

PS Evolution of Frasnian Mixed Carbonate-Siliclastics Systems: Outcrop-Based Characterization of Sequence Stratigraphy and Architecture, Cline Channel and Jasper Basin Areas, Alberta, Canada*

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Abstract

Ten (third-order) Composite Sequences are recognized within a Second-Order depositional sequence spanning the uppermost Givetian to the base of the Famennian from the Alberta basin. The eight youngest composite sequences are defined from the Cline Channel and Jasper Basin areas utilizing stratal and facies stacking patterns, regional correlation of sequence boundaries and maximum flooding surfaces integrated with conodont biostratigraphy. Most sequence boundaries observed are subaerial exposure surfaces, seen in outcrop or inferred from onlap of tidal flat or reef margin deposits onto foreslope facies. The Cline Channel is filled asymmetrically from southeast to northwest within the study area. Progradation is on a foundation of bank derived fine-grained carbonates and extra-basinal clays (forming argillaceous carbonates and calcareous shales). In the Cripple Creek area, on the southern margin of the Cline Channel, the second order Frasnian cycle is characterized by initial retrogradation followed by aggradation to retrogradation and finally, progradation in the upper Frasnian. At Wapiabi Gap, the overall stacking pattern is aggradational. In both the Cline Channel and the Nikanassin area of the Jasper Basin, decreasing accommodation within the second order highstand is exemplified by the reduction of composite sequence thickness and the replacement of open marine with bank interior facies as the basin.

References Cited

Weissenberger, J.A.W., P.K. Wong, and M.G. Gilhooly, (in press), Stratigraphic architecture of the Frasnian Jasper Basin, north-central Alberta Front Ranges: in Playton, T.E., Kerans, C., Weissenberger, J., and Montgomery, P., (eds.), New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy: SEPM Special Publication.

Wong, P.K., J.A.W. Weissenberger, and M.G. Gilhooly, (in press), Sequence Stratigraphic Architecture of the Frasnian Cline Channel, Central Alberta Front Ranges: in Playton, T.E., Kerans, C., Weissenberger, J., and Montgomery, P., (eds.), New Advances in Devonian Carbonates: Outcrop Analogs,

Reservoirs, and Chronostratigraphy: SEPM Special Publication.

Wong, P.K., J.A.W. Weissenberger, and M.G. Gilhooly, (in press), Revised Regional Frasnian Sequence Stratigraphic Framework, Alberta outcrop and subsurface: in Playton, T.E., Kerans, C., Weissenberger, J., and Montgomery, P., (eds.), New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy: SEPM Special Publication.

ABSTRACT

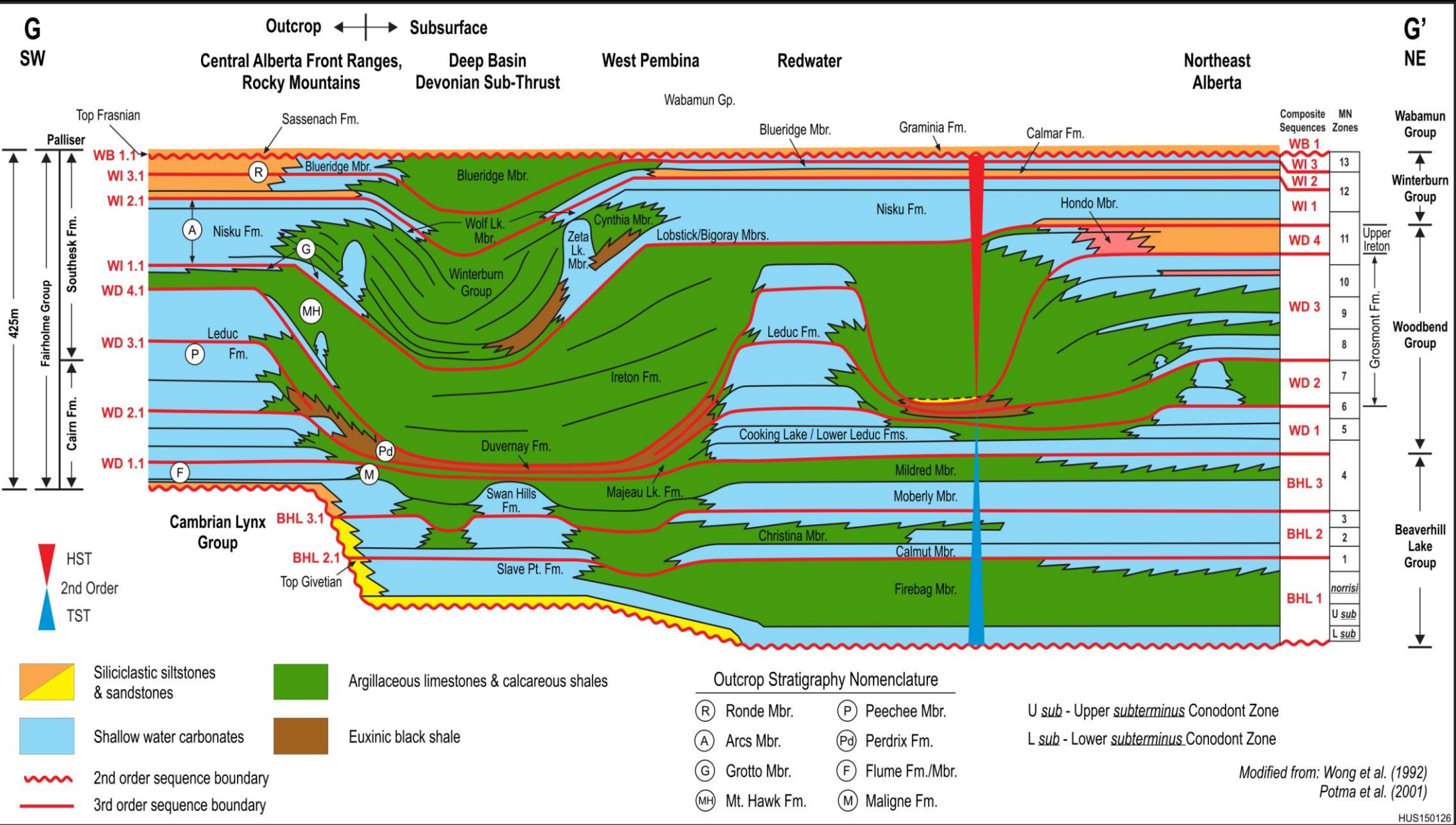
- Many of the classic Frasnian outcrops from the Alberta Front Ranges, from the Cascade (Burnt Timber) Channel to the South Jasper Basin are placed into a sequence stratigraphic framework.
- Ten third-order composite sequences and their constituent high frequency (fourth-order) sequences span the uppermost Givetian to Frasnian strata. They reflect stratigraphic architecture typical of a (second-order) depositional sequence: transgression followed by regression, or basin-opening and filling.
- The eight youngest composite sequences are defined from the Cline Channel and Jasper Basin areas utilizing stratal and facies stacking patterns and the regional correlation of sequence boundaries and maximum flooding surfaces, integrated with conodont biostratigraphy. Most sequence boundaries observed are subaerial exposure surfaces, seen in outcrop or inferred from onlap of tidal flat or reef margin deposits onto foreslope facies.
- Composite and high frequency sequences (CS and HFS) can be confidently extended from outcrop to subsurface. A combination of well log and outcrop cross-sections, integrated with biostratigraphy, support these correlations. These regional (time) surfaces allow better understanding of basin evolution and architecture
- The basin was filled asymmetrically by mixed carbonate-clay successions that form the dominant east to west prograding strata. Two main types of sediment contribute to the basin fill: extrabasinal clays and intrabasinal carbonates. Extrabasinal siliciclastics, mostly clay, were ultimately sourced from the Caledonian orogeny which extended from the east coast of Greenland to the Canadian Arctic Islands.
- Influence of the Second-Order sequence is expressed in the architecture of composite and high frequency sequences. For example, the tripartite character (lowstand-transgressive-highstand) of CS in the lower and middle part of the sequence is followed by the appearance of a distinct falling stage component in the upper part of the Frasnian.
- An increased frequency of truncation surfaces and off-lapping strata is consistent with diminishing accommodation. With progressive basin infill and shallowing paleobathymetry, foreslope declivity decreased from a minimum of 10° to less than 1.5° as foreslopes became more ramp-like. This is accompanied by a change of lowstand geometry, from wedge to tabular shaped.
- Deposition of coarser terrigenous clastics is also limited in most of the basin, except at CS and HFS boundaries, in the lower part of the second-order sequence. Restricted marine circulation onto the carbonate platforms and basin filling in the late Frasnian coincided with extensive siliciclastic silt deposition in the study area. In the upper Frasnian, particularly in the Jasper Basin, influx of terrigenous silt forms mixed carbonate-siliciclastic deposits. Silt was deposited during third and fourth-order lowstands, by-passed into the basin, and re-worked during intermittent inundation of the carbonate platforms.
- Beyond the basic transgressive-regressive architecture of the Second-Order Givetian-Frasnian Sequence, we document more detailed observations such as: 1) controls affecting the onset, cessation and extent of euxinic shale deposition in the mid-Frasnian and its relation to the second-order MFS; 2) the relative speed and distribution of illitic basin fill within the second-order highstand; 3) the effect of basin fill and off-bank sediment transport on regional and local carbonate platform architecture, such as the configuration of *in-situ* carbonate lowstands, initiation of reefs along favorable fairways, and overall margin stacking patterns; and 4) the magnitude of relative sea level falls associated with the development of sequence boundaries.

Database

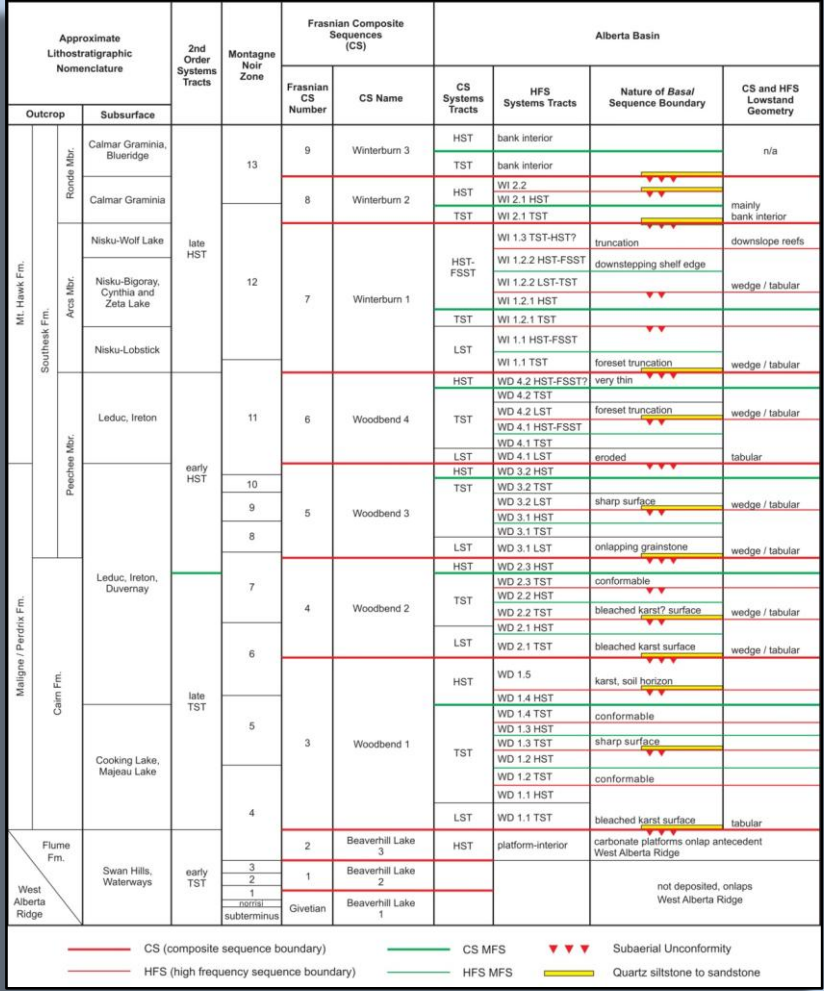
- Outcrop: 64 sections described along the front ranges of Alberta from the Canmore to the Miette area.
- Detailed mapping of 17 continuously exposed, platform to basin transitions where flooding surfaces, sequence boundaries and facies contacts were walked out and/or correlated with photograph panoramas. These outcrop “windows” were linked by additional stratigraphic sections and reconnaissance undertaken between them.
- Extensive subsurface database (partly summarized in Potma *et al.*, 2001) was expanded for this study. A detailed re-interpretation of the Redwater and Golden Spike reefs and the Grosmont Shelf was undertaken. Regional well-log cross-sections, including 30 wells, establish the correlations across the basin.

Acknowledgements

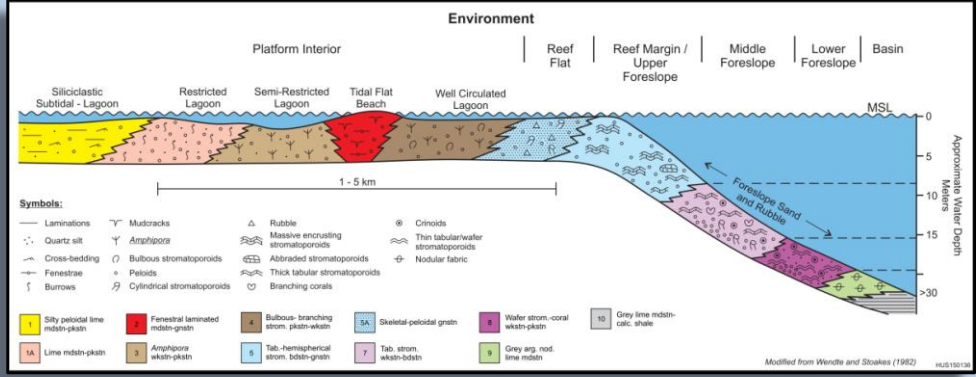
The authors wish to thank Imperial Oil, PanCanadian Petroleum and Husky Energy for support in conducting Devonian Research. Sincere thanks are also due to our many colleagues who participated as researchers and filed assistants over the years, particularly Ken Potma and to Phil Argatoff for drafting the figures.



Late Devonian (mainly Frasnian) paleogeography of North America showing location of Alberta (black outline) with respect to the paleo-equator (red line). Map from Ron Blakely, cpgeosystems.com..



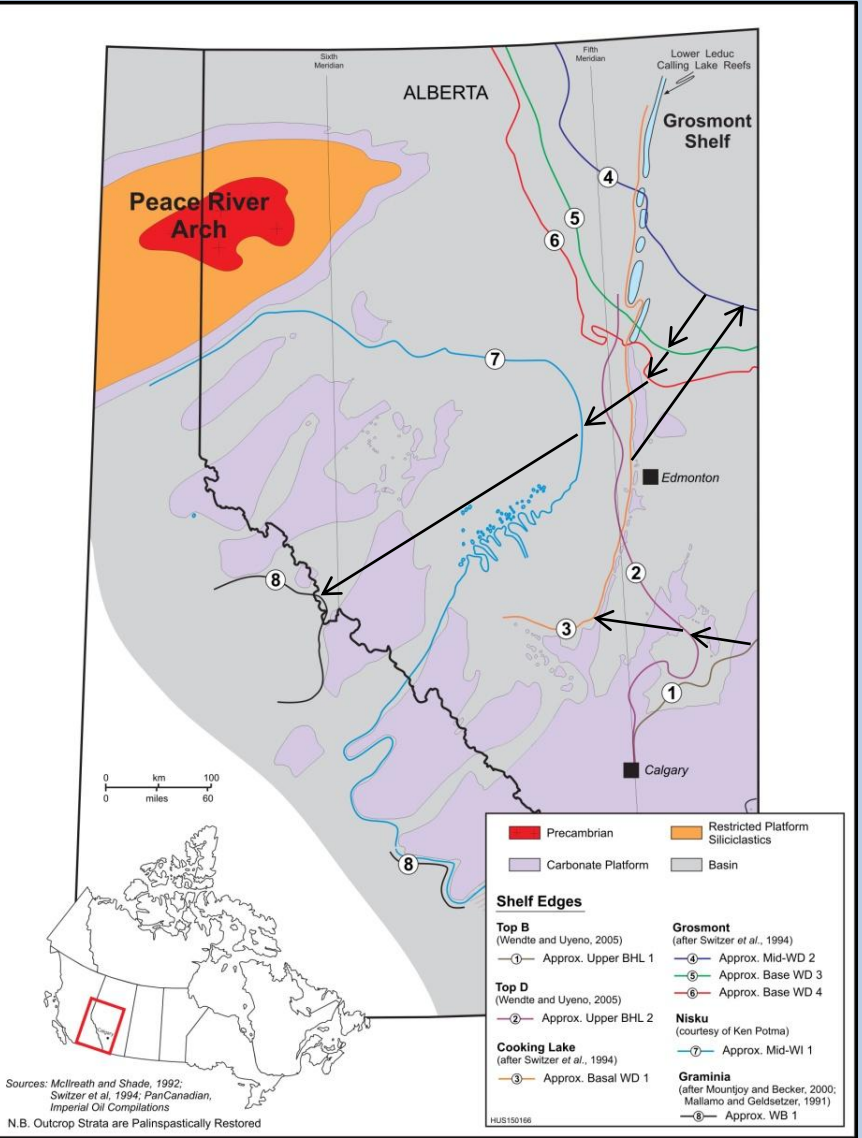
Summary of the composite and high frequency sequences recognized, main features of associated sequence boundaries and their systems tract breakdown. Givetian-Frasnian supersequence, Alberta Basin.



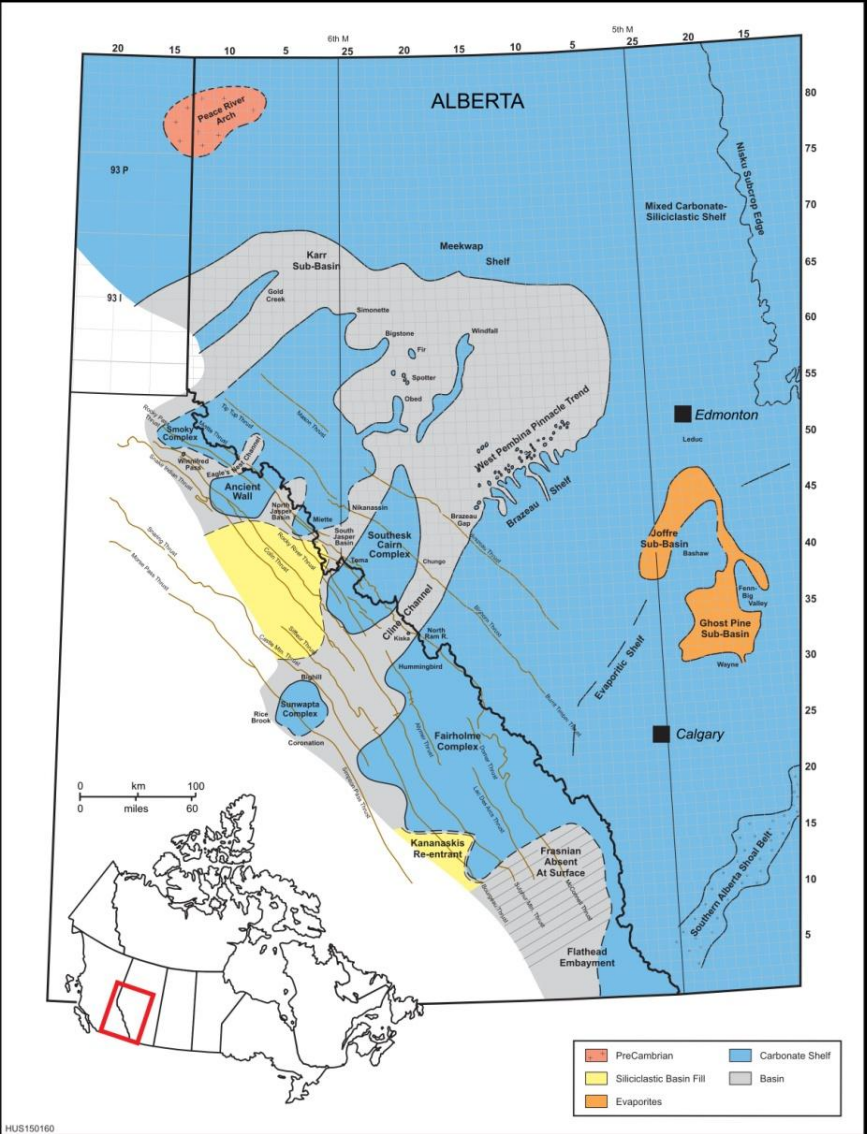
Depositional model for Frasnian reefal carbonate platforms, Alberta.

Frasnian second-order supersequence (late TST to late HST) at the Cripple Creek area. The WD2 MFS (= supersequence MFS) marks the turnaround from aggradation to progradation. It can be traced from branching coral wackestone-packstone of the foreslope (left) into the high TOC lime mudstone and shale of the Duvernay Formation (right). The WB1.1 sequence boundary (top) coincides approximately with the Frasnian-Famennian boundary.

Schematic sequence stratigraphic cross-section (G-G') of the late Givetian to basal Famennian strata of Alberta showing the major third-order Frasnian composite sequences. The second-order late Givetian-Frasnian supersequence extends from the base of the Watt Mountain Formation to the base of the Wabamun Group. Basin fill is a mix of platform derived carbonates and fine-grained extra basinal clay (forming argillaceous limestones and calcareous shale).



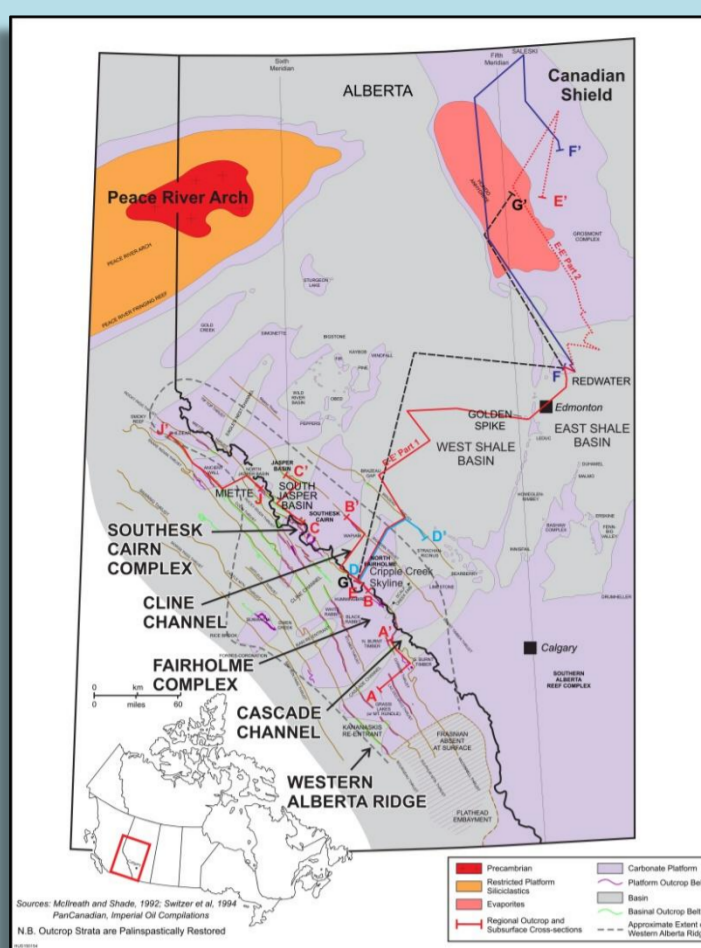
Map showing the location of successive carbonate shelf edges of the Givetian-Frasnian second-order supersequence, Alberta Basin. Numbers record the progression of shelf edges, from the oldest (1) to the youngest (8).



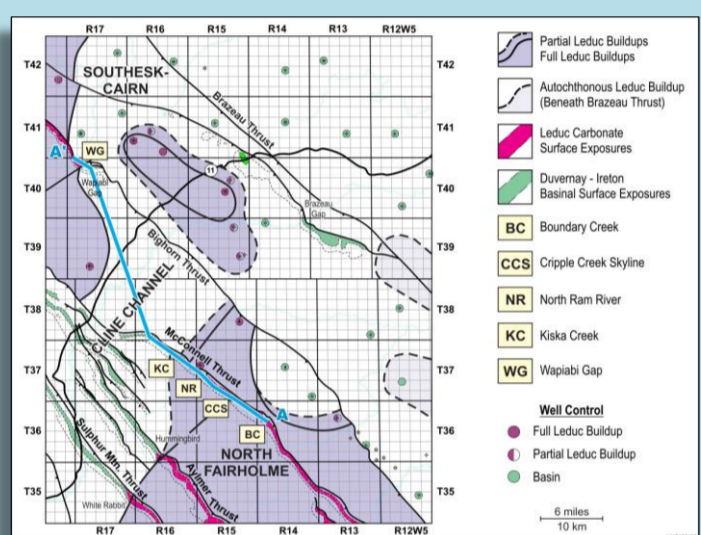
Nisku paleogeography map. At this time, the Alberta Basin is nearly filled with extensive shelfal areas. Courtesy of Ken Potma.

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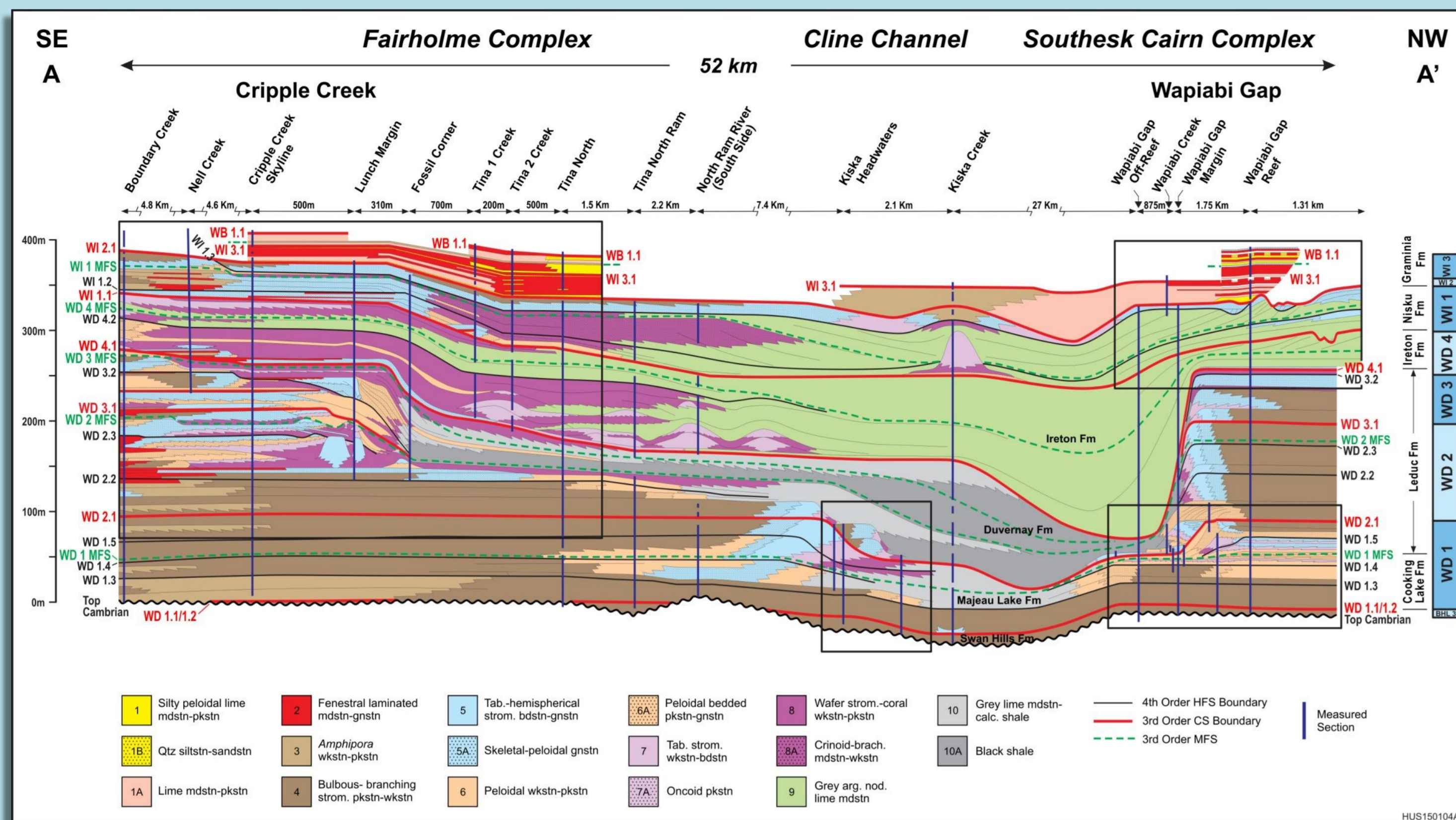
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Palinspastically-restored paleogeographic map of the Leduc Formation reefs of Alberta and adjacent British Columbia. The reef distribution approximately represents base Woodbend Sequence 4 deposition.



Map showing line of cross-section A'-A in relation to the Frasnian Cline Channel and the Southesk Cairn and Fairholme Complexes. This paleogeographic map is not palinspastically restored. Wapiabi Gap is located on the Big Horn thrust whereas Cripple and Kiska Creeks are on the McConnell thrust.



Southeast to northwest cross-section of the Cline Channel, from Cripple Creek to Wapiabi Gap. Line of cross-section is located to the left. Because of scale constraints, lithofacies of the platform-interior are colored by the dominant type. Boxes demarcate areas of continuous exposure and detailed study; where measured sections were supplemented by photomontages and field mapping.

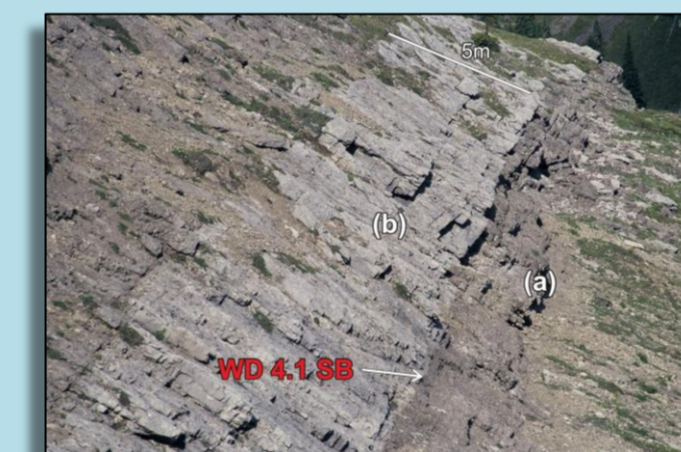
Red iron oxide stained shale at the WD2.1 sequence boundary, underlain by laminated peloidal packstone-grainstone distal foreslope strata. Reef-flat stromatoporoid rubble grainstone overlie the sequence boundary. Wapiabi Gap Off Reef.



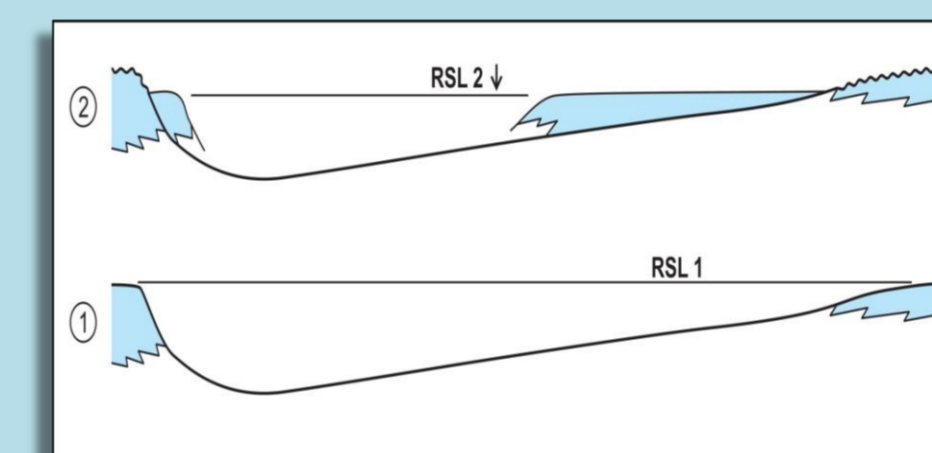
Branching stromatoporoid-stromatoporoid fragment grainstone transgressive lag (b) overlying ravinement modified WD2.1 sequence boundary. Bedded peloidal-skeletal packstone and grainstone (a) underlie sequence boundary, 0.75 km north of Wapiabi Creek



The WD 2.1 sequence boundary (indicated by red arrows), separating red iron oxide stained thin bedded packstone and grainstone foreslope strata from overlying backstepping *Amphipora* packstone-wackestone, skeletal grainstone and stromatoporoid rubble, Wapiabi Gap Off Reef.

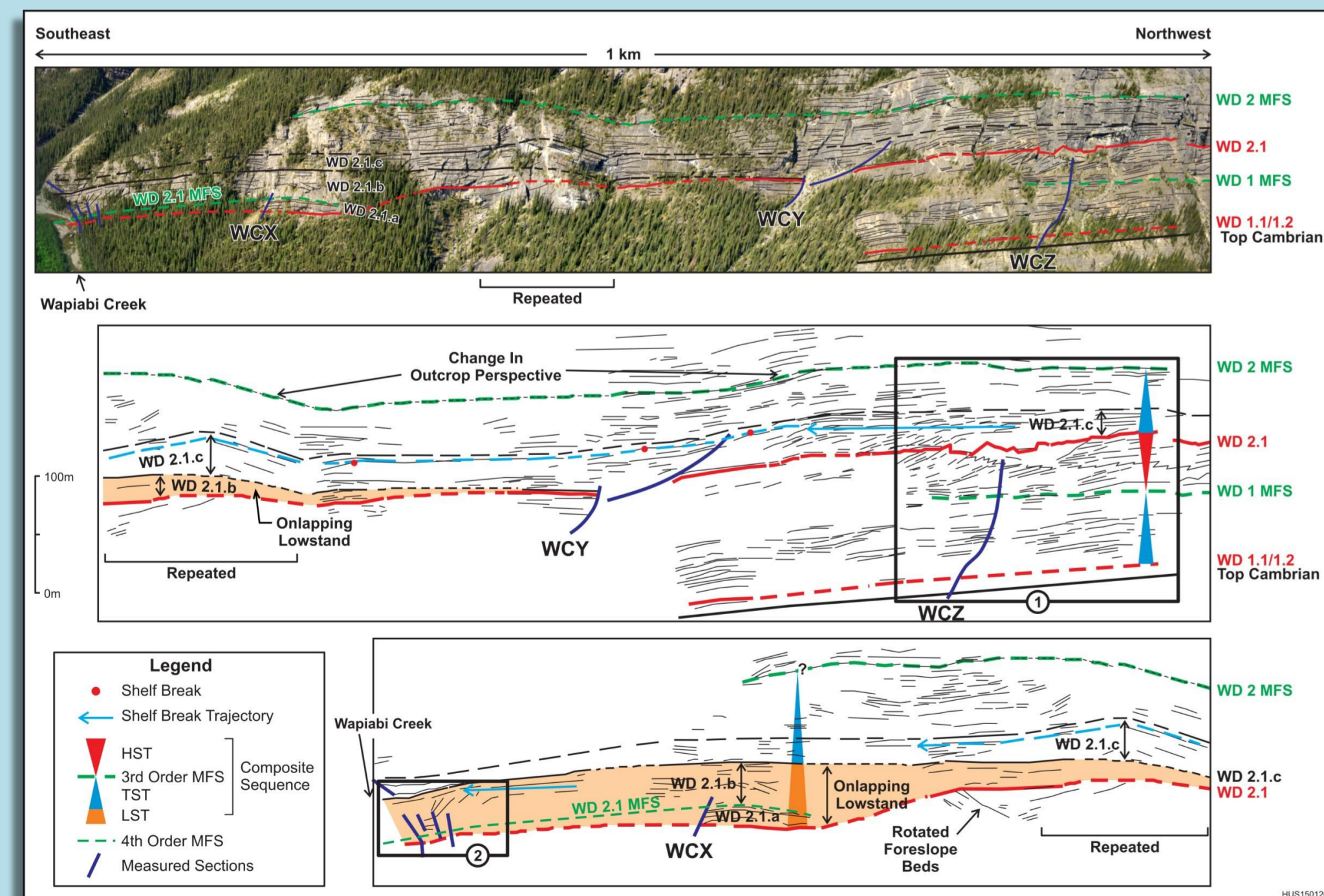
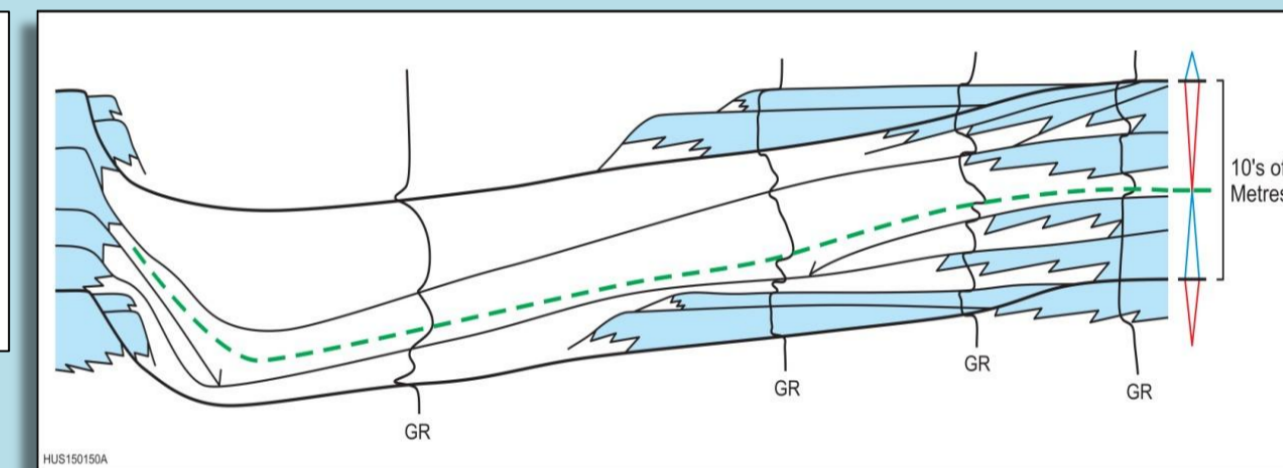


Upper foreslope skeletal grainstone (b) overlying and separated from lower foreslope branching coral packstone and wackestone (a) by the WD4.1 sequence boundary, 100 m north (basinward) of the Lunch Margin location.

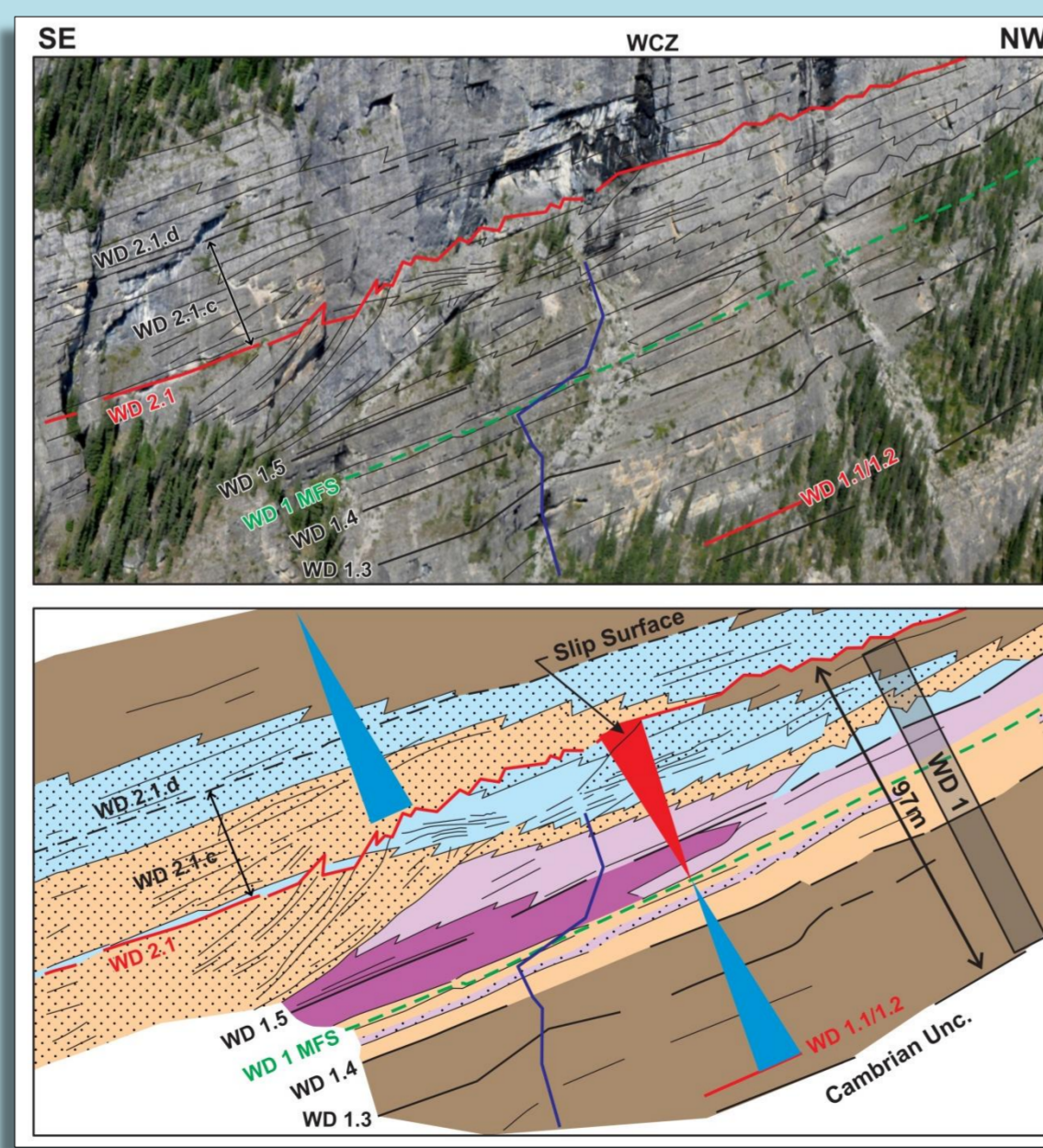


Contrasting response to a relative sea level fall on high (left) and low (right) declivity slopes. Wedge shaped lowstands form on steeper slopes and tabular-shaped lowstands on gentler slopes. Westward prograding mixed carbonate siliciclastic slopes, represented on the right of the figure, are generally ramp-like with slopes less than a degree.

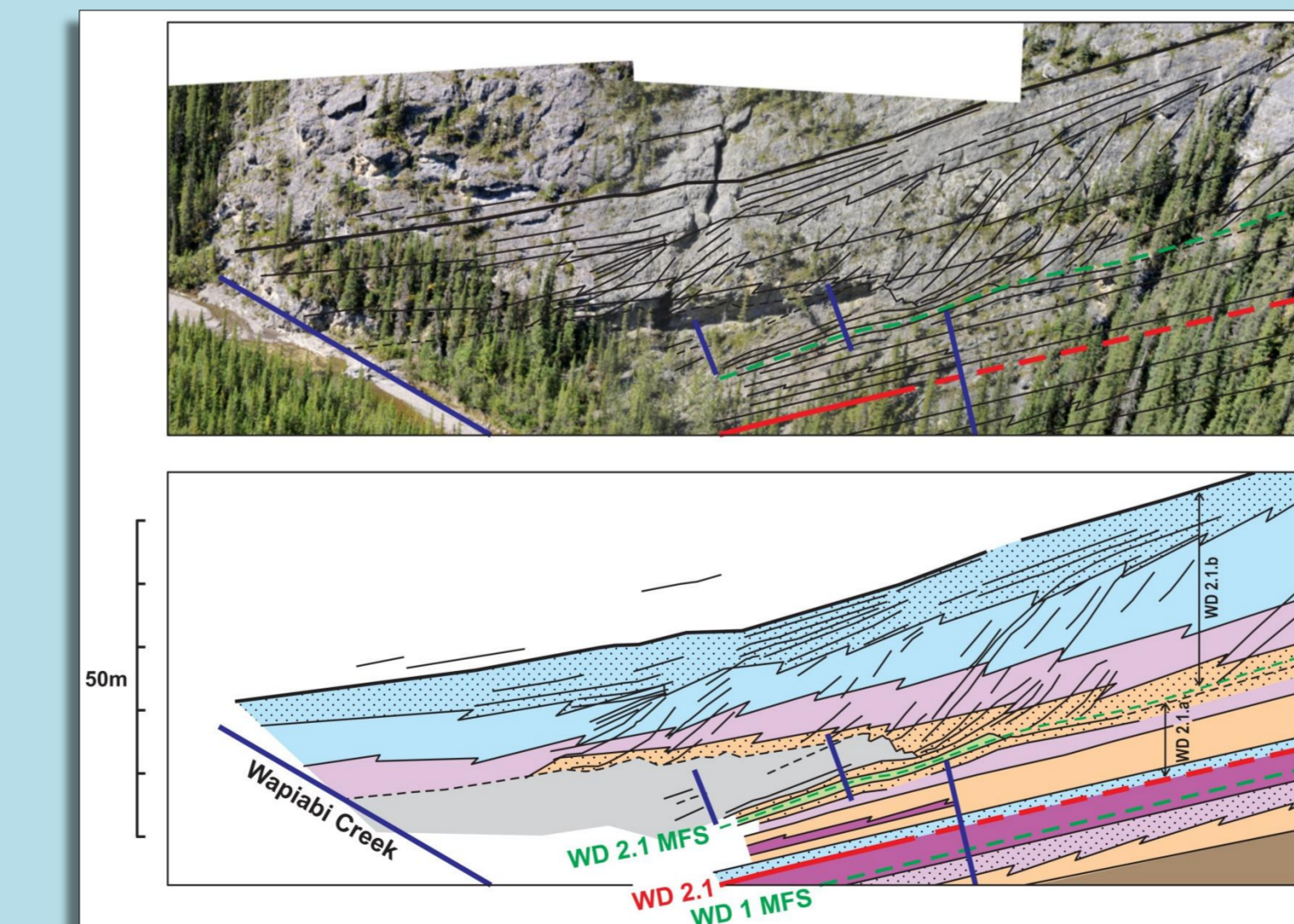
HFS stacking pattern and inferred gamma-ray log response.



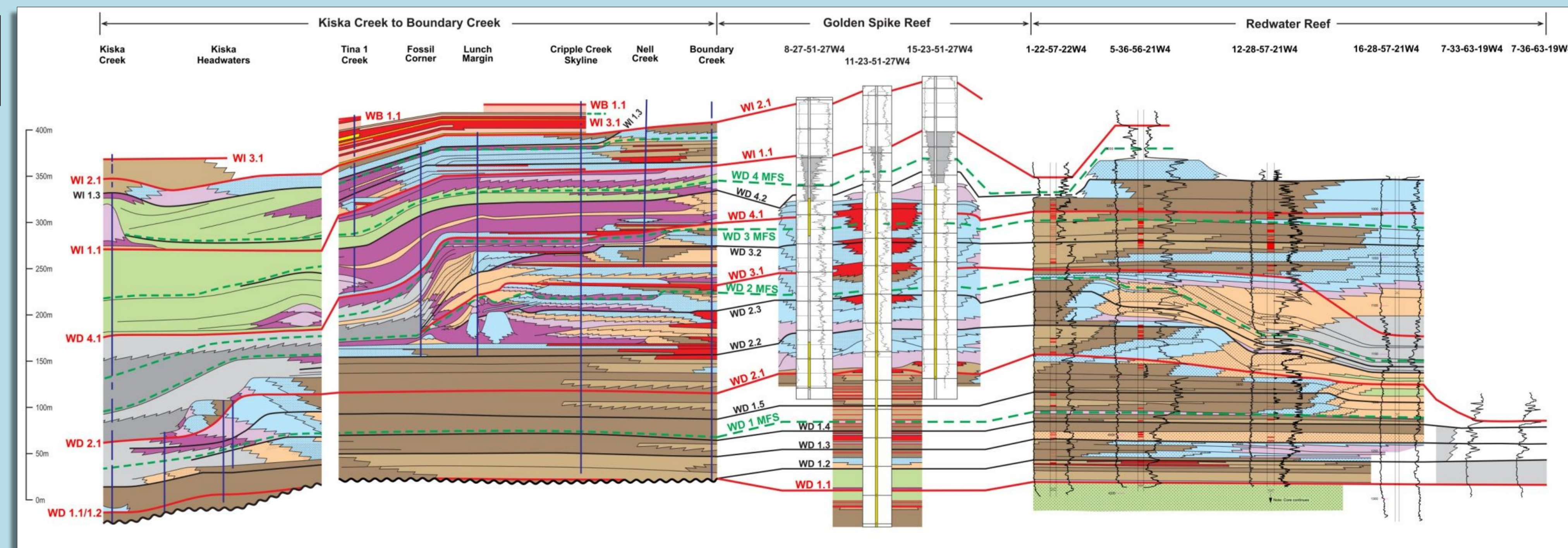
Interpreted photomontage of stratal stacking patterns within the WD1 and WD2 composite sequences showing onlapping and progradational geometries associated with the WD2 CS lowstand (W2.1.a and W2.1.b cycle sets). Underlying WD1 CS highstand foresets are truncated along the ravinement-modified WD2.1 sequence boundary, as shown in box 1 and Figure on the right. Progradation of the WD2.1.c cycle set (= WD2 CS TST) ends at the lowstand shelf edge, immediately south of Wapiabi Creek. Northside, Wapiabi Creek.



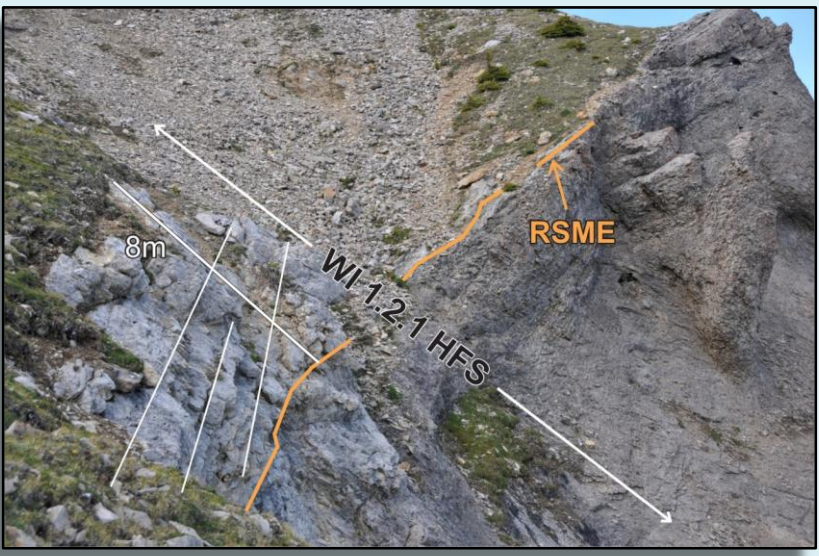
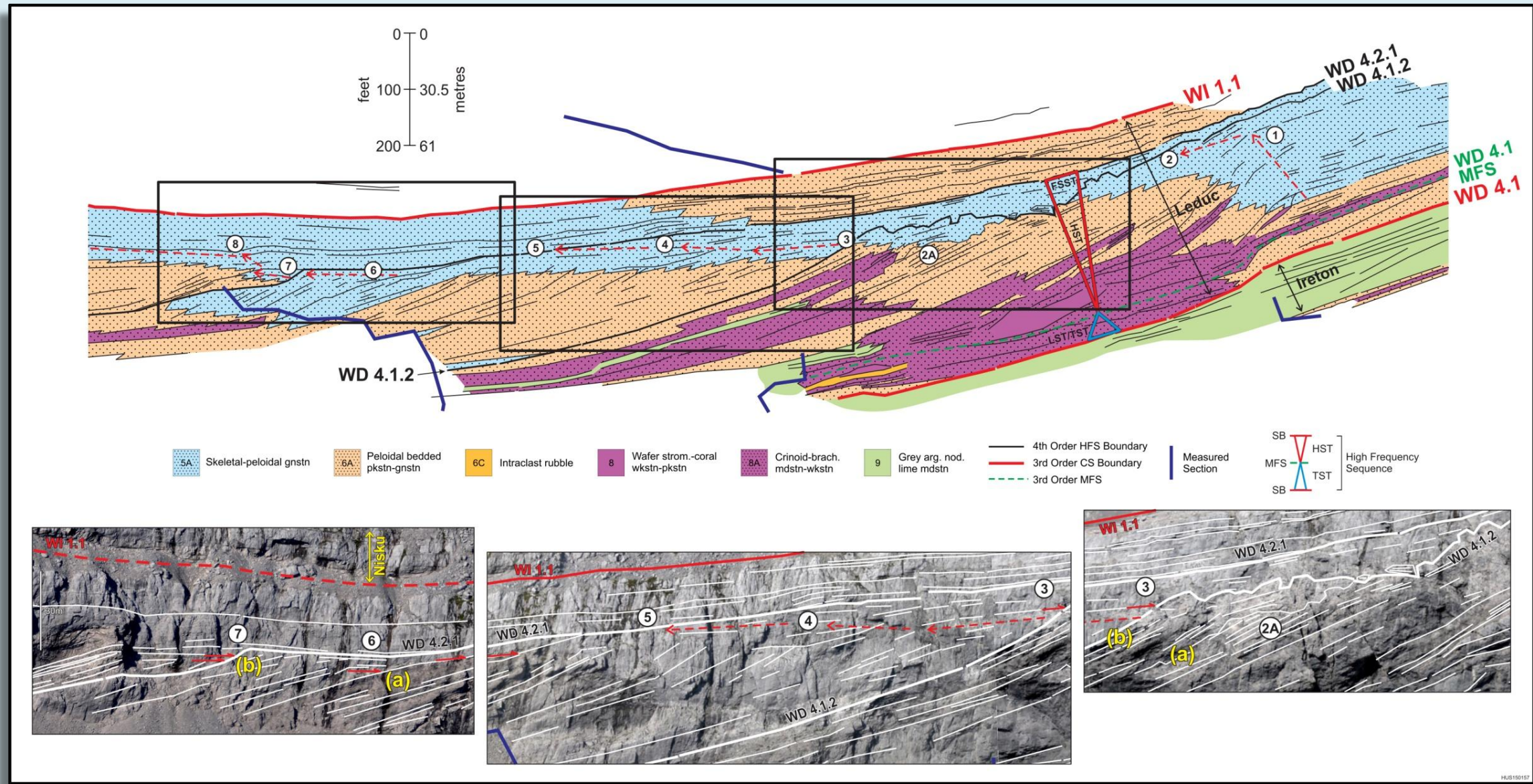
Outcrop photograph and interpreted overlay of the WD1 CS showing systems tracts, component HFS, stratal stacking patterns, lithofacies, ravinement truncation and transgressive lag of stromatoporoid grainstone above the WD2.1 sequence boundary (extreme left). Note change in stratal patterns, from sub-horizontal and aggradational to progradational, across the WD1 MFS. Wapiabi Gap.



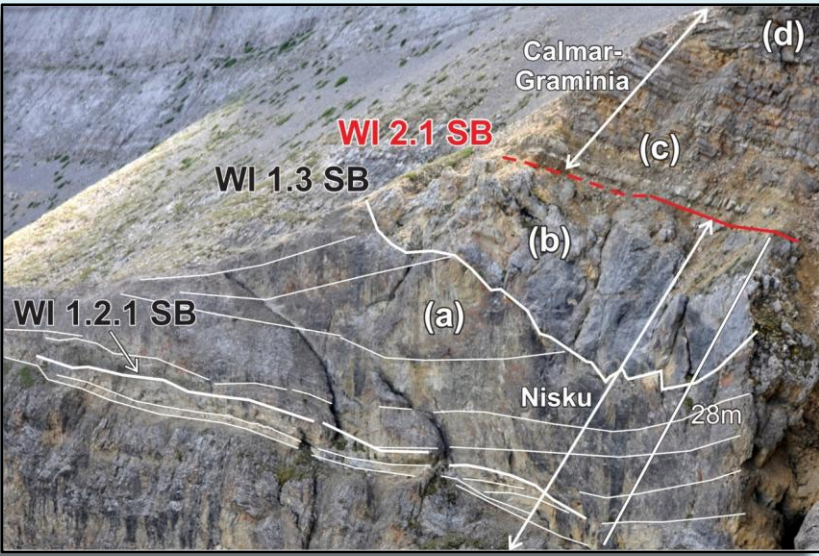
The WD2.1 HFS lowstand consisting of prograding hemispherical stromatoporoid boundstone overlying tabular stromatoporoid packstone-boundstone at Wapiabi Creek. Carbonate sand overlies the erosive contact developed on organic-rich calcareous shale. Note the steep foreslope dips of 25-30°.



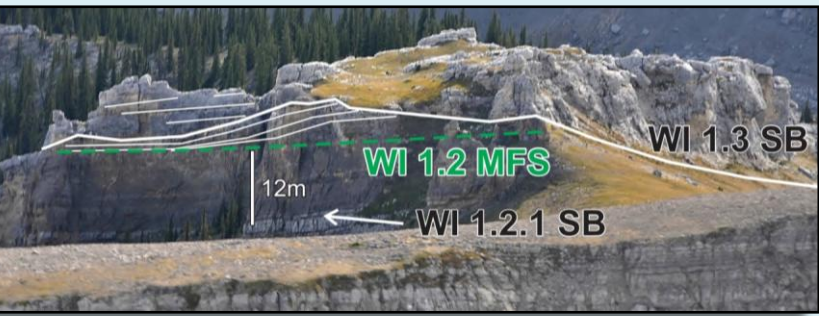
Correlation of Frasnian high frequency and composite sections between the Redwater and Golden Spike reefs to the southeast margin of the Cline Channel, between Boudary and Kiska creeks. Cross-section data are from: Redwater (Wendt 1994 and Chow et al. 1995), Golden Spike (Potma et al. 2001), and Cline Channel (Wong et al. in press). Logs of the Redwater and Golden Spike cross-sections are gamma-ray (left) with/without sonic (right) curves. At Golden Spike, HF5 are defined by upward-shoaling lithofacies successions (WD1.2, WD1.2 and WD2.3). High frequency HST are often characterized by an increasing frequency of fenestral laminated packstone (tidal-flat deposits) leading to the karsted sequence development. In contrast, the TST is typified by diminishing tidal-flat deposits leading away from the sequence boundary (WD3.1 and WD3.2). A 'hourglass' gamma-ray log signature defines the WD1.2 and WD1.3 HFS in the more basinally located wells. 7-33 and 7-36



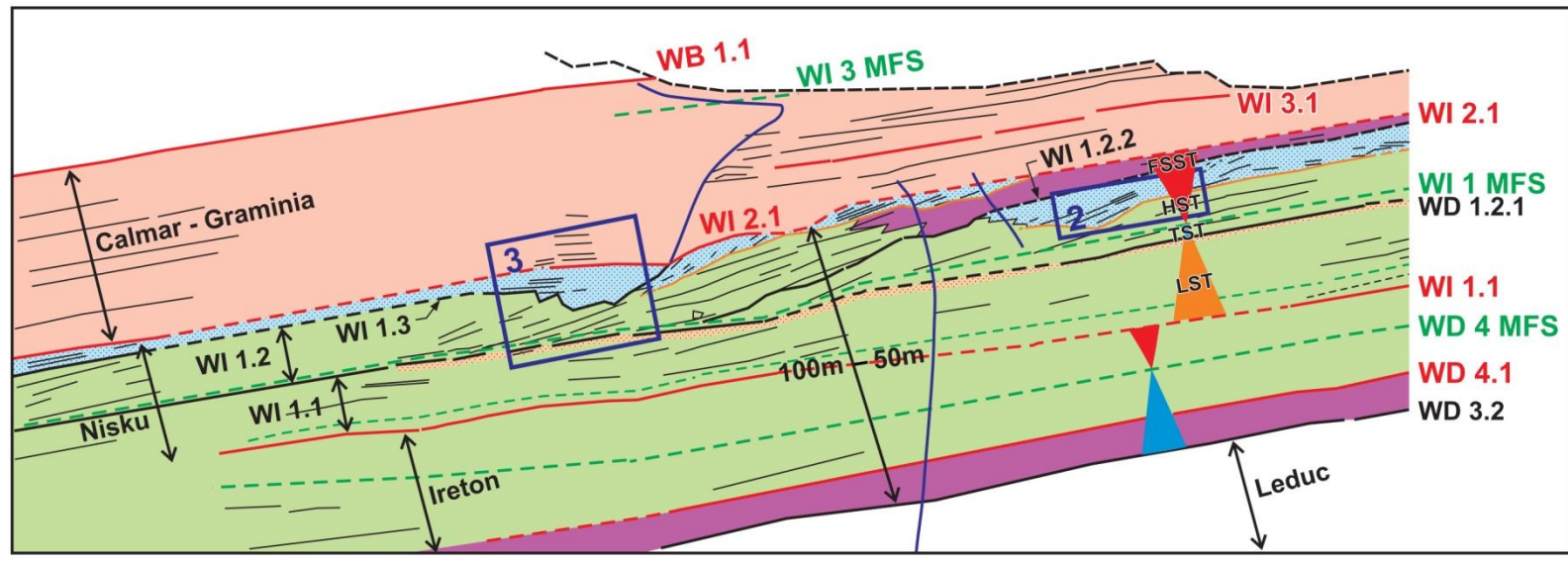
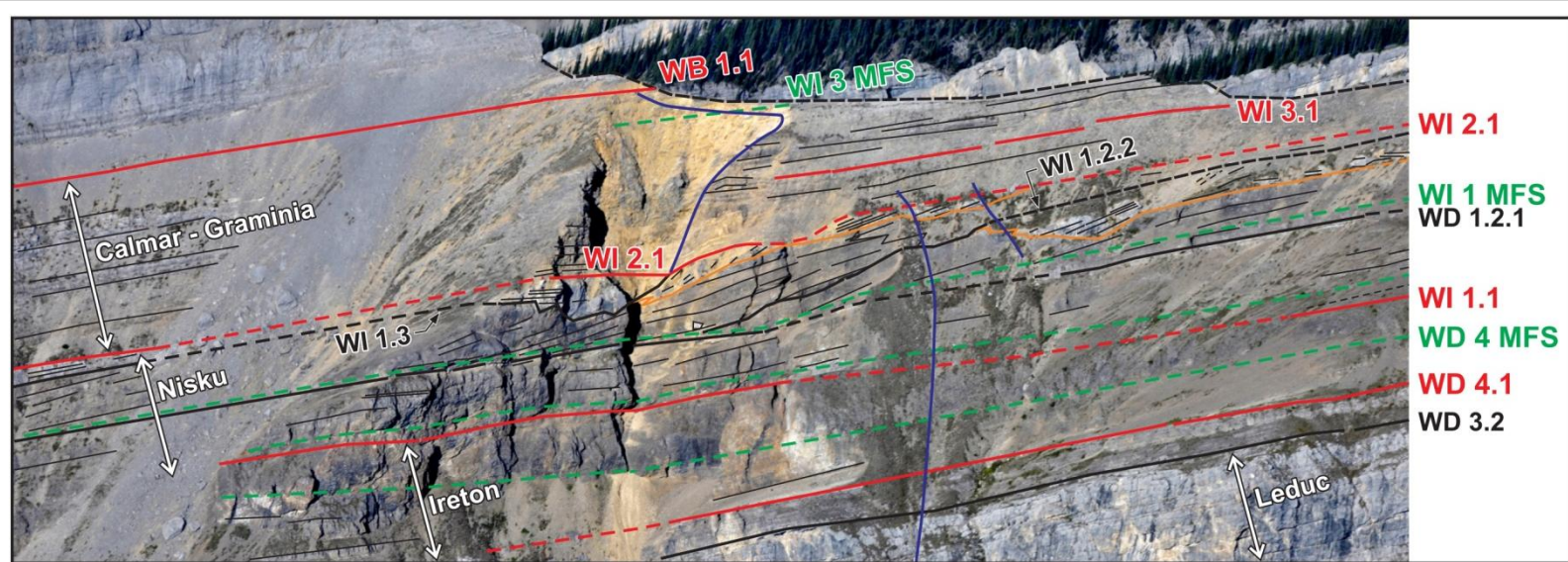
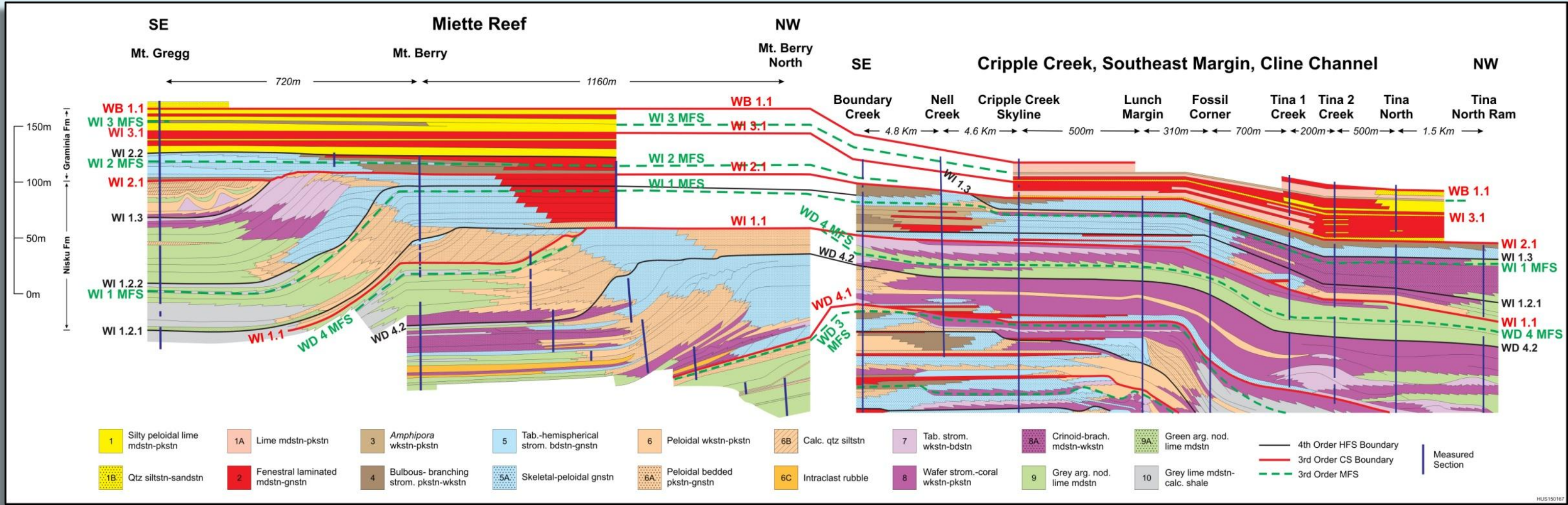
Stromatoporoid rubble and grainstone foresets of the WD1.2.1 downlap onto the regressive surface of marine erosion (RSME), developed over lower foreslope strata. The sharp RSME separates grey argillaceous, cherty and nodular-bedded lime mudstone from the overlying skeletal grainstone. This surface continues toward the skyline on the upper right. Wapiabi Gap



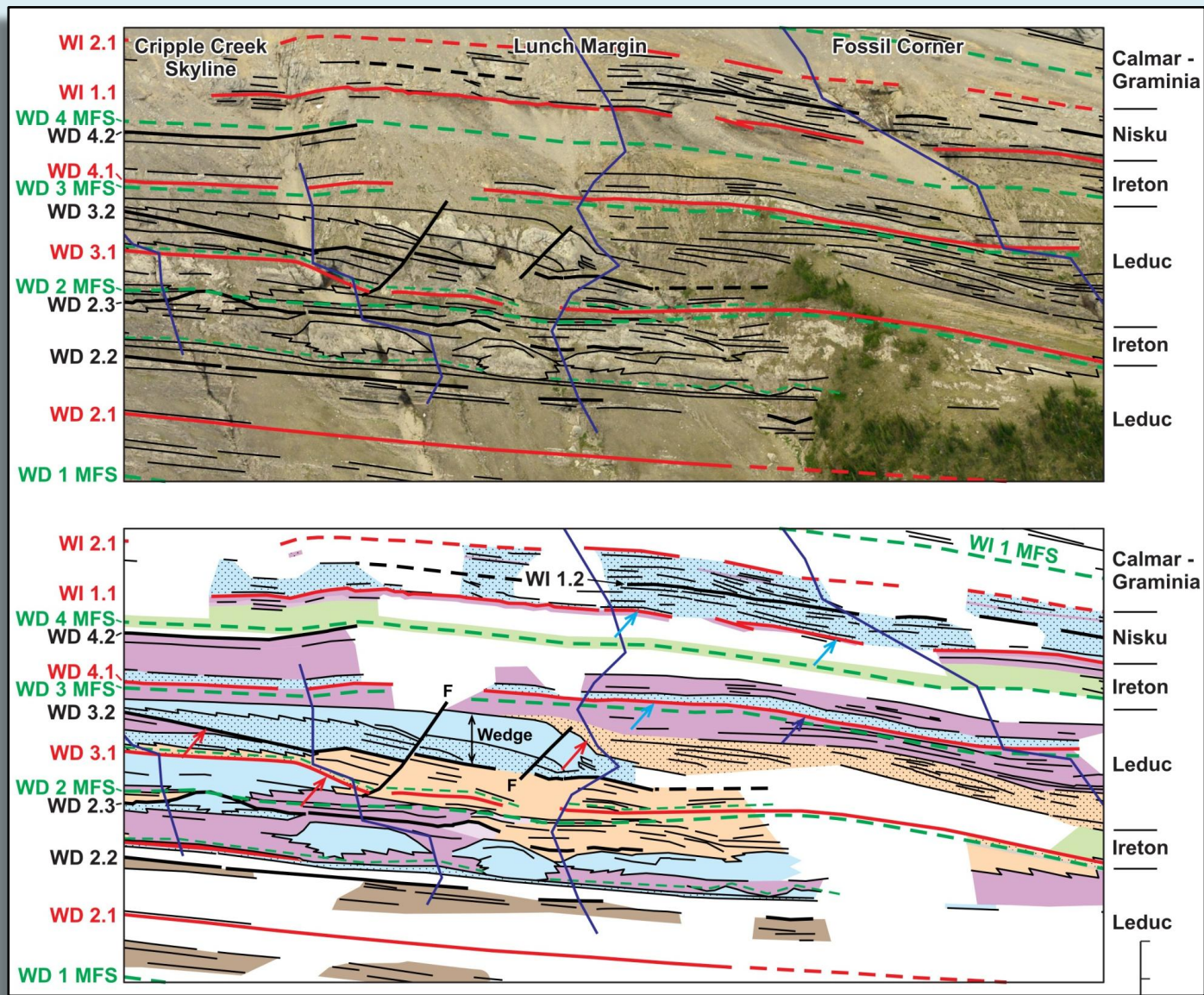
Wapiabi Gap Skyline photograph showing a channel along the WI1.3 sequence boundary downcutting into lower foreslope deposits (a) of the WI1.2 HFS. Channel erosion extends approximately halfway down to the level of the WI1.2.1 sequence boundary. Note truncation of foresets. It is infilled by prograding stromatoporoid rubble and grainstone (b). Depth of channel is approximately 15 m. Strata (c) overlying the WD2.1 surface are composed of metre-scale cyclic platform-interior lime mudstone to cryptalgal laminite. Locally disrupted beds (d) are likely from collapse associated with gypsum dissolution



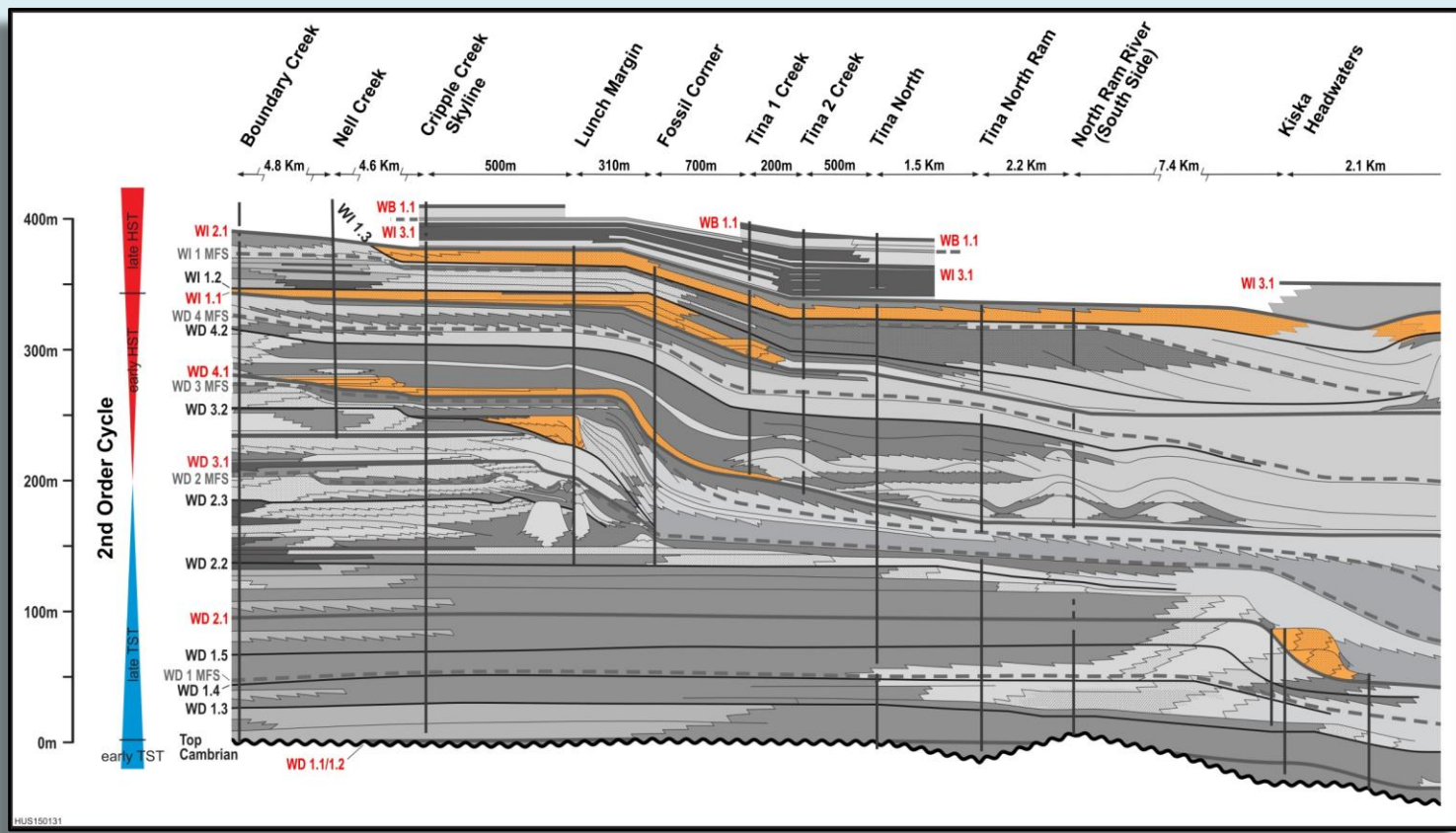
Transverse (upper photograph) and axial (lower) views of second channel at the WI1.3 sequence boundary. Down-cutting extends approximately to the level of the WI1.2.1 surface. It is filled by prograding stromatoporoid rubble and grainstone of upper foreslope and reef-flat origin. This feature is approximately 25 m deep and located 270 m northwest of the previous example.



Lithofacies and sequence stratigraphy of the WI1 to WI3 CS at the Wapiabi Gap skyline. Platform-interior facies are colored according to the dominant facies type. The regressive surface of marine erosion (RSME) is interpreted to be the result of wave erosion during falling relative sea level



Detailed view, southeast margin of the Cline Channel at Cripple Creek, showing the composite and high frequency sequence stratigraphy. The role of clay basin-fill is shown by the evolution of foreslope gradients from the WD3.1 to the WI1.1 HFS. Foreslope dips decrease from 10-20° (red arrows) to less than 5° (light blue arrows) with influx of extrabasinal clay and the accompanying change to more ramp-like profiles. The abrupt increased gradient on the WD4.1 surface (dark blue arrow) coincides with the distally steepened segment of the underlying WD3 foreslope.



Lowstand development in the Cripple Creek area (Boundary Creek to Kiska Headwaters), showing geometry (wedge or tabular) and frequency in relation to the second-order Givetian-Frasnian supersequence.

References

The figures in this poster are sourced from the following papers:

Weissenberger, J.A.W. Wong, P.K. and Gilhooly, M.G. (in press). Stratigraphic architecture of the Frasnian Jasper Basin, north-central Alberta Front Ranges. In: Playton, T.E., Kerans, C., Weissenberger, J., and Montgomery, P., (eds.), New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy: SEPM Special Publication, xx, p. xx.

Wong, P.K. Weissenberger, J.A.W. and Gilhooly, M.G., (in press). Sequence Stratigraphic Architecture of the Frasnian Cline Channel, Central Alberta Front Ranges. In: Playton, T.E., Kerans, C., Weissenberger, J., and Montgomery, P., (eds.), New Advances in Devonian Carbonates: Outcrop Analogs, Reservoirs, and Chronostratigraphy: SEPM Special Publication, xx, p. xx.

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