other fields of the Fore-foothills area. The late Laramide compression also led to a slow process of uplifting and isostatic rebounding of the Peace River Arch which exhumed and reactivated pre-existing faults leading to the presence of induced seismicity events along major reactivated faults over the core of the arch.

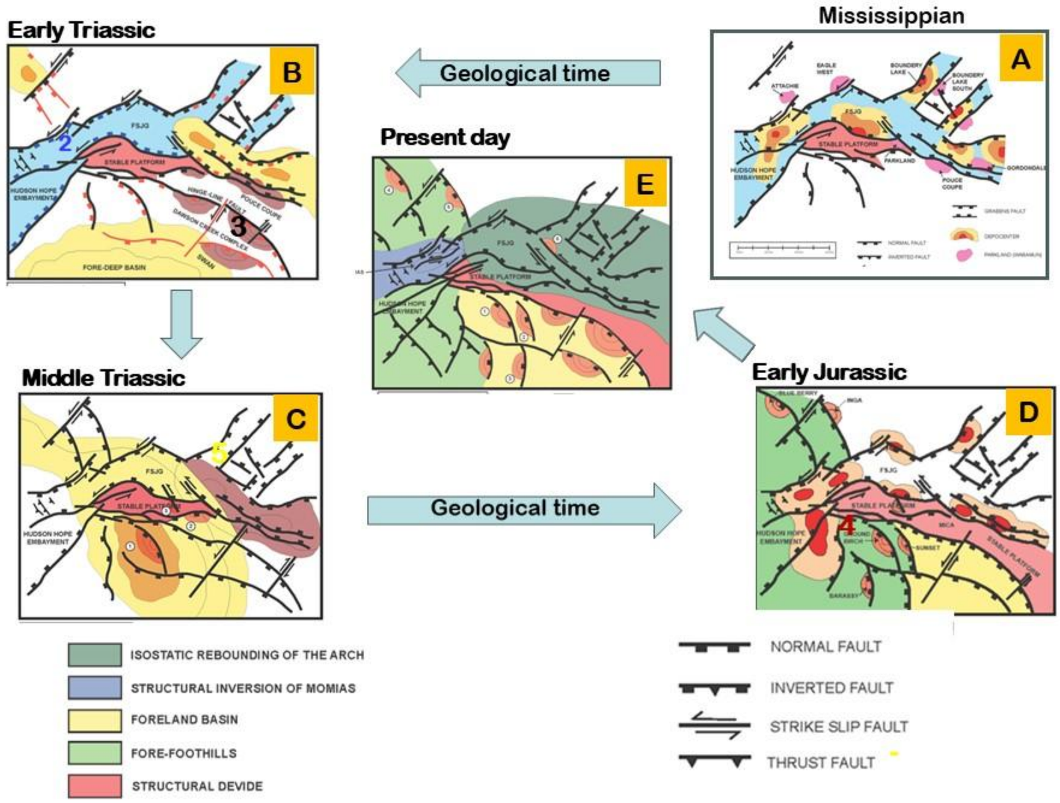

Figure 2- A series of tectono-stratigraphic maps that describe the tectonic evolution of the Peace River Arch and the northern parts of the Deep Basin areas.

Examples of data sets used to build the regional tectonic maps

Examples of some key data sets that were used to build the different regional tectonic maps shown so far are illustrated in figures 3A-E

- The first map of figure 3A shows the portion of the tectonic map that covers the core of the Peace River Arch and the FSJG areas.
- The second map of figure 3B shows a Kiskatinaw isopach map of the central parts of the FSJG. The map shows the location of major depo centers of this formation which include the central graben, the main Eastern Arm as well as the well-defined Neptune Arm that hosts the Boundary Lake field. The structural position of the Parkland gas field that is formed at the intersection of two main graben faults is also illustrated.
- The third map of figure 3C shows a Bluesky structure map that illustrates the inversion of the Hudson Hope Embayment. Note that both the major faults in this area manifest strong expression on the Bluesky structure map indicating that they were tectonically active in recent time.
- The four map of figure 3D illustrates the magnetic expression of the Dawson Creek Complex which occurs at the intersection of the hinge-line fault with reactivated strike-slip faults. This area is known to be technically active and a focal point of induced seismicity event.
- The final map of figure 3D shows a seismic line across the Hinge-Line fault near the Dawson Creek Complex. The line was datum on top of the Bluesky formation to illustrate the presence of the foreland basin in Triassic times.

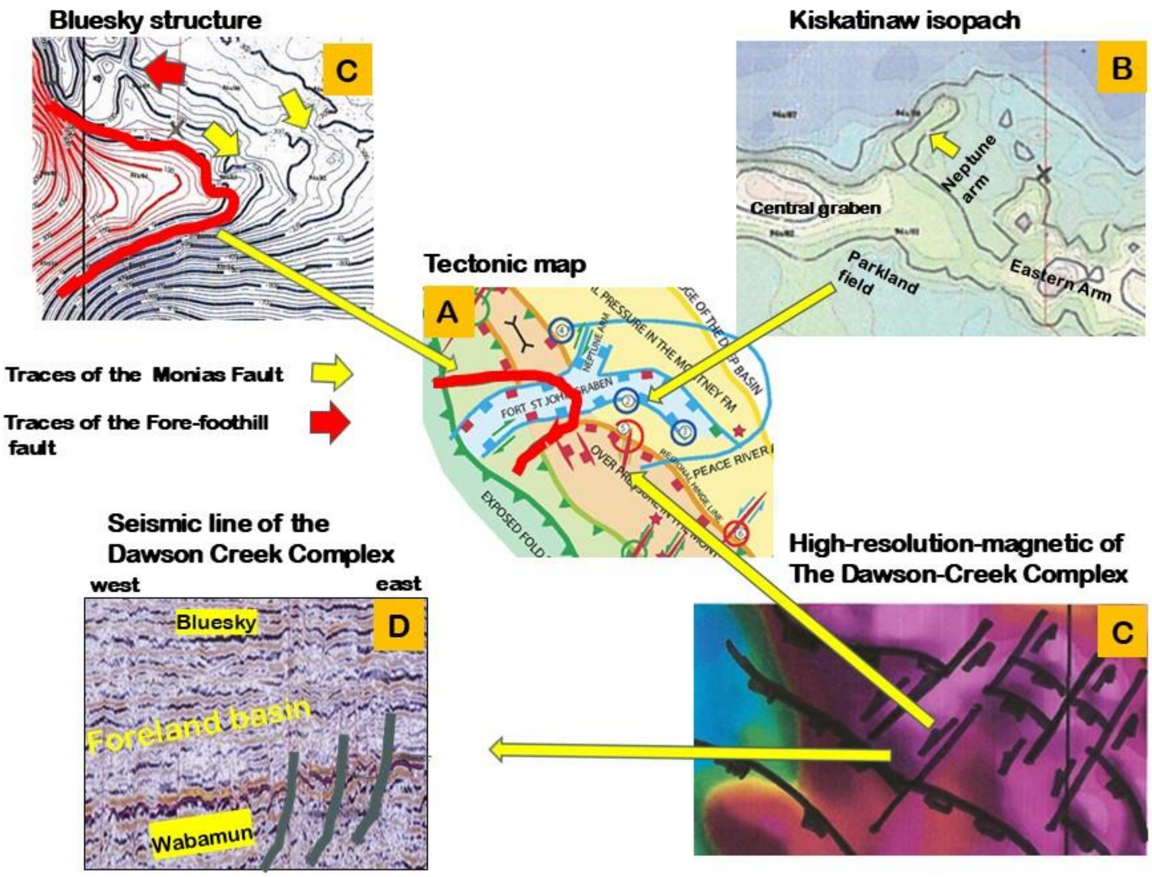

Figure 3- Examples of several data sets used to build the different tectonic maps shown in figure 2.

Extending the tectonic investigation to southern Alberta

The following example is used to illustrate the extension of the tectonic map further into Southern Alberta which recently experienced significant induced seismicity events associated with horizontal drilling activities (Sultz et al 2023). The data set shown in figure 4 combines the existing tectonic map of the Deep Basin with a structure map of Base of the Fish Scale that was published by Sultz in 2003, and a regional Lithophone seismic line that was collected by the Geological survey of Alberta (figure 4 A-C, respectively). The data illustrates that the basic structural setting of this area follows the same pattern as found in the Deep Basin area, with the exception that this area appears to experience greater extension associated with a stronger influence of the loading of the thrust sheet to the west. The two deep grabens shown on the map represent a small portion of several graben features that are found south of the USA border and are known to be part of the Great Fall Sheer Zone (see also figure 6). The wells that are shown here produce oil from a fractured reservoir of the Upper Banff formation. The drilling of these wells may have triggered several induced seismicity events in the vicinity of these producing wells (shown as a blue star).

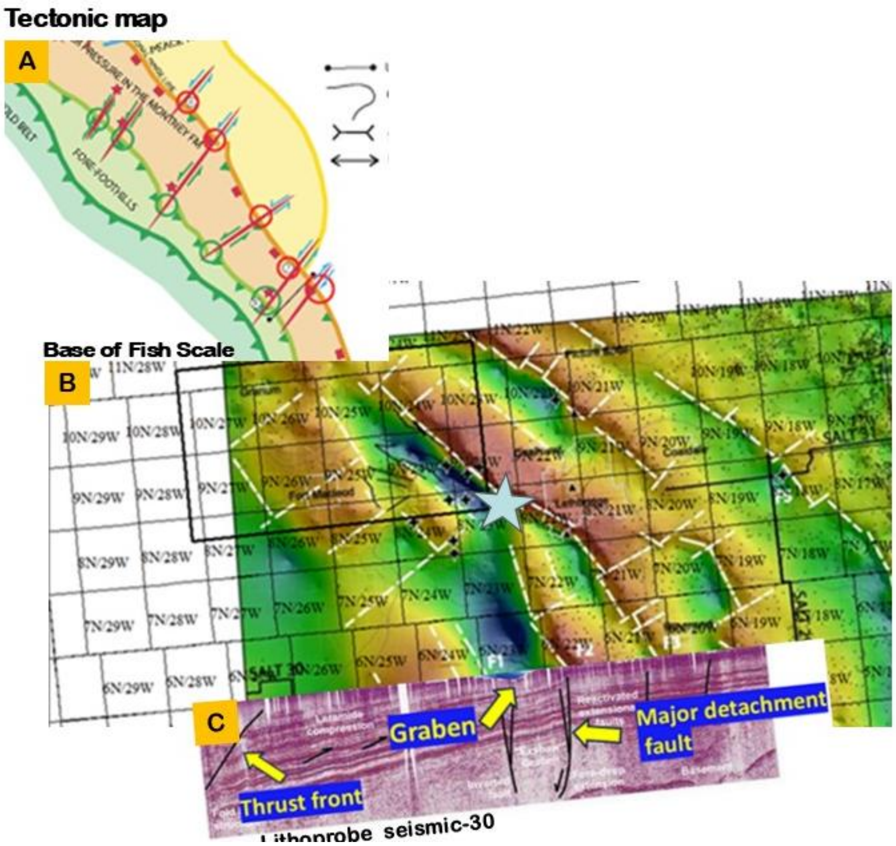

Figure 4- Examples of data sets used to assess the structural setting of Southern Alberta area and the effect of horizontal drilling of Upper Banff wells on the location of major induced seismicity events.

Conclusions and recommendations.

The Western Canadian Sedimentary basin is probably one of the best documented mature basins of the world. Yet, for some reason this basin did not receive the same tectono-stratigraphic attention as many other basins of the world (e.g. Ziegler 1982). An early version of the type of tectonic maps that can be built for the entire basin is illustrated in figure 5. The map is focused on the recognition of major tectonically active faults that have been well documented in the existing literature and are known to affect unconventional tight reservoirs and or cause significant induced seismicity events. The map was extended south into the USA to include the Great Falls Shear Zone that is partially mapped and recognized in southern Alberta.

We hope that this presentation will trigger greater interest in the geoscience community to further engage in extending this mapping effort over the entire WCSB.

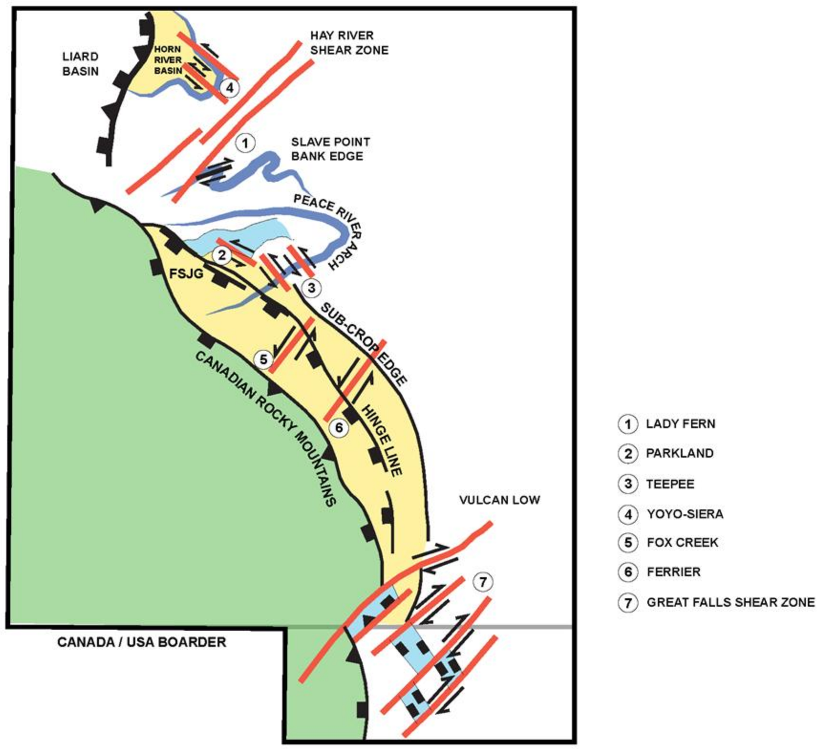

Figure 5- An example of a regional tectonic map that was expanded to cover most of the active areas of the WCSB.

References

Barclay, J. E., Krause, F. F., Campbell, R. I., Utting, J. 1990. Dynamic casting and growth faulting: Dawson Creek Graben Complex, Carboniferous-Permian Peace River Embayment, Western Canada. In: Geology of the Peace River Arch. S.C. O'Connell and J, S. Bell (eds.). Bulletin of Canadian Petroleum Geology, v. 38a, p. 115-145.

Berger, Z. 1994. Satellite hydrocarbon exploration: Interpretation and integration techniques. Springer-Verlag Berlin Heidelberg. New York. 319 p.

Berger, Z., and G.R Davies, 1999, The development of linear hydrothermal dolomite (HTD) reservoir facies along wrench or strike slip fault systems in the Western Canadian Sedimentary Basin: Canadian Society of Petroleum Geologists Reservoir, January, v.26, p.34-38.

Berger, Boast, and Mushayandebvu. 2010. Structural Synthesis of Emerging Unconventional Oil and Gas Plays along the Fold Belt Region of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists. The Reservoir, v. 37, issue 5. p. 26-30

Davis, G. R. and Smith, L. B. 2006. Structurally controlled hydrothermal dolomite reservoir facies, an overview. In: Structurally controlled hydrothermal alteration of carbonate reservoirs. Bulletin of the American Association of Petroleum Geologists, v. 90, no. 11, p. 1641-1690.

Furlong, C.M., Gingras, M.K, Moslow, T. and Zonneveld, J.-P (2018) The Sunset Prairie Formation: designation of new Middle Triassic formation between Lower Triassic Montney formation and Middle Triassic Doig formation Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, 66, 193-214.

Harding, T.P. 1984. Graben hydrocarbon occurrence and structural style. AAPG Bull 68: 333-362.

Schultz, R., Mei. S., Pana, D. Stern, Vol. 2015. The Cardstone Earthquake Swarm and hydraulic Fracking of the Exshaw formation (Alberta Bakken Play). Bulletin of the Sedimentology Society of America 105(6): 2871-2884.

Ziegler, P.A. (1982) Geological Atlas of Western and Central Europe. Amsterdam: Shell Int. Petrol. Mij. B.V. and Elsevier Science Publishers. Pp. 130 and 40 encl. ISNB 978-0-444-42084-8