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Update on the In Situ Stress Chapter of the 2027 CEGA Geological Atlas of the Western Canada Sedimentary Basin

Pat McLellan, M.Sc., P.Eng.
McLellan Energy Advisors
Lead Author, In Situ Stress Chapter of the 2027 CEGA Atlas

Summary

This presentation outlines much of the progress made to date on the compilation, analysis and interpretation of data for the in situ stress chapter of the 2027 CEGA Atlas of the WCSB. Selected examples of horizontal stress orientations and minimum horizontal stress magnitudes from the Montney Play area are described, as well as the methodologies being used to measure and analyze these data. Important applications of in situ stress data for well design, hydraulic fracturing, and the assessment of induced seismicity hazards in the Montney are mentioned. Summaries of the estimated number of SHmax orientations and Sv, SHmax and SHmin magnitudes from across the Atlas area are provided.

Background

Building on the compilation of in situ stress orientations and magnitudes in the 1994 CSPG AGS GSC Atlas of the Western Canadian Sedimentary Basin (Mossop et al, 1994), our sub-committee has been busy for a few years compiling stress data for four provinces and a portion of two territories. The new enlarged 2027 Atlas area stretches from the BC interior to eastern Manitoba and from the US border to the Arctic coast as shown in Figure1.

Figure 1: Western Canada showing the outline of the area covered by the 2027 CEGA Geological Atlas of the WCSB in four provinces and two territories. (https://atlas2027.ca)

Methodology

Methods typically used for measuring in situ stress magnitudes and orientations in the WCSB are summarized in Table 1. Most of the data that we have ready access to are derived from a limited number of sources, e.g., for stress orientations the historical data on borehole breakouts analyzed on oriented caliper logs and image logs are expected to comprise more than 90% of the data in our compilation. Maximum horizontal stress orientations derived from earthquake focal mechanism inversions are an important type of stress data, which will be compiled and analyzed in the seismicity chapter of the 2027 Atlas (see Eaton et al. 2025, this meeting). A comparison of wellbore-scale determinations of SHmax versus those analyzed from typically deeper earthquakes in the basin will be part of the final version of 2027 Atlas.

Vertical stress magnitude determinations are typically undertaken by integrating bulk density log data. As they are often the most accurate and the most easily determined stress component in the basin, we have not, to date, spent a lot of effort compiling this information from public domain sources. Minimum horizontal stress magnitude determinations from mini-fracs or DFITs (Diagnostic Fracture Injection Tests) are of considerable interest for applications like hydraulic fracturing, induced seismicity, wellbore stability and other issues. Only limited amounts of this data have traditionally made its way into the public domain, so we have spent a considerable effort compiling such data from industry sources and publications. Step-rate tests, pressuremeter testing, and mining measurements are similarly rarely performed and only a few such datasets are published. Drilling leakoff tests (LOTs), while popular in the offshore, are less commonly conducted in the WCSB with a goal of obtaining a quality SHmin stress measurement, and as such, are not included in our database.

Table 1: Main sources of in-situ stress orientation and magnitude data measured in the WCSB that are compiled for the 2027 CEGA Atlas

In-situ Stress Orientations	In-Situ Stress Magnitudes
• Oriented caliper logs	• Bulk density logs for vertical stress
• Borehole image logs	• DFITs, mini- and micro-fracs for SHmin
• Sonic log shear wave anisotropy	• Pressuremeter stress data
• Hydraulic fracturing microseismic and Distributed Acoustic Sensing (DAS)	• Step rate tests (waterflooding, disposal operations)
• Earthquake focal mechanism inversion	• Underground mining stress measurements
• Core-based methods (ASR, DSCA, overcoring)	

Selected Initial Results and Discussion

Figure 2 shows an example of horizontal in situ stress orientations (SHmax) determined largely from borehole breakouts in the Montney play area of NEBC and Alberta, as initially reported by Bell et al (1994) and compiled with additional data by Haug and Bell (2016), and later by McLellan (2021). Note the relatively consistent NE-SW orientation of SHmax for the area shown. More detailed local investigations for selected parts of the Montney, like the Kiskatinaw Seismic Monitoring and Mitigation Area (KSMMA), will also be summarized in the 2027 Atlas chapter.

Figure 3 is an example of the type of detailed DFIT data that has been collected by some operators in well-developed parts of the Montney play. McLellan et al (2016) reported on the statistical variation of both SHmin magnitude and reservoir pressure gradients across Talisman Energy's Farrell Creek field in NEBC. Using consistent interpretation methods, 32 DFIT tests were analyzed. Note the considerable

variation in both formation pressure and SHmin gradient values, probably due to the influence of the local faulted structure and some degree of reservoir depletion in selected areas.

In the last decade an important development in the interpretation of DFIT fracture closure pressures (FCP), our best proxy for SHmin magnitude, has been the recognition of an alternative selection methodology for this value, often referred to as the "compliance closure" (McClure et al 2016). While still controversial in some parts of the well testing community, our Atlas chapter will present examples of the latter methodology and its comparison to the classic or "holistic" FCP pick, popularized by Barree et al (2009). Differences in the order of 10-15% between the two FCP values, have been reported by several workers. (Virues et al, 2023).

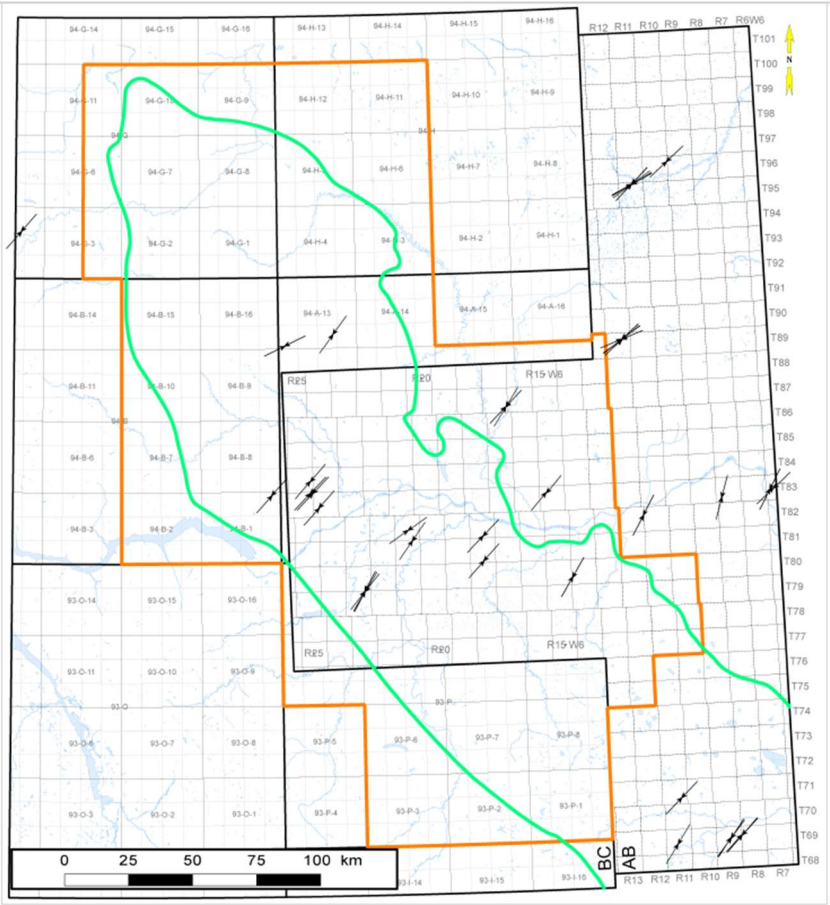

Figure 2: Map of NEBC and NW Alberta showing the Montney play outlined in green and the orientation of SHmax derived from selected borehole breakouts and drilling induced fractures (McLellan, 2021).

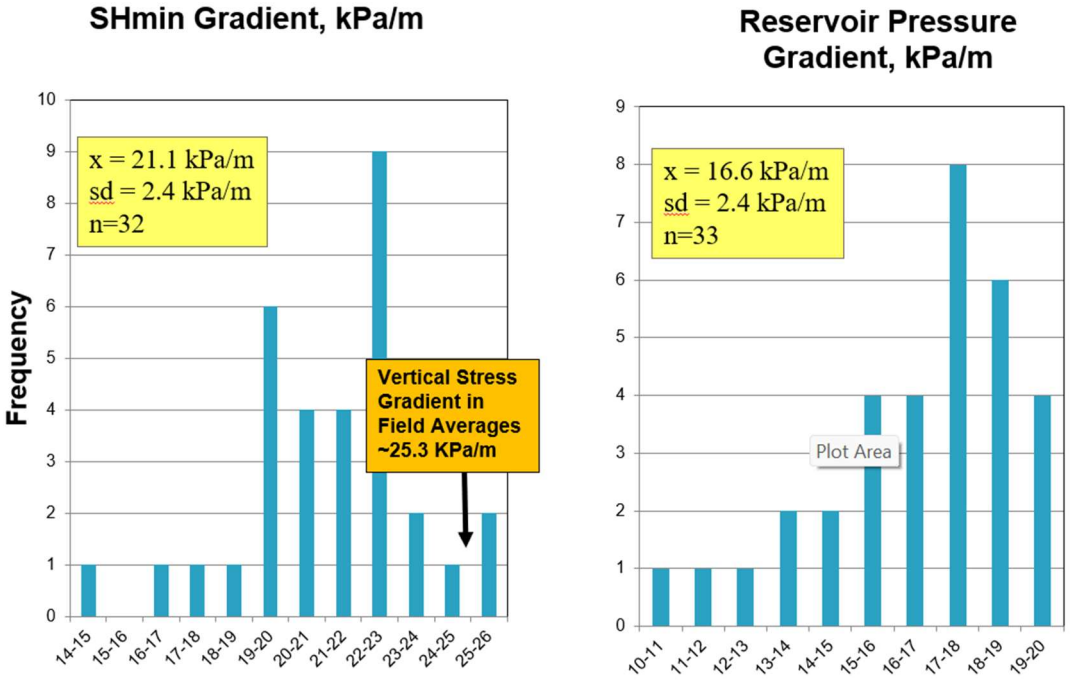

Figure 3: Example of DFIT derived SHmin and reservoir pressure gradients measured by Talisman Energy in the Montney Formation in the Farrell Ck field, NEBC. McLellan et al (2016). Fracture closure pressures were selected using the FCP pick on a Gdp/dG vs time plot after Barree et al. (2009). x = mean value, sd = standard deviation.

Table 2 shows our current estimates for the number of maximum horizontal in situ stress (SHmax) orientations, organized by the technique used, in the 2027 Atlas version versus the data compiled in the 1994 Atlas (Bell et al, 1994). Maps of stress orientations, derived by different methods, will be shown for selected parts of the basin.

Table 3 shows our current estimates for in situ stress magnitudes (Sv, SHmax, and SHmin), organized by the technique used, in the 2027 Atlas version versus the data compiled in the 1994 Atlas (Bell et al, 1994). Plots of stress magnitude versus depth, for several techniques, will be used to present this information for selected regions in the WCSB.

Preliminary Learnings

- The in situ stress chapter of the 2027 CEGA Atlas is progressing well and we expect to have our draft maps, figures and text completed by the end of 2025. The complete digital Atlas publication is scheduled for release in 2027.
- There is relatively good coverage of the orientation of the maximum horizontal in situ stress, SHmax, in several formations of Alberta and British Columbia, especially the Montney and Duvernay, obtained mainly from borehole breakouts and drilling induced fractures identified in caliper and image logs.
- Detailed observations of SHmax at the well pad scale have been obtained from a small number of distributed acoustic sensing (DAS) tests conducted to monitor hydraulic fracturing treatments.
- SHmax orientations, obtained largely from borehole breakouts and drilling induced fractures at the wellbore scale in the WCSB are sometimes noted to differ from earthquake focal mechanism derived estimates of SHmax orientation.

Table 2: Predicted number of maximum horizontal stress (SHmax) orientations by technique in the 2027 Atlas versus the 1994 Atlas.

	1994 Atlas	2027 Atlas Estimated	Comment
Total Number of SHmax Orientations	**192 in 182 wells**	**>450 in > 350 wells**	
Borehole Breakouts	181	>350	Dominant data source
Core Relaxation Based Methods	3	10	DSCA, ASR, petal fractures
Microseismic Monitoring of Hydraulic Fractures	1	10	Where tensile events are clear
Drilling Induced Fractures (DIFs)	0	30	Visible on borehole image logs
Overcoring	3	10	Mines, dams, AECL radioactive waste site
Distributed Acoustic Sensing (DAS, DSS)	0	5	Relatively new but rarely reported in public
Structural Geology Inference	2	10	Recent outcrop fault re-activations
Earthquake Focal Mechanism Inversions	0	*TBD*	To reside in the Atlas Seismicity Chapter

Table 3: Predicted number of in situ stress magnitudes by technique in the 2027 Atlas versus the 1994 Atlas.

	1994 Atlas	2027 Atlas Estimated	Comment
Total Number of SHmin Magnitudes	**188 in 182 wells**	**>330 in > 250 wells**	**Limited by proprietary nature of most tests**
Micro-, Mini-fracs, DFITs	40 In 24 wells	>200	Highest quality HF tests. Mainly in horz wells.
Mini-fracs 1988 Petroleum Society of CIM Database	107	~107	SHmin picks using methods of that time
Overcoring	2	20+	Mines, Dams, AECL Rad Waste Site
Leak-off Tests (LOTs)	35	0	Not included due to data quality issues
Total Number of SHMax Magnitudes	14	~25	From breakout inversion, polygon plots, other
Total Number of Sv Magnitudes	5	>200	Maybe mappable for selected formations.
Pore Pressures	0	>100	From DFITs.

Note: For the most part the reporting interpreted stress magnitudes are from public sources

- There is a rich dataset of DFIT-derived SHmin magnitudes for many formations in the Atlas, especially as measured in fracture stimulated horizontal wells in unconventional reservoirs such as the Montney and Duvernay. Selected oilsands reservoirs and their caprocks have also been extensively tested, since SHmin is required to set maximum injection pressures for SAGD and CSS operations.
- SHmax magnitude measurements in the WCSB are relatively scarce, as it is rarely tested in vertical openhole wellbores. It can, however, be calculated based on hole enlargement and with a knowledge of rock mechanical properties.
- Vertical stress is easily and accurately calculated from bulk density logs, ideally from wells with good log coverage below surface casing

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We would also like to thank the many individuals, corporations and research agencies who have generously supported our sub-committee with the provision of data and their guidance in its interpretation.

Any company with proprietary stress orientation and or magnitude data, which you are willing to make public in this Atlas chapter should contact Pat McLellan, lead author.

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