Late Devonian Depositional Evolution of Western Montana and East-Central Idaho – Jefferson, Three Forks, and Sappington Formations*

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Abstract

Late Devonian rocks of western Montana and east-central Idaho record mixed carbonate and siliciclastic deposition (<100 to >1000 m thick) on a dissected ramp that formed in the tectonically active Antler foreland basin. 3rd-order sequence stratigraphy integrated with available biostratigraphy correlates these strata from Idaho over the Lemhi Arch into western Montana. Downramp in Idaho and in the Central Montana Trough (CMT), the Frasnian Jefferson Formation records consistent facies stacking patterns and stratigraphic geometries, including well developed incised channels. 3rd-order high (Idaho) to low (Montana) accommodation sequences are comprised of mixed siliciclastic and carbonate rocks with tidal flats passing into mottled lagoonal to open marine rocks with coral-stromatoporoid biostromes and reefs. Up-ramp tidal flats predominate and thin into stacked TST/HSTs. Subsequently, intrashelf basins in Idaho and Montana filled with evaporite, microbial dolostone, and red-green afossiliferous shale that accumulated in repeatedly flooded sabkhas of the Early Famennian (Jefferson Grandview and Three Forks Logan Gulch members).

At least one correlative off-shelf quartz arenite lowstand wedge occurs in Idaho. Small coral-stromatoporoid reefs also developed along the margins of the CMT where accommodation space and open circulation allowed. A series of stromatoporoid reefs occurs behind the Lemhi Arch in the western CMT and Ruby- Snowcrest trough of SW Montana, but they are partially

eroded by latest Devonian uplift. Moldic and dolomitic porosity and brecciation often is well-developed in the top of subtidal/ biostromal intervals beneath sequence boundaries recording subaerial exposure. The latest Devonian (Middle and Late Famennian) is marked by paleogeographic reorganization of the shelf with continued differential tectonic loading and deposition of the marine Three Forks Trident Member. It is comprised of 3 shale-limestone sequences in Idaho (up to 90 m thick) followed by Sappington Formation deposition below McGowan Creek Formation turbidites in Idaho and distal ramp Mississipian Lodgepole facies in Montana. The Trident is open marine within the CMT, but it is eroded or was not deposited on the northern and southern margins of the CMT. Likewise this unit was truncated in western Idaho by Antler uplift. Very distal, thin Sappington shale and siltstone were deposited below turbidites in the Lost River Range.

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Late Devonian evolution of western Montana and east-central Idaho – Jefferson, Three Forks, and Sappington formations

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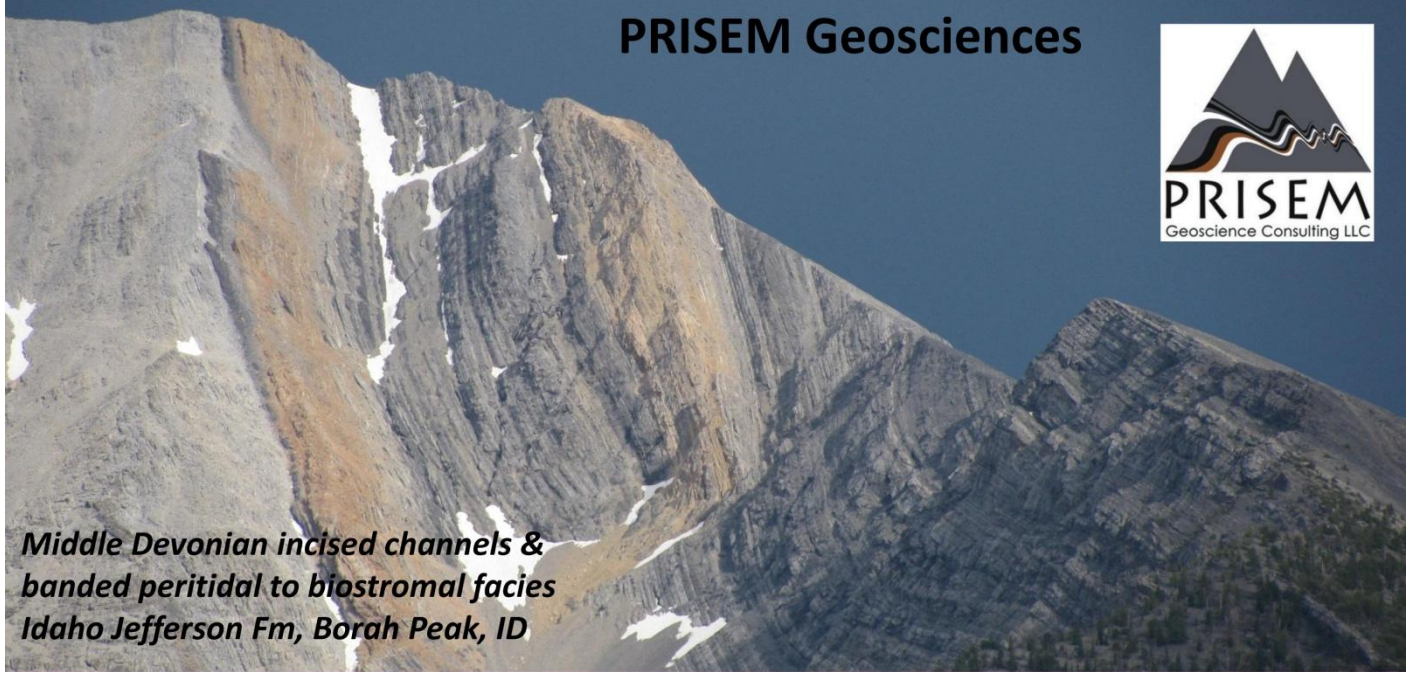
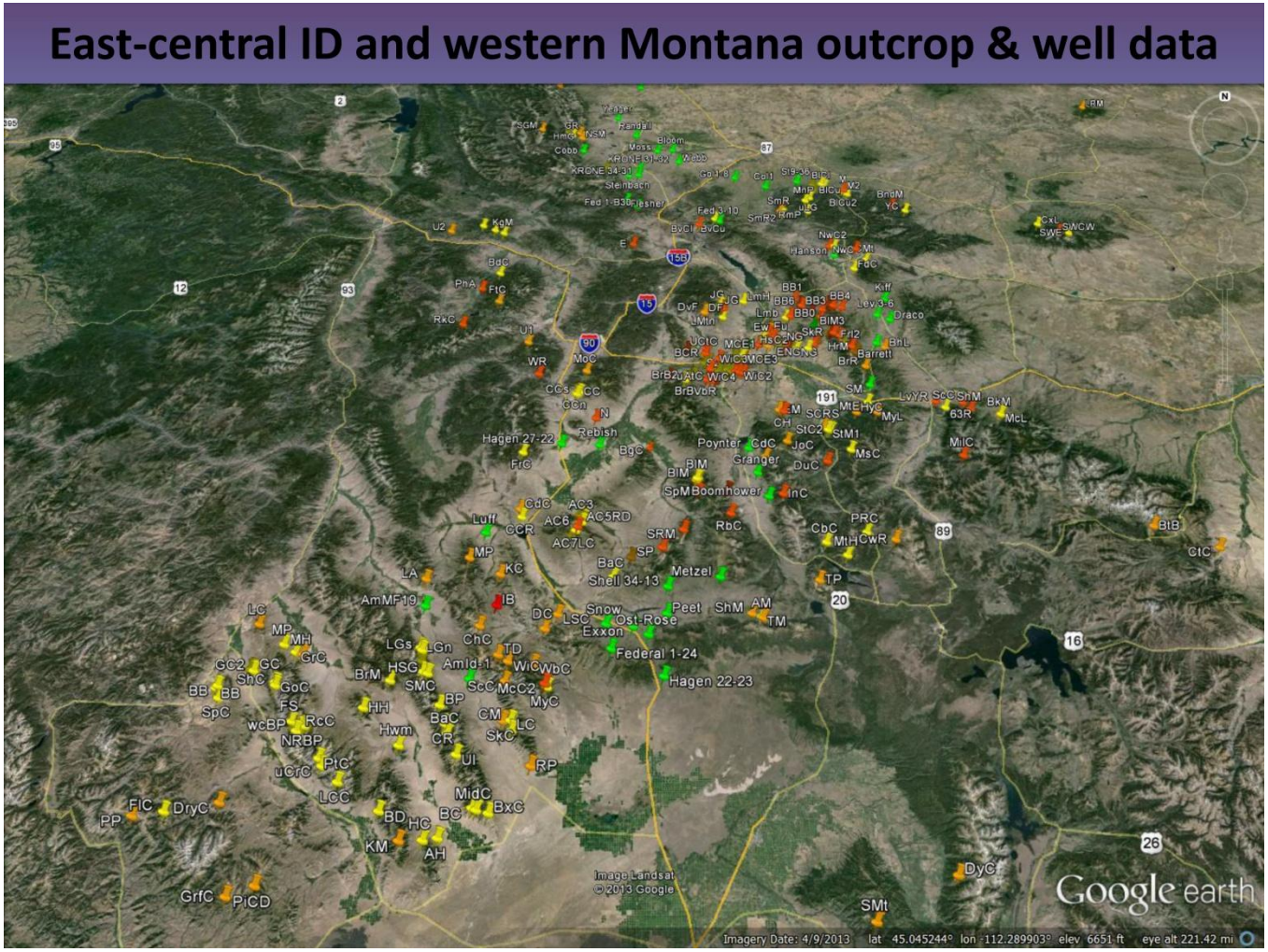


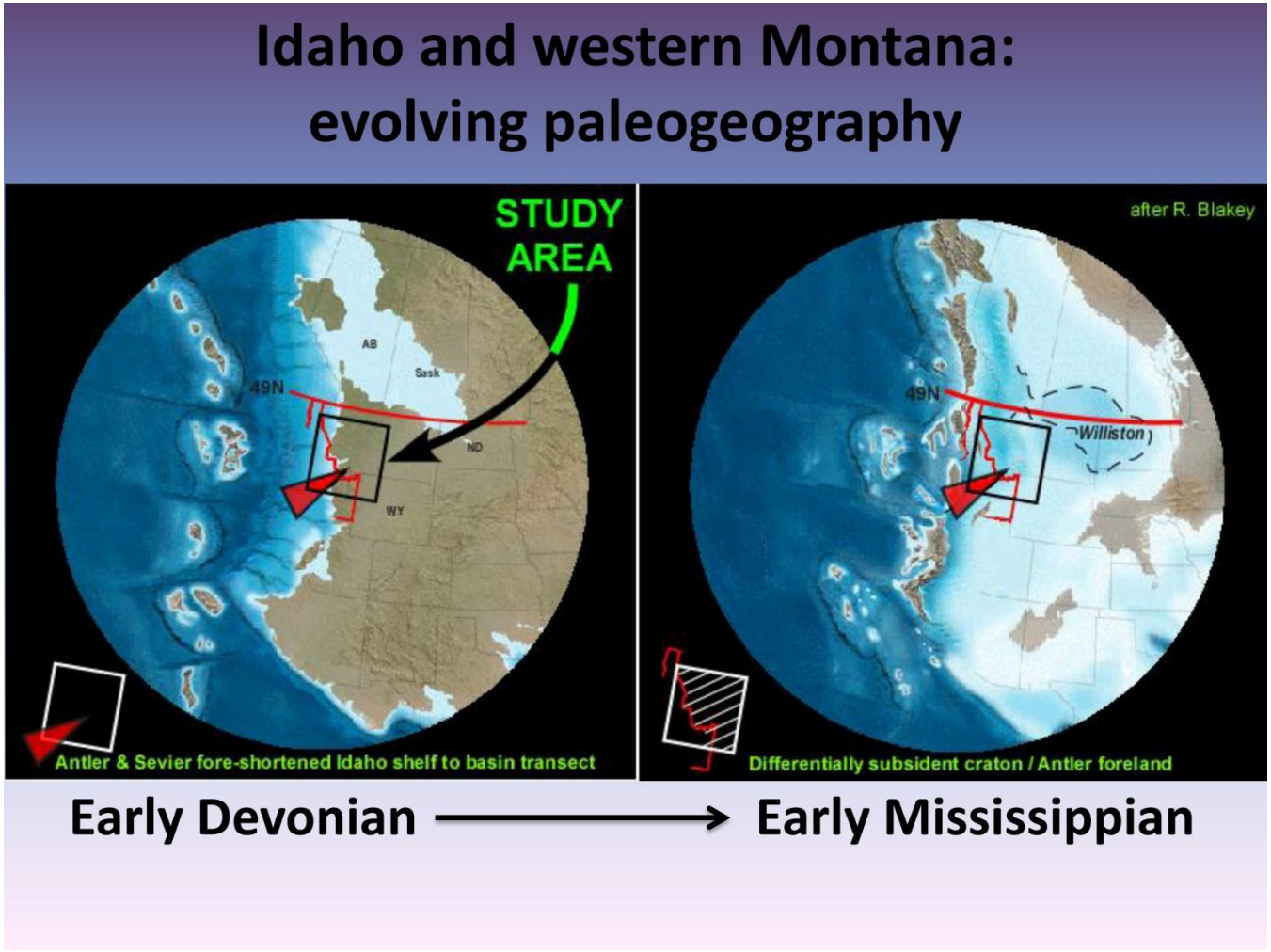
Middle Devonian incised channels & banded peritidal to biostromal facies Idaho Jefferson Fm, Borah Peak, ID

Presenter's notes: This talk is an introduction to the shelfal carbonates in Idaho, comparing and contrasting them with rocks on the more stable Montana craton.

East-central ID and western Montana outcrop & well data

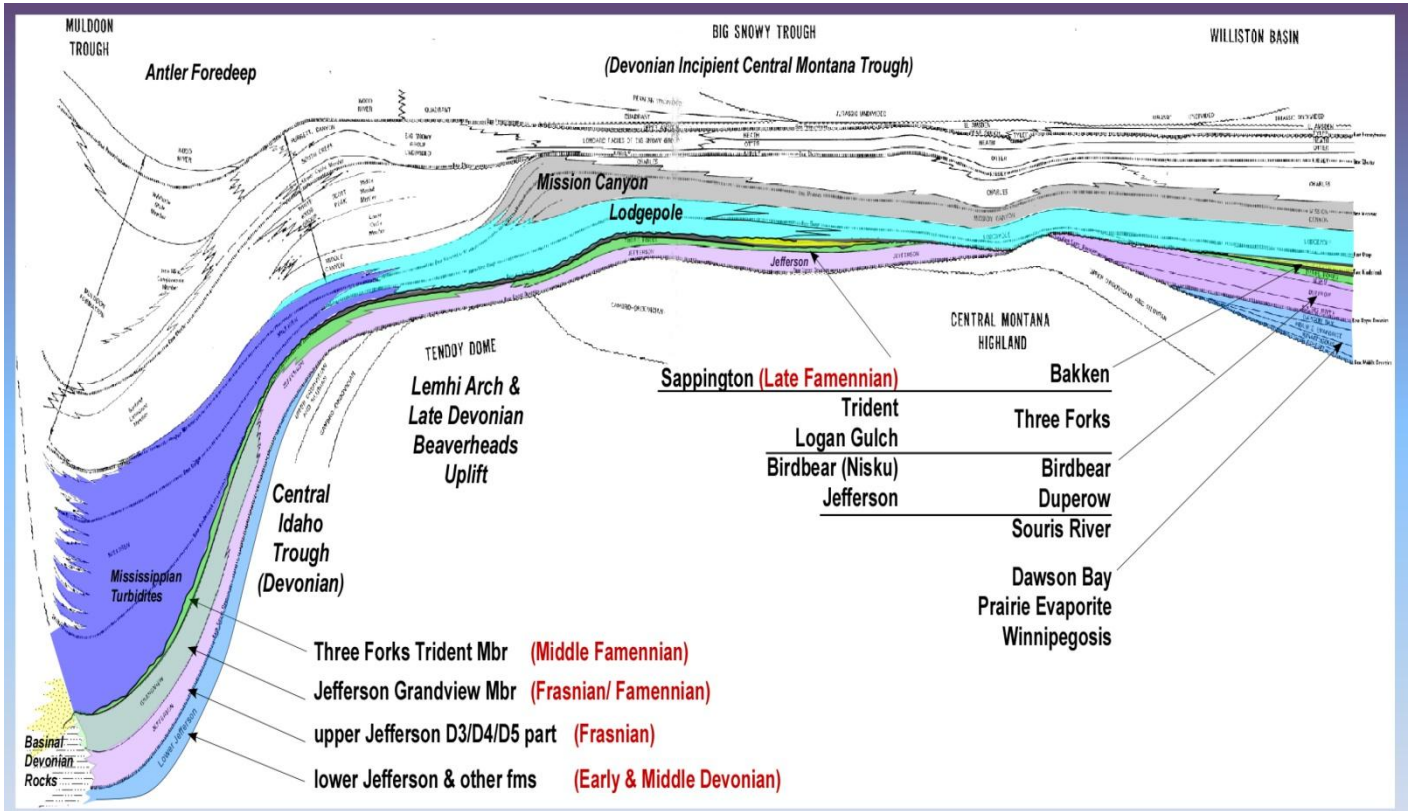


Presenter's notes: Regional Study Area – East Central Idaho, SW MT & western MT.
Out growth out of Graders 1998 MS in the Lemhi Range / Pope-Doughty/PRISEM D-M studies & field trips (2008-2014).
Outcrop locations = yellow & orange; Well data = Green



Presenter's notes:

1) Idaho geology and Montana geology – post-early Pz passive margin to active Antler sedimentation.
2) Numerous parallels with western Canada Basin and Williston Basin.



Williston Basin to Idaho Paleozoic cross-section

(by Pete Rose; colored to show Devonian-Lower Mississippian)

Presenter's notes: On this cross section you can see the basic geometry of the Devonian formation below the Mississippian.

(Presenter's notes continued on next page)

(Presenter's notes continued from previous page)

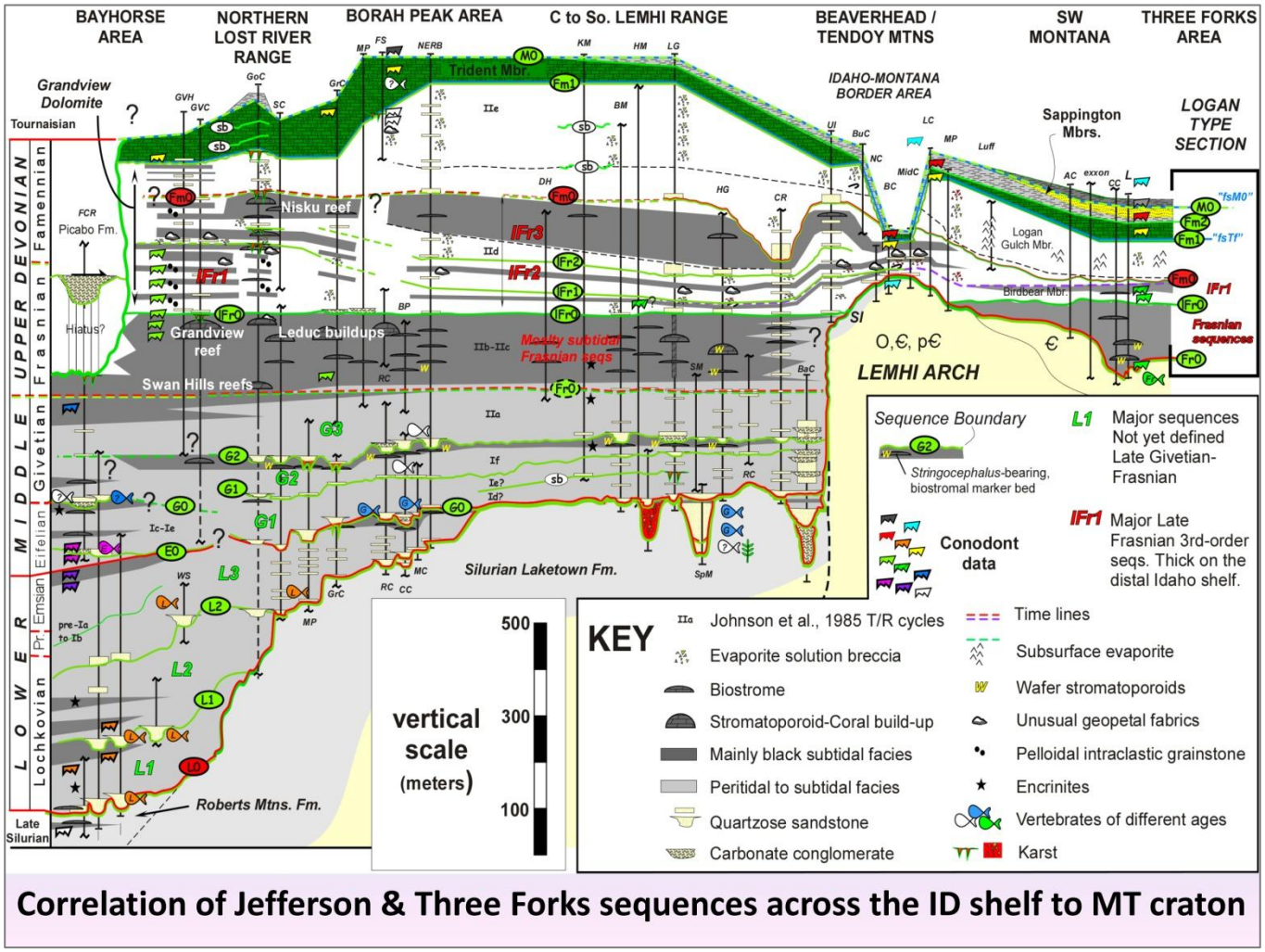
Major subbasins and highs.

Very quickly trying to cover all these units (by time or by location?!). Difficult.

Note: Aaron Rodriguez will talk about the Sappington in the developing CMT: you can see here how shallow water.
Yellow clastics are lost to the west (just lower and upper black shales & disconformity to the west, NO Sappington between the 3F Trident & overlying Mississippian turbidites in ID.)

Jefferson and Birdbear/Nisku lumped in PINK. Obviously much more accommodation in ID during Late Frasnian Nisku and Three Forks time.

(Grandview Member = partly equivalent 3 Nisku cycles there & following intrashelf evapoiritc basin below the regionally flooding marine Trident system (Green).



Correlation of Jefferson & Three Forks sequences across the ID shelf to MT craton

Presenter's notes: Back to the subsidence Idaho Shelf (the much thinner Logan Type Section is referenced on the far right). 1) Western L to M Devonian sequences with abuntant fish-bearing incised channels. Facies repetition; significantly different ages. Eg. L1-G3. Limited assimilated conodont data (1960-1995). *(Presenter's notes continued on next page)*

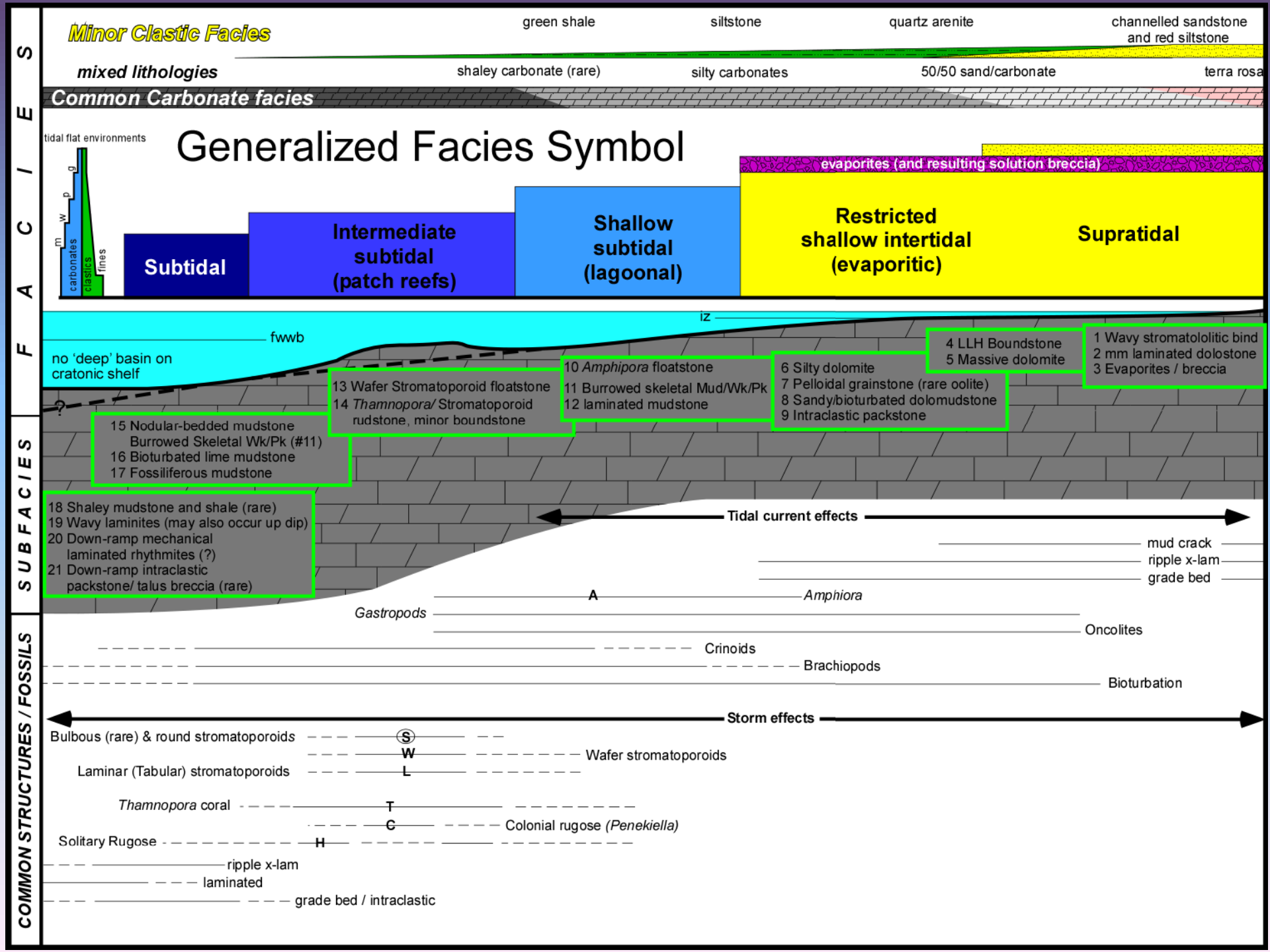
(Presenter's notes continued on next page)

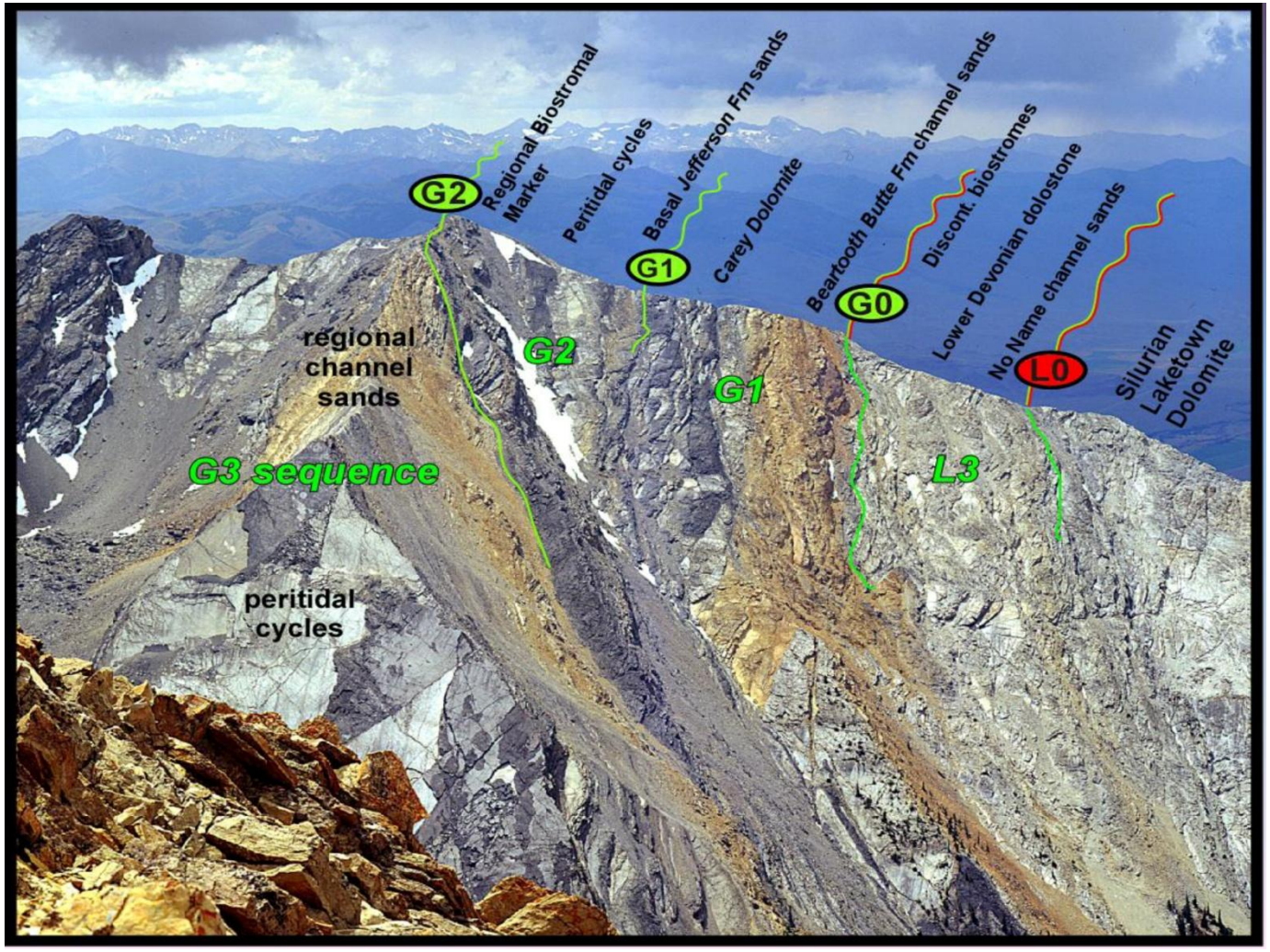
2) Incised paleovalleys in Lemhi – 100 - 300 METERS deep (wow). Facies dominated by mixed siliciclastic peritidal (LT) to (DK) marine subtidal Dolostone . LMST only in latest Frasnian & Famennian.

3) Frasnian sequences NOT DEFINED in Idaho: Note approx occurrence of Swan Hills, Leduc, Nisku buildups. Grader thinks 3 NISKU cycles occur here as in Canada.

4) Note late Frasnian seqs lFr1, 2 & 3 below widely picked F-F boundary SE Fm0. One of lFr1 is equivalent to a single sequence at Logan (Birdbear) – contains Rhenana semicatovai conodont (need to check).

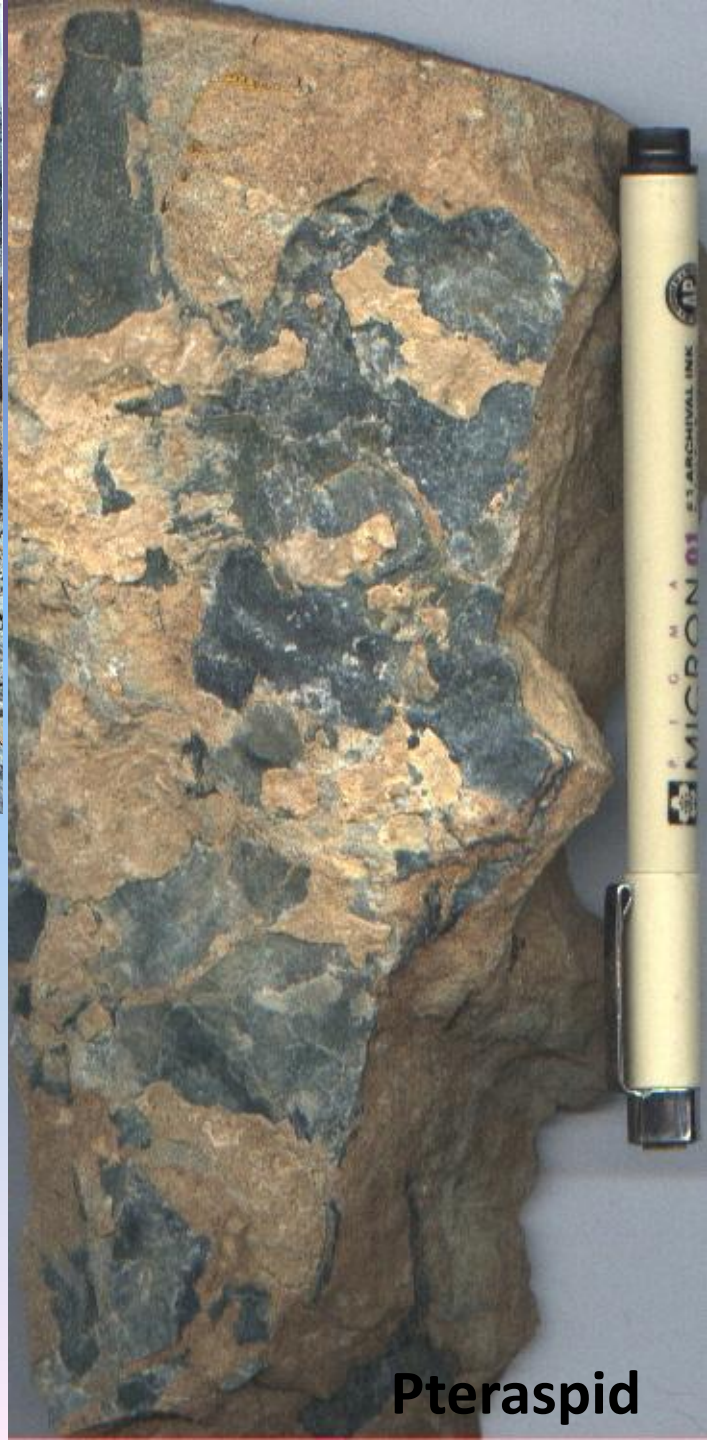
5) Above Fm0 = restricted faceis, stromatolites, evaporites in subsurface, solution breccias (Logan Gulch Mbt 3 Forks. Also marine Trident Mbr, and Sappington Fm (apparently eroded form Idaho).

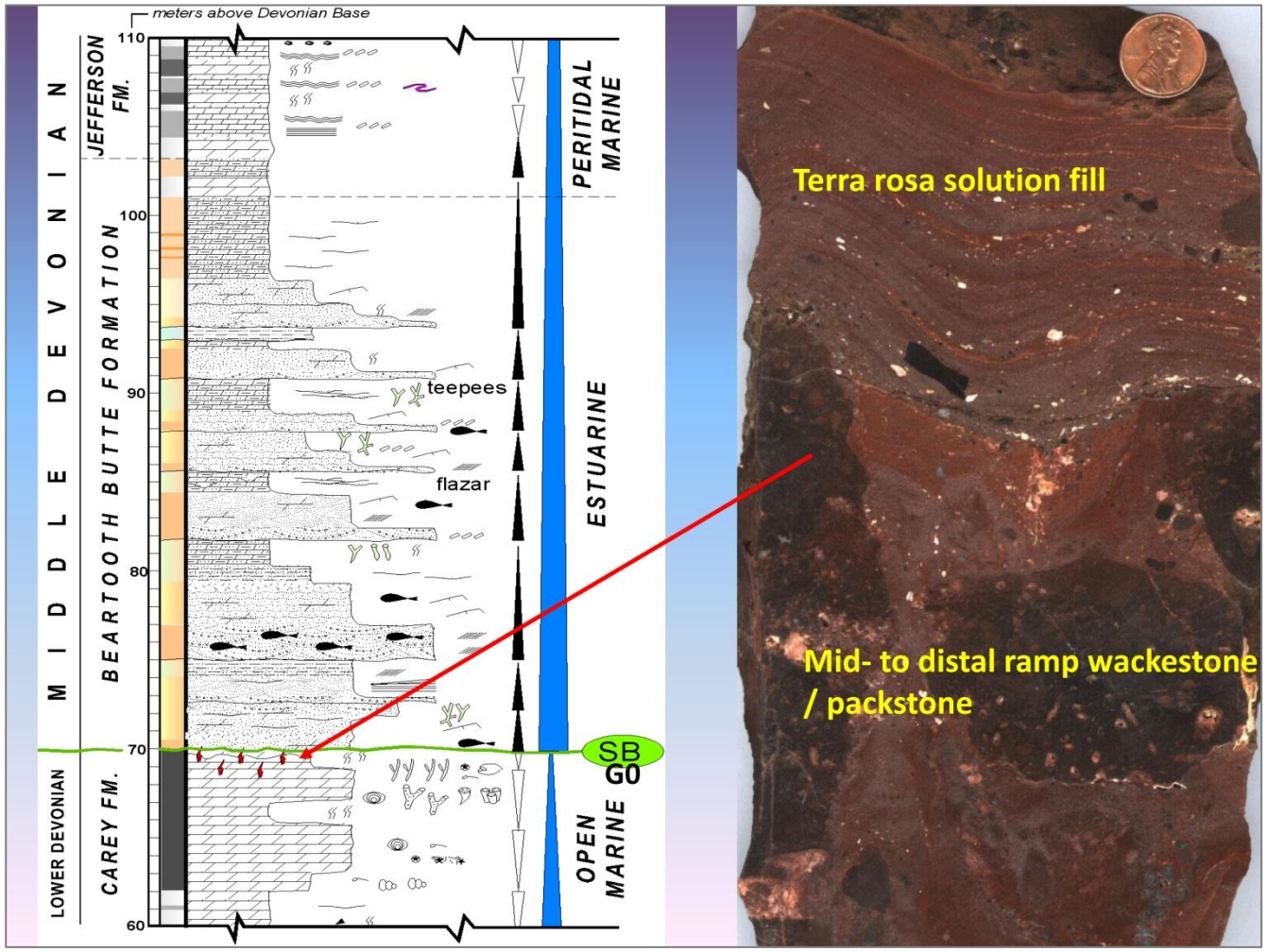

FACIES
SUBFACIES
COMMON STRUCTURES / FOSSILS
Minor Clastic Facies
green shale
siltstone
quartz arenite
channelled sandstone and red siltstone
mixed lithologies
shaley carbonate (rare)
silty carbonates
50/50 sand/carbonate
terra rosa
Common Carbonate facies
tidal flat environments
m
w
p
g
carbonates
clastics
fines
Generalized Facies Symbol
Subtidal
Intermediate subtidal (patch reefs)
Shallow subtidal (lagoonal)
evaporites (and resulting solution breccia)
Restricted shallow intertidal (evaporitic)
Supratidal
iz
fwwb
no 'deep' basin on cratonic shelf
?
1 Wavy stromatololitic bind
2 mm laminated dolostone
3 Evaporites / breccia
4 LLH Boundstone
5 Massive dolomite
6 Silty dolomite
7 Pelloidal grainstone (rare oolite)
8 Sandy/bioturbated dolomudstone
9 Intraclastic packstone
10 Amphipora floatstone
11 Burrowed skeletal Mud/Wk/Pk
12 laminated mudstone
13 Wafer Stromatoporoid floatstone
14 Thamnopora/ Stromatoporoid rudstone, minor boundstone
15 Nodular-bedded mudstone Burrowed Skeletal Wk/Pk (#11)
16 Bioturbated lime mudstone
17 Fossiliferous mudstone
18 Shaley mudstone and shale (rare)
19 Wavy laminites (may also occur up dip)
20 Down-ramp mechanical laminated rhythmites (?)
21 Down-ramp intraclastic packstone/ talus breccia (rare)
Tidal current effects
mud crack
ripple x-lam
grade bed
A
Amphiora
Gastropods
Oncolites
Crinoids
Brachiopods
Bioturbation
Storm effects
Bulbous (rare) & round stromatoporoids
S
W
Wafer stromatoporoids
Laminar (Tabular) stromatoporoids
L
Thamnopora coral
T
C
Colonial rugose (Penekiella)
Solitary Rugose
H
ripple x-lam
laminated
grade bed / intraclastic



Presenter's notes: 4 stacked Lower to Middle Devonian Channel & platform/ramp in the Lost River Range (generally extra rock thickness & sequences as on goes west).

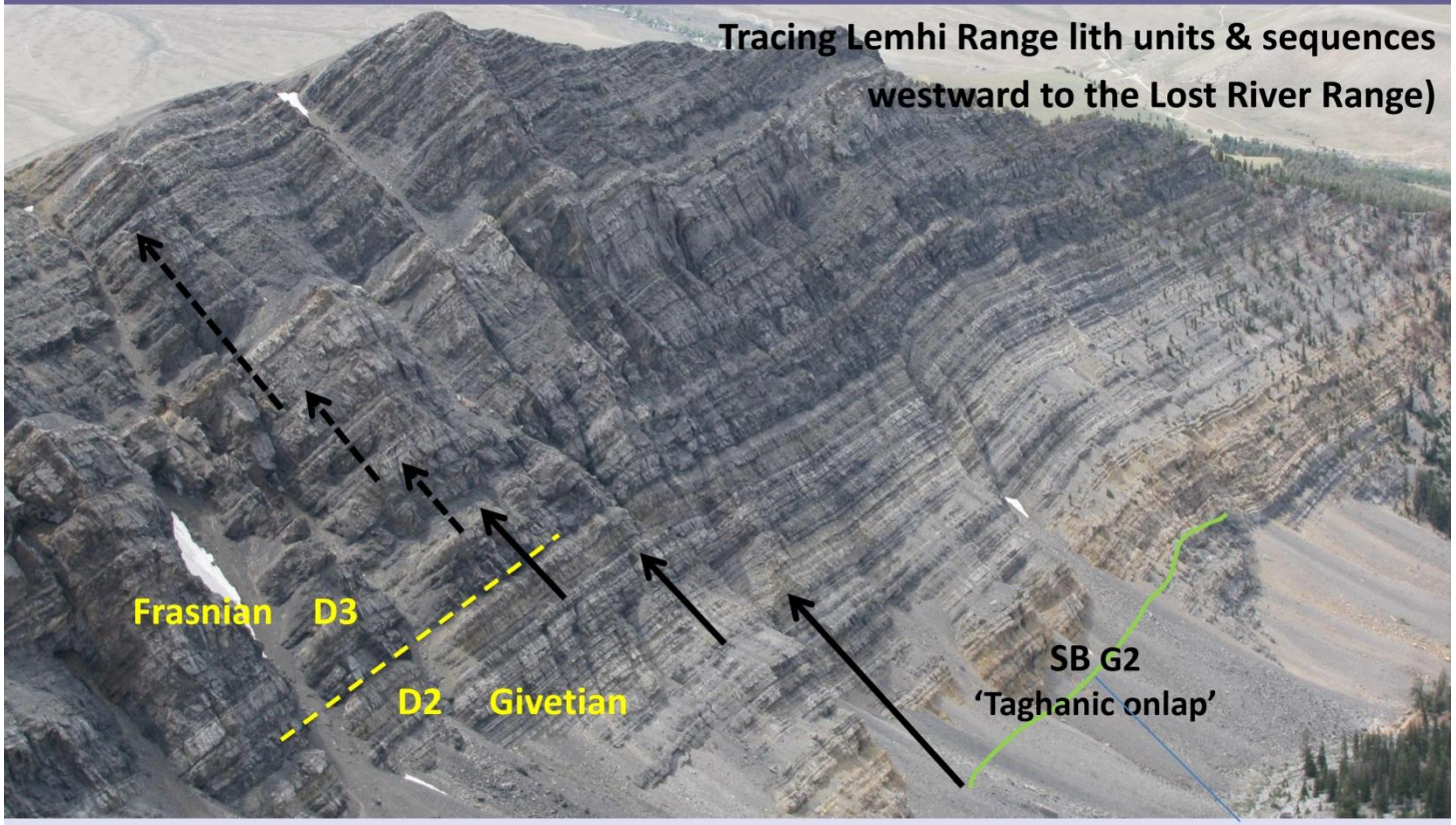
Subtidal, biostromal dolostone incised by fluvial to estuarine fish-bearing intertidal rocks
(SB G0 Borah No-name Cirque)





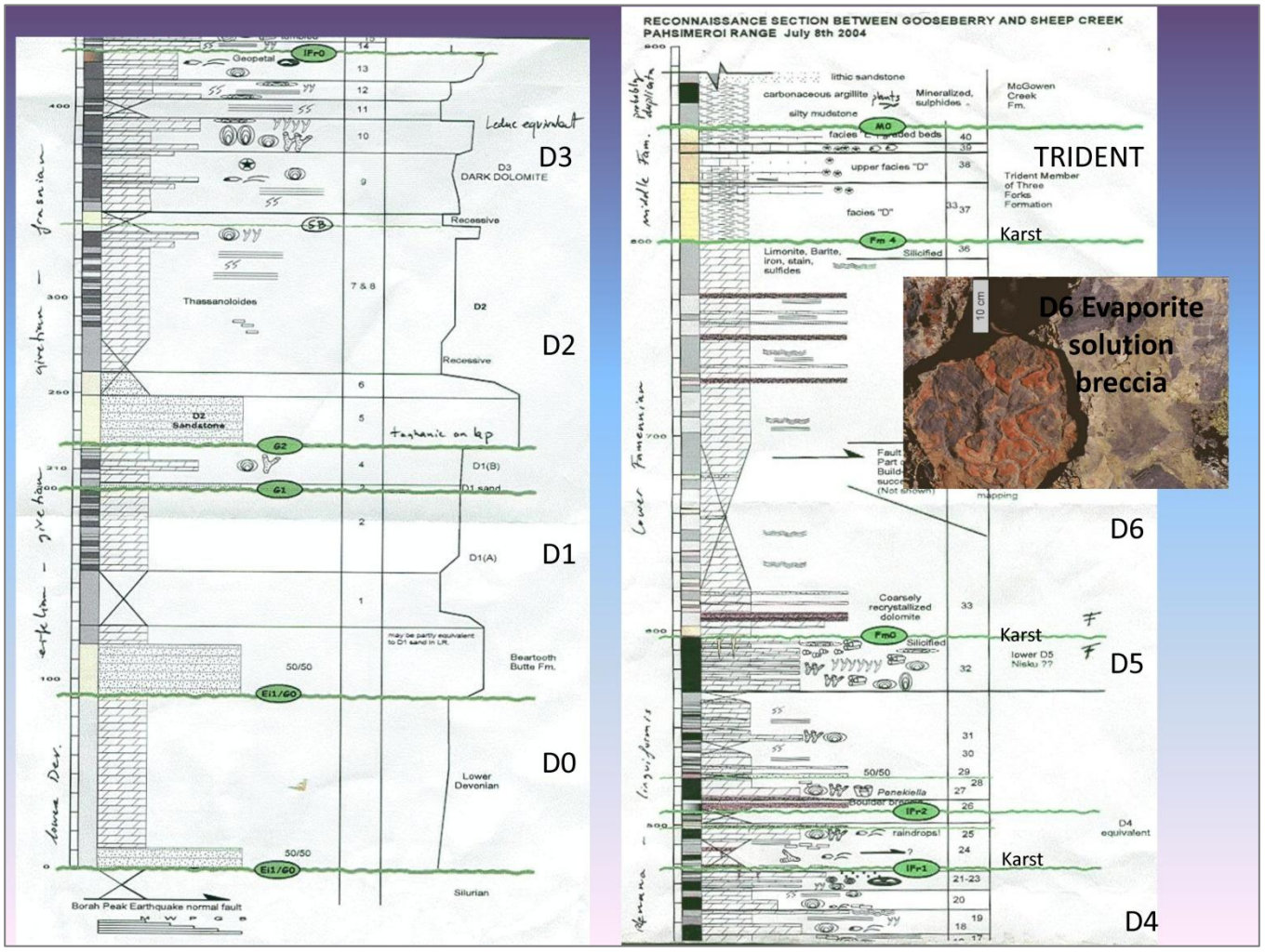
Presenter's notes: Pattern of karsted and/ or erosionally-cut subtidal marine rocks is common theme.
Devonian time. Transitional facies seen on these SBs –
But SBs more complex in latest Devonain (often marine over marine).

D2-D3 Givetian-Frasnian transition above SB G2

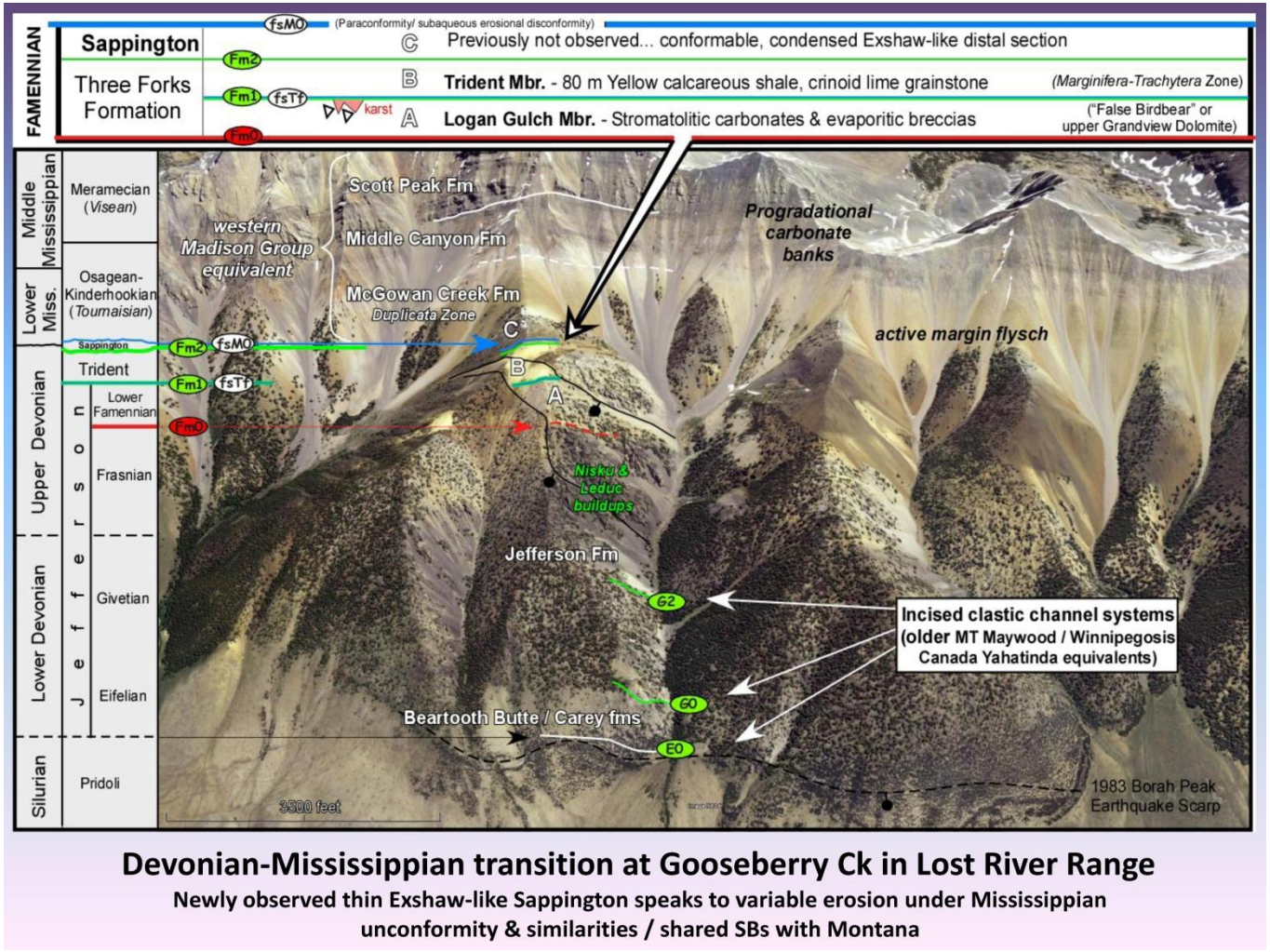


- Basinward shift above SB G2: D2 amalgamated clastic channels w/ rooted beds, mudcracks
- D2 & underlying black D1 biostromal unit traced regionally
- D2 = 'stripy' peritidal cycles deepen-upward to D3/ Dark Dolomite" (Frasnian).
- No Shales. Few Studies. Reefs in the top of D3.

Presenter's notes: D2-D3 transiton and SB G2 in Lost River Range.



Presenter's notes: 170 m of strata that correlate to the 3 late Frasnian Nisku Cycles (between lFr0 and Fm0).
Highly fossiliferous ending in a major coral stromatoporoid bioherm with abundant Amiphora
and large thrombolitic and lamellar stromatoporoids at the top, below Fm0. And the end of life! Only stromatolites (D6).



Devonian-Mississippian transition at Gooseberry Ck in Lost River Range

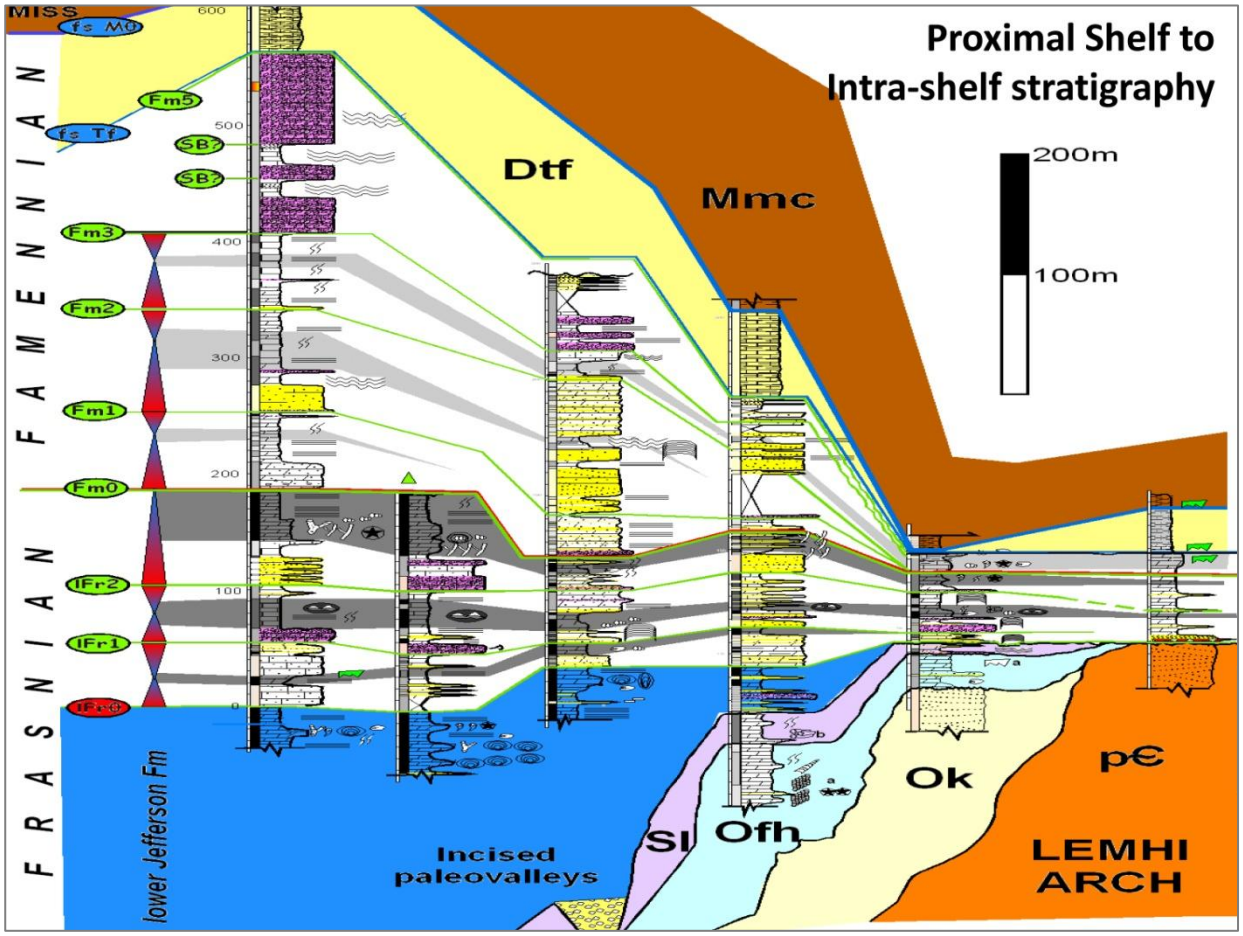
Newly observed thin Exshaw-like Sappington speaks to variable erosion under Mississippian unconformity & similarities / shared SBs with Montana

Presenter's notes: Devonian-Mississippian transition at Gooseberry Creek in east-central Idaho (Lost River Range) showing missing Sappington Member of the Three Forks Formation (Bakken/Exshaw equivalent) and range front extensional structures

(Presenter's notes continued on next page)

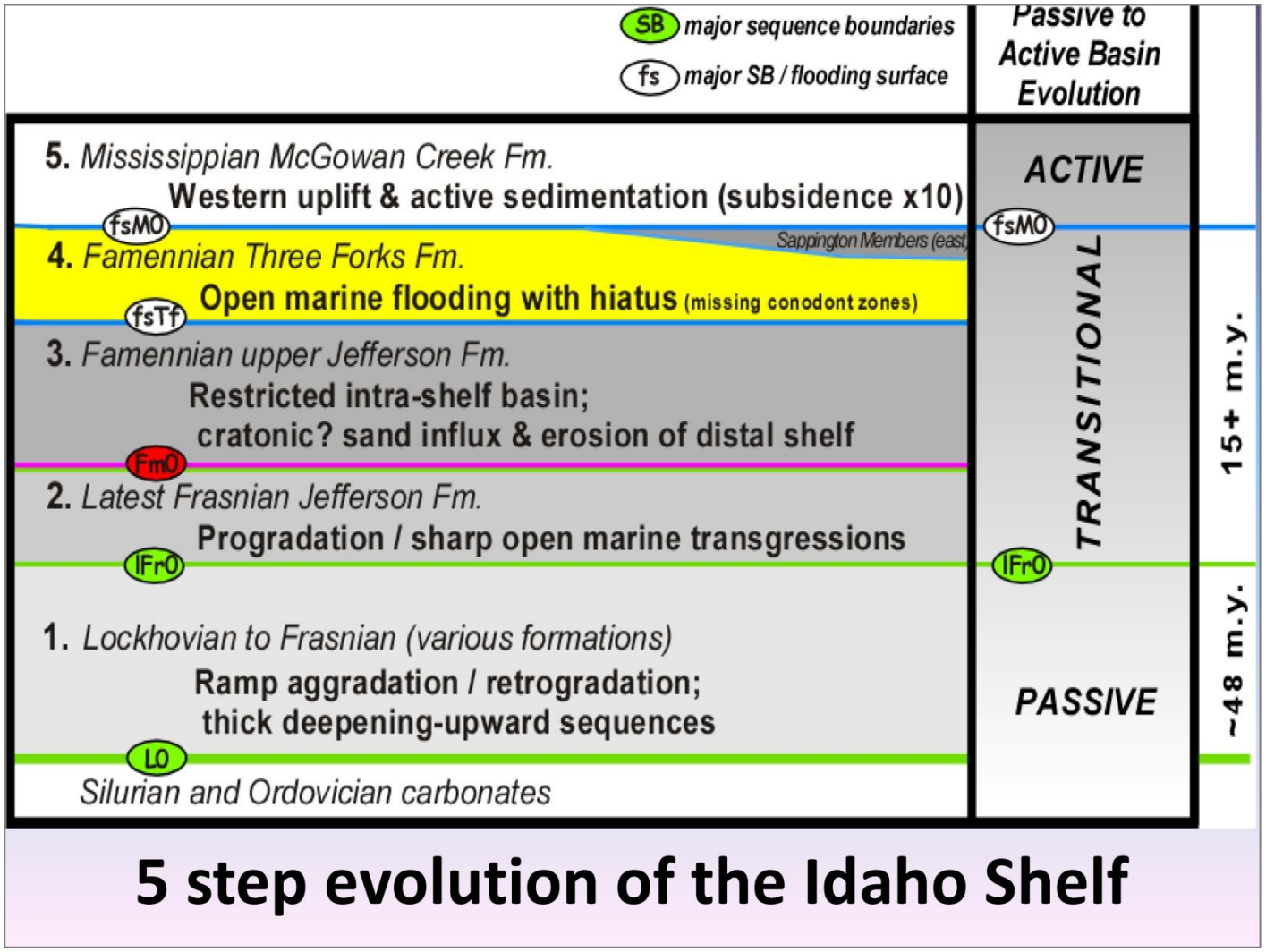
(Presenter's notes continued from previous page)

developed in shales, siltstones, sandstones, marls, and limestones. A hiatus in the conodont succession occurs at the D-M boundary. No latest Devonian Lower Bakken-equivalent black shales (Expansa Zone) or Middle Bakken shoreface LST sandstones, or transgressive Upper Bakken black shale (Praesulcata--Sandbergi Zone; c.f. Smith and Bustin, 2000) have been identified .THIS CHANGED LAST SUMMER WHEN I FOUND A THIN SHL/SILT/SHL PACKAGE WITH CORRECT ICHNOFACIES. SO PERHAPS SAPPINGTON DOES OCCUR LOCALLY, BUT CUT OUT UNDER COMPLEX BASAL MISS FLOODING SURFACE (FsM0). However locally thick, black shales and plant-bearing clastics occur in the McGowan Creek Formation turbidites overlying the Trident Fm. A genetically interrelated system is thought to connect these Antler foreland basin sediments (extension of the Canadian Prophet trough) to strata and disconformities on the foundering stable continental shelf of Montana (i.e. intrashelf subbasins). Different regions along the Antler supracontinental borderlands/seaways recorded different accumulation histories: e.g. the Lemhi Arch vs. Central Montana Trough vs. Central Idaho Trough.

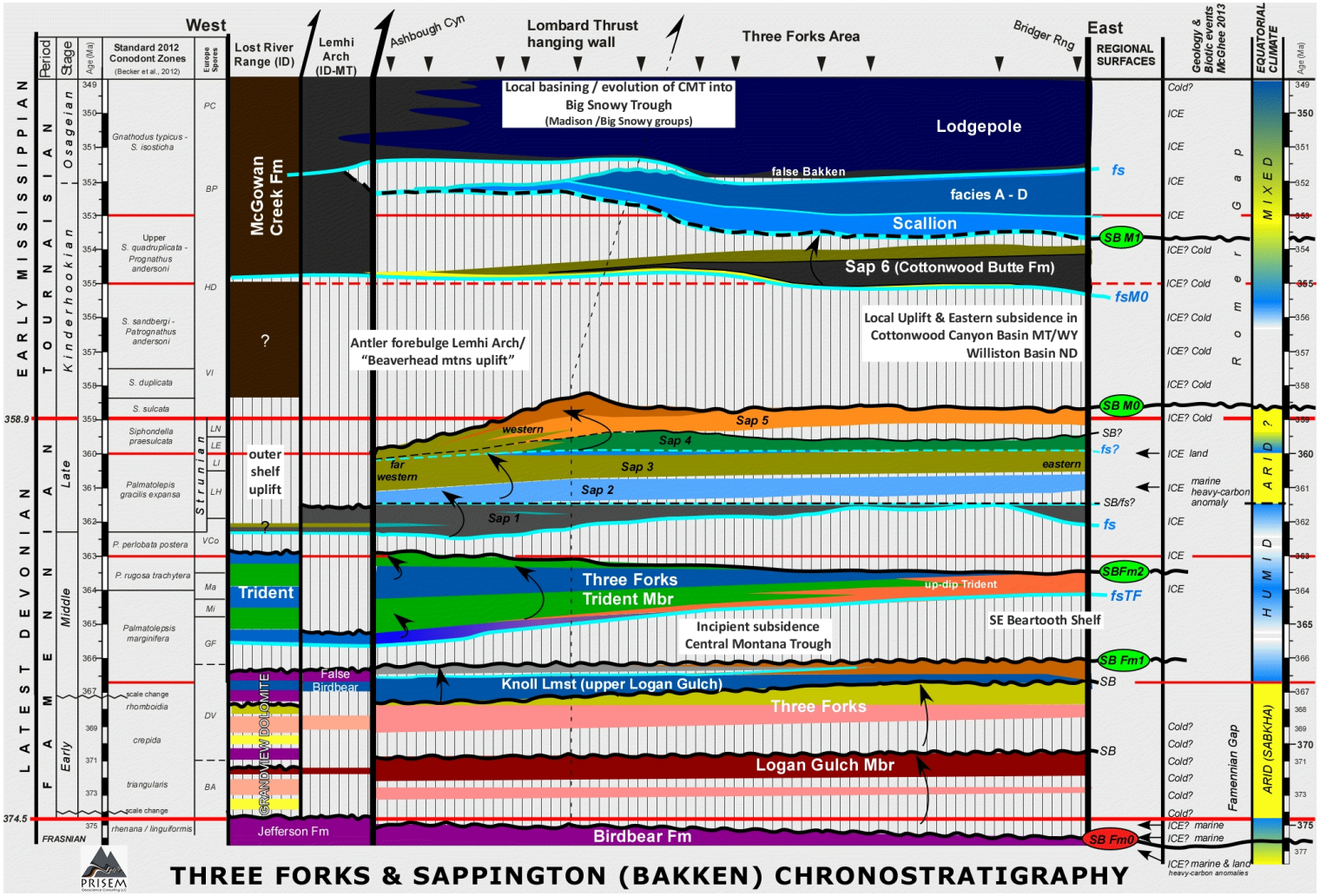


Presenter's notes: And part of a correlation back across the Idaho shelf to over the Lemhi Arch to Long Canyon in the Beaverhead Mountains, suggesting that some of the biggest and most cyclic sea level changes occurred at the end of the Late Frasnian.

One can also see thickening into a Lower Famennian restricted evaporite basin associated also with intrashelfal lowstand quartzose clastics.



Presenter's notes: Latest Frasnian and Early Famennian Jefferson Fm is a big player in geohistroy of the Shelf.
In reality, very little recent work has been done to outline this history.



Presenter's notes: The same latest Devonian units (above the Jefferson & Birdbear) on the more stable Craton are shown here (with reference back to Lemhi Arch, and the Idaho Shelfal depocenter - Lost River Range).

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(Presenter's notes continued from previous page)

These main SBs carry to Idaho (actually we saw them in the basin and carried them over the ID-MT border/Lemhi Arch to west Montana: e.g. Frasnian-Famennian boundary **Fm0** in red.

This scheme is based on established & some new paleonotolgy (conodonts and palynology being down at the UI).
Sabkha - Logan Gulch, Widespread Knoll Limestone (like us, Paul Schietinger working with Sonnenberg has also discussed in his MS this petroliferous unit which has been an oil-prone drilling target in NW Montana [when the Sappington/Exshaw is not looking good]. He suggested it might be considered the base on the Trident, although we keep it here as part of the LG.
Logan Gulch Mbr = correlative part of the upper Jefferson GRANDVIEW DOL.)

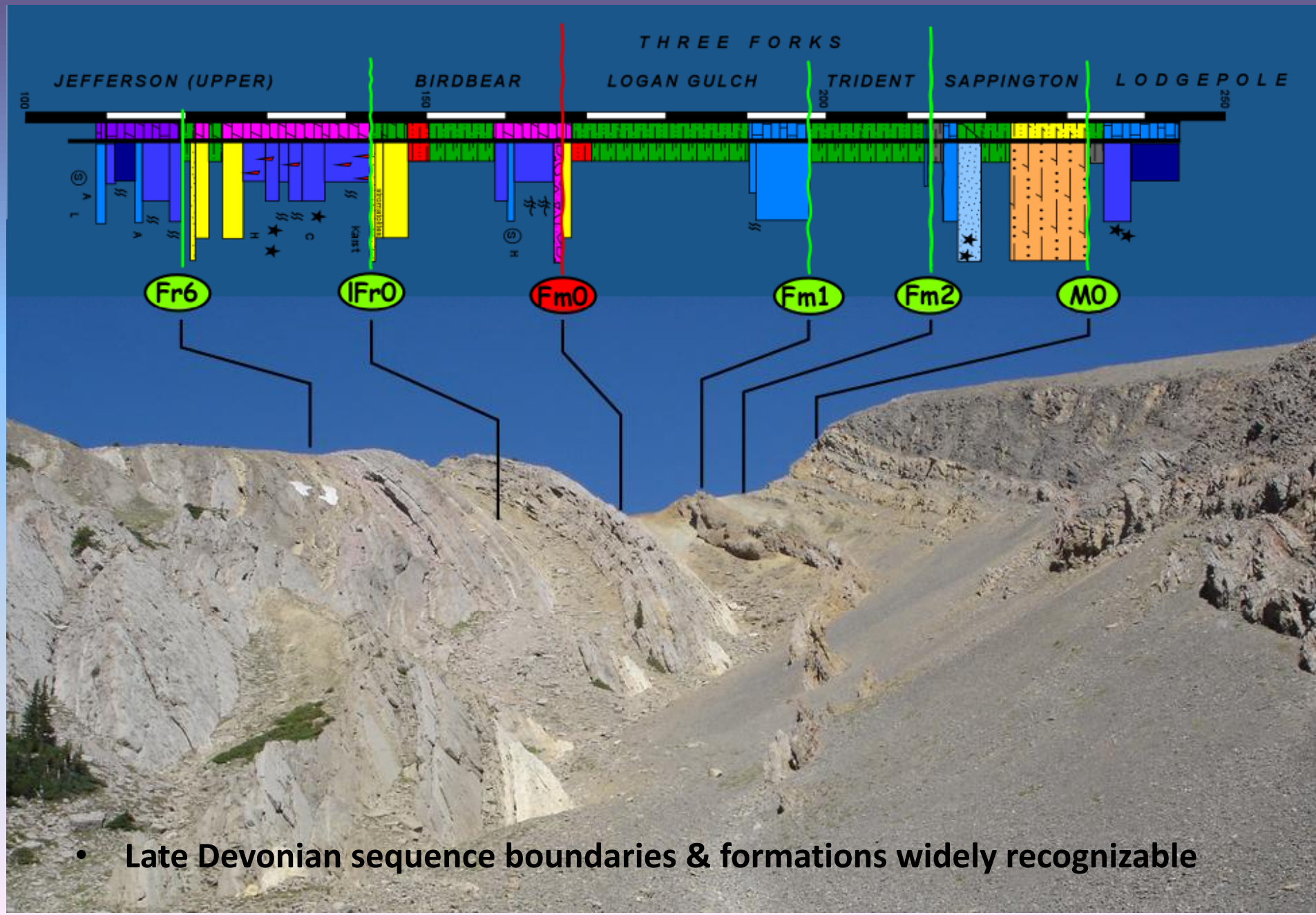
Followed by the v. fossiliferous green shales and marine limestones of the 3F Trident, the various off shore to transitional units of the Sappington, which we have adopted from 1960s Gutschick and Sandberg work (sap1 – 5).

Also we have broken out the basal Mississippian which involves the upper black shale, mid ramp crinoidal, glauconitic packstones of the Scallion, below the Lodgepole (correlative to McGowan Ck to the west).

Obviously tectonically active, quite a bit of hiatus, evidence for exposure, and conodont hiatus (as well as condensed horizons associated with flooding surfaces).

Note outer shelf uplift in ID, differential subsidence and deposition over the Lemhi Arch/now "Beaverheads Uplift", and extra Miss subsidence to the east.

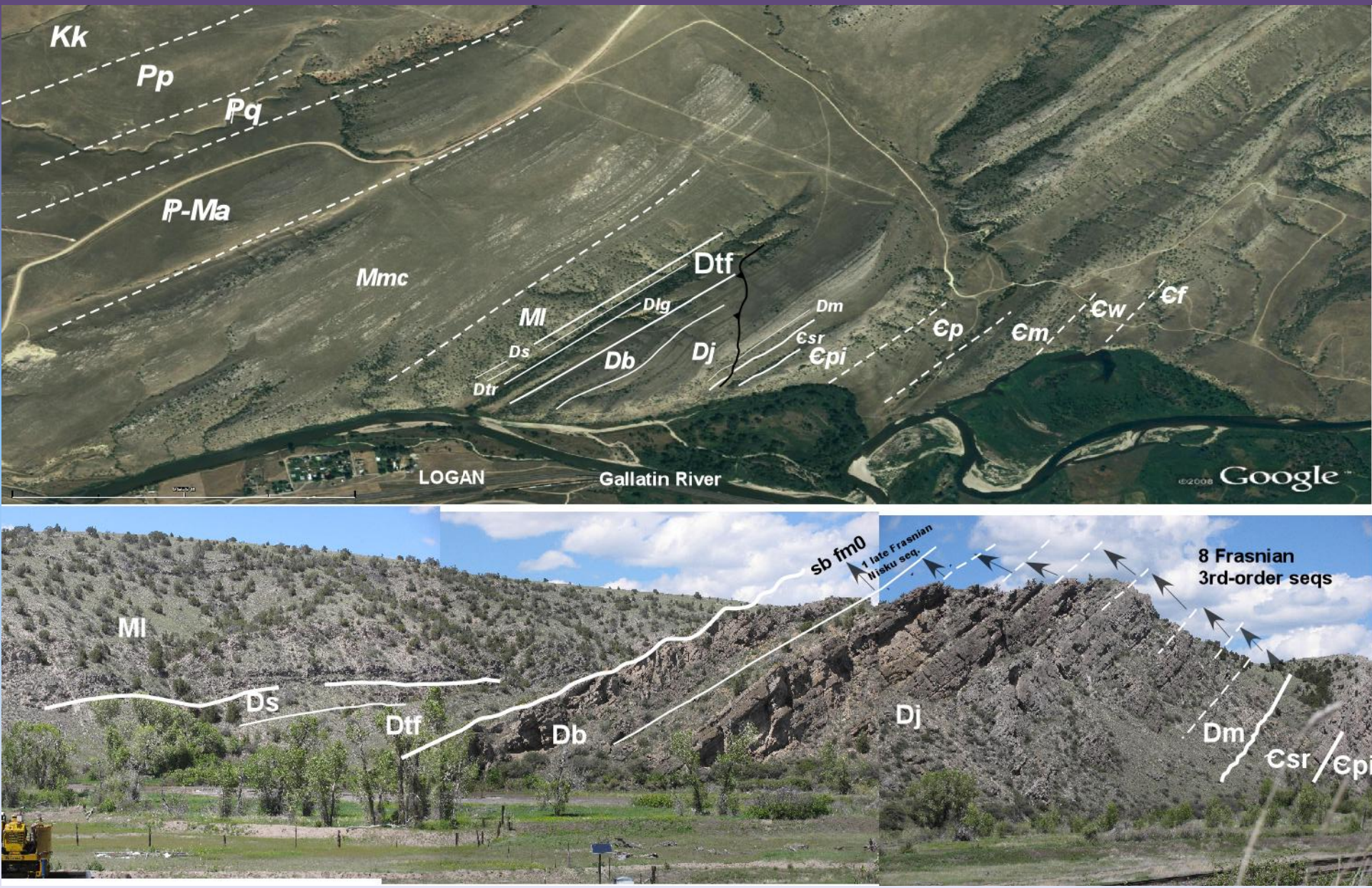
Sacajawea-Hardscrabble cirque (Bridger Range)



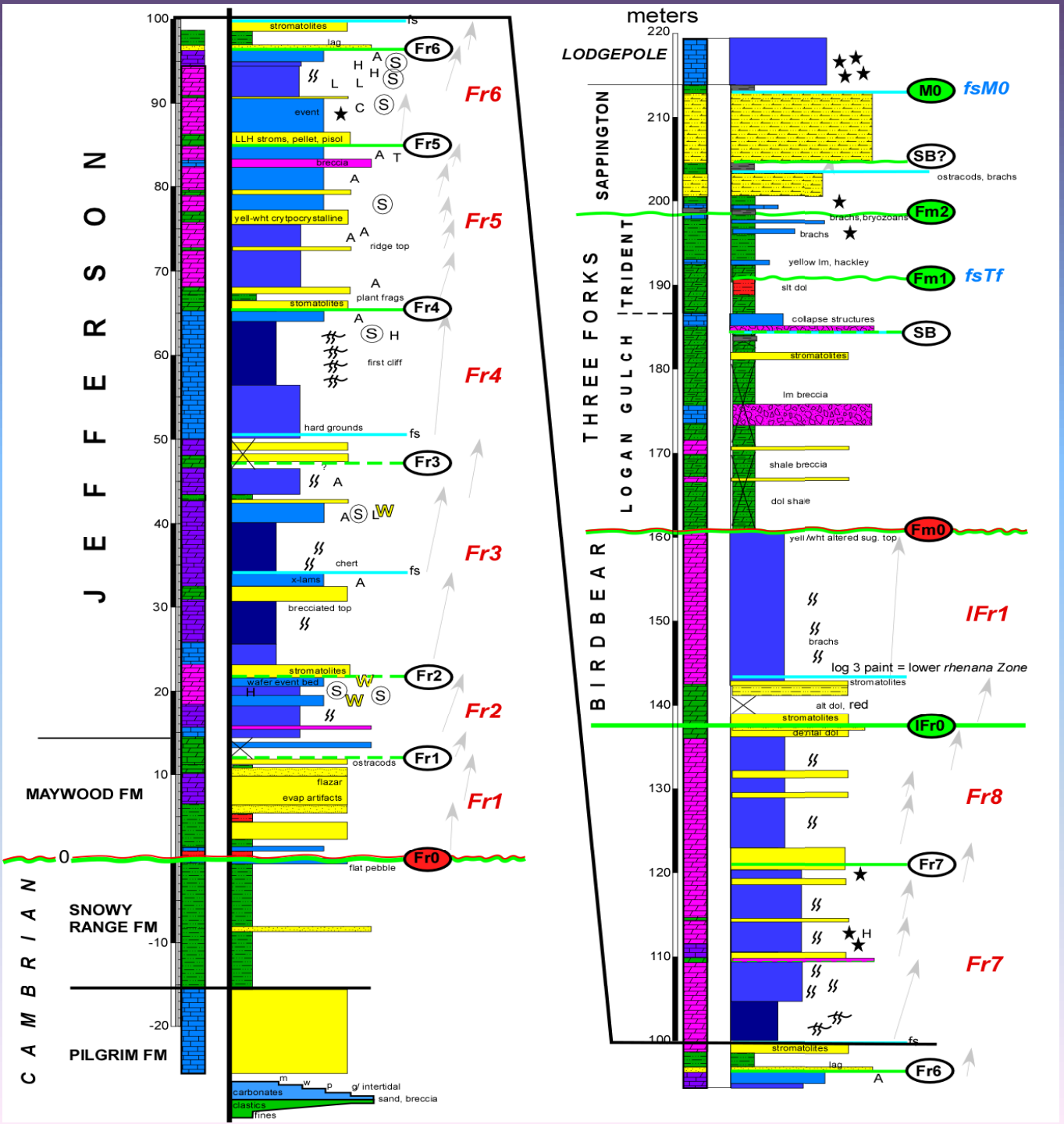
- Late Devonian sequence boundaries & formations widely recognizable

LATE DEVONIAN AT HARDSCRABBLE, BRIDGER RANGE

(aka., Fairy Lake Cirque, Sacajawea, Pomp Peak, Peak 9559)

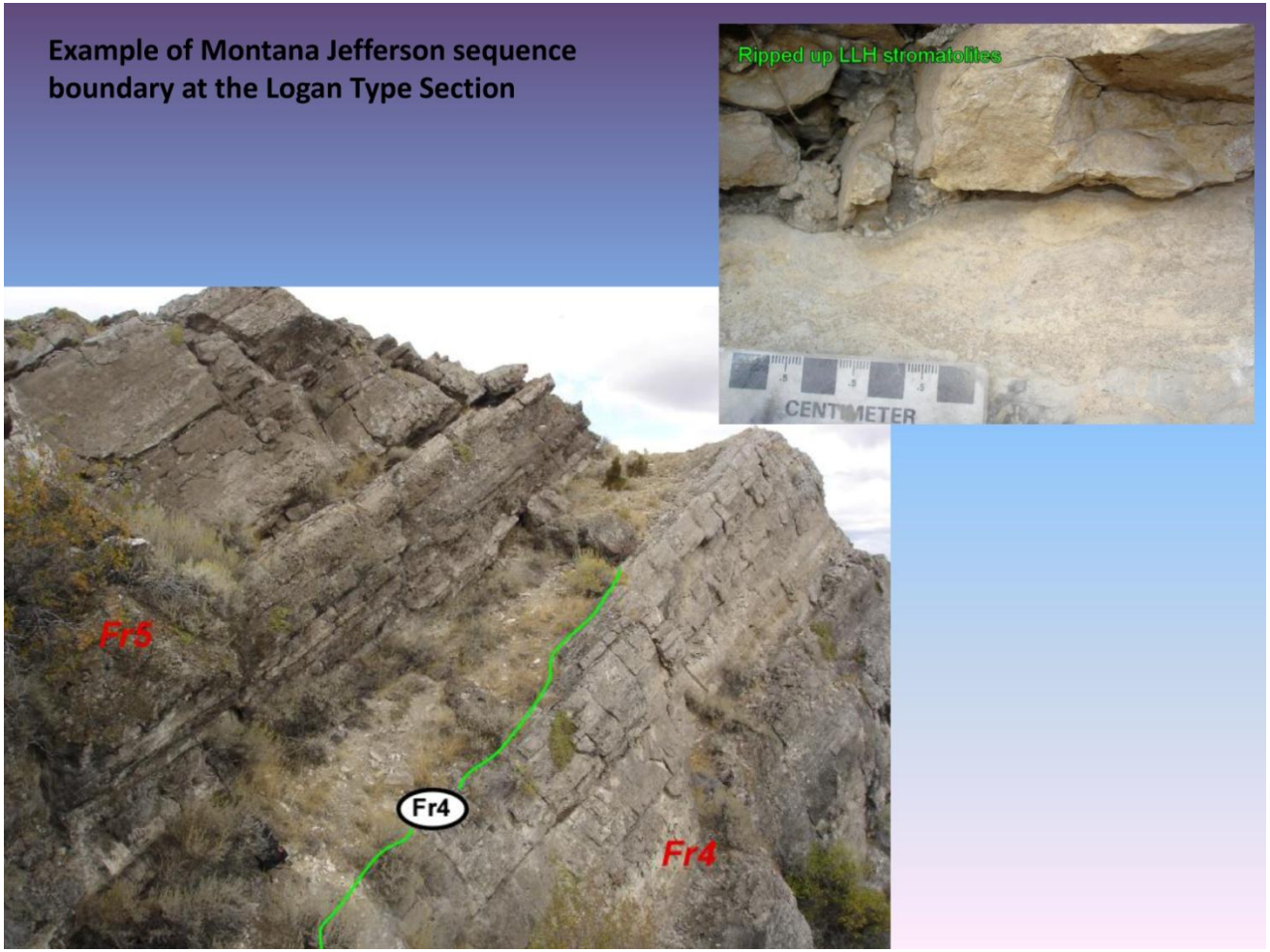


LOGAN Devonian Type Section

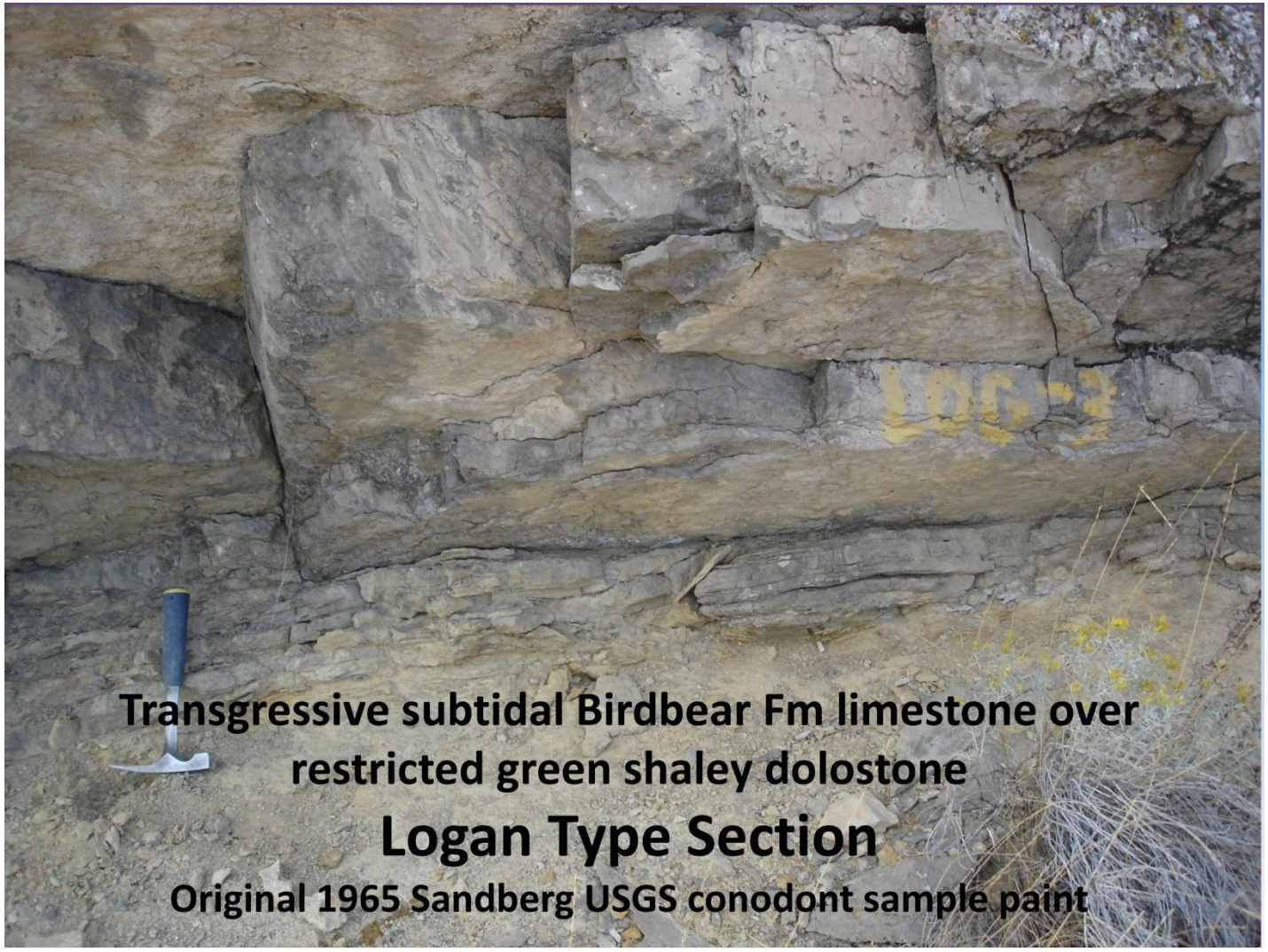


LOGAN GULCH Devonian Type Section

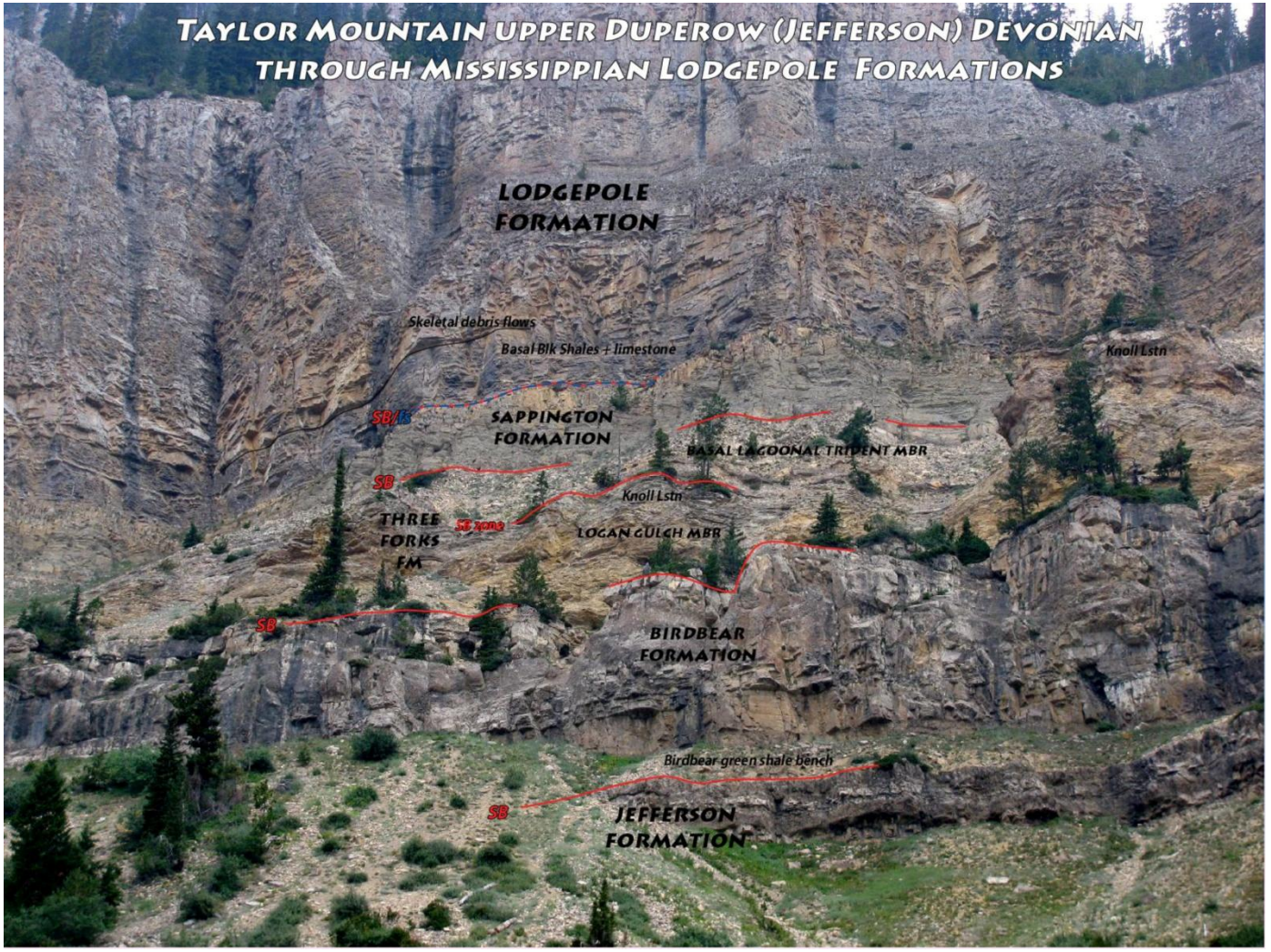
Nine Frasnian stacked TST/HST low accommodation lagoonal cycles



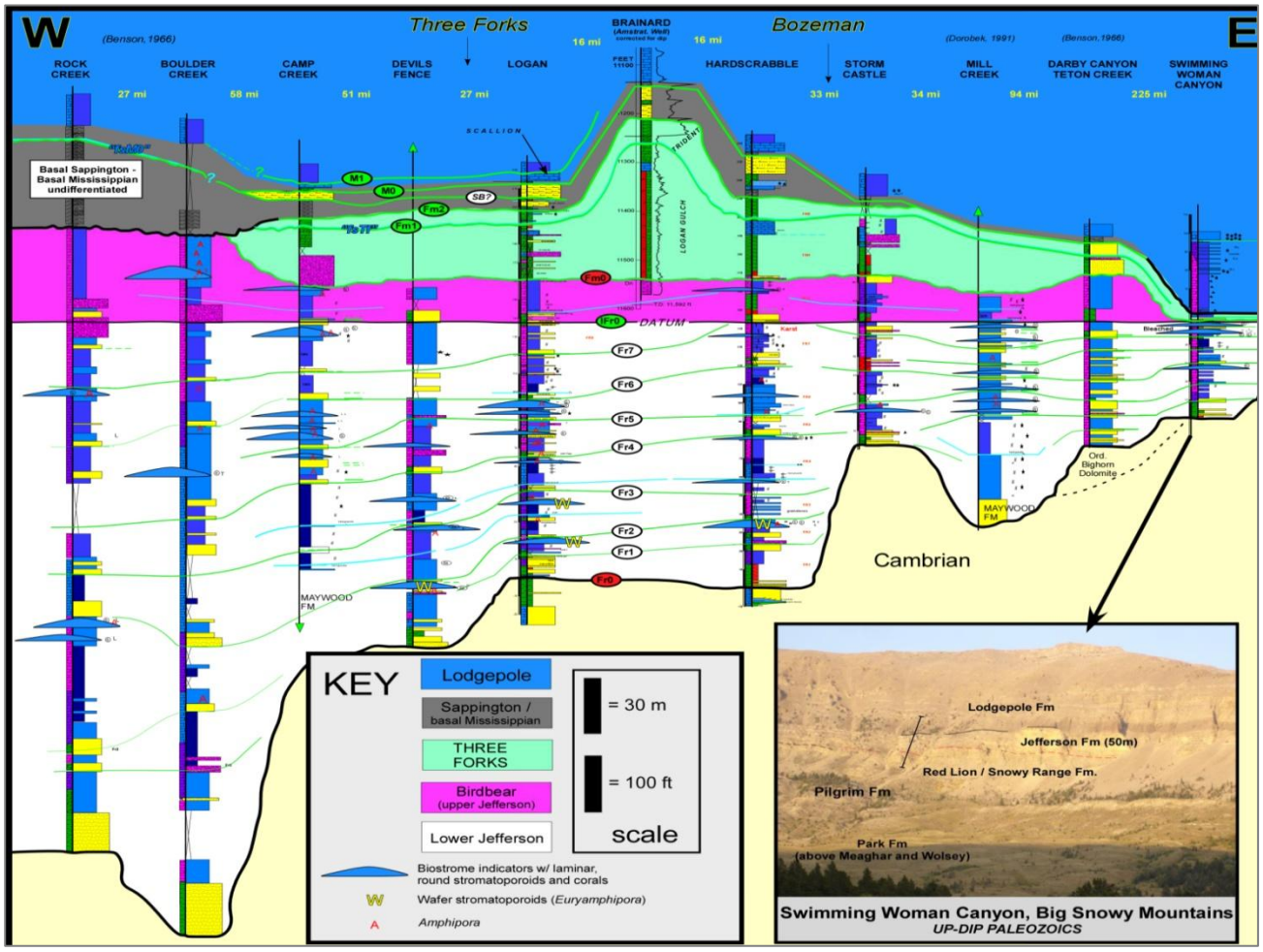
Presenter's notes: Nodular marine limestone shallows into lighter wackestone with round stromatoporoids & horn corals (HST of Fr4).
Sharply overlain (SB) by sandy dolorudstone with transported stromatolites & green siltstone with plant fragments.
Lagoonal *Amphipora* floatstone & marine burrowed dolomudstone continues above (LST/TST of sequence Fr5).



Presenter's notes: The late *rhenana semichatovai* conodont put s this unit into the early latest Frasnian (pre-*linguiformis).*



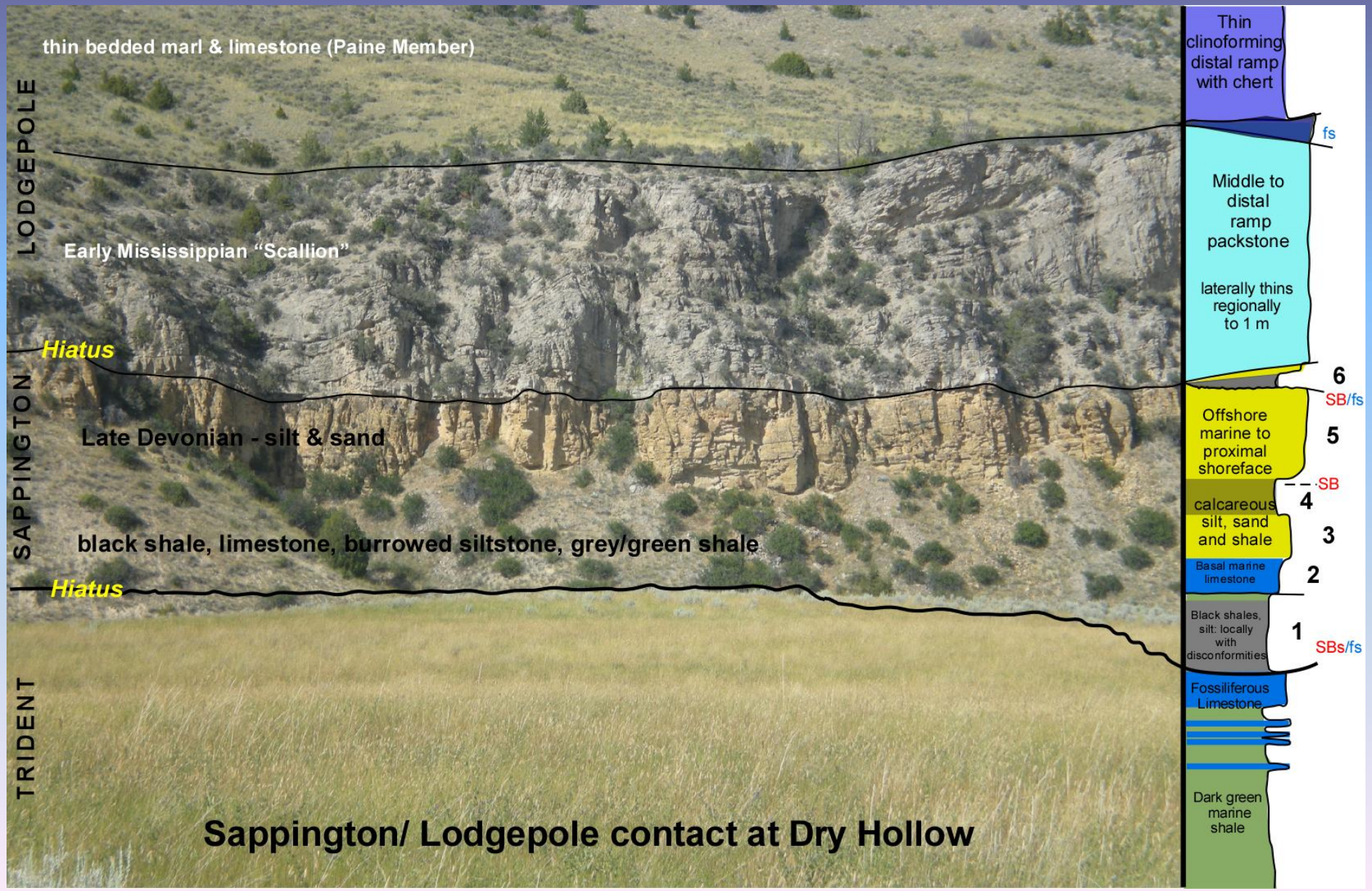
Presenter's notes: Same relationships can be carried to SW MT, but are lost over the Lemhi Arch (here facies are changing significantly in the Trident and Sappington).

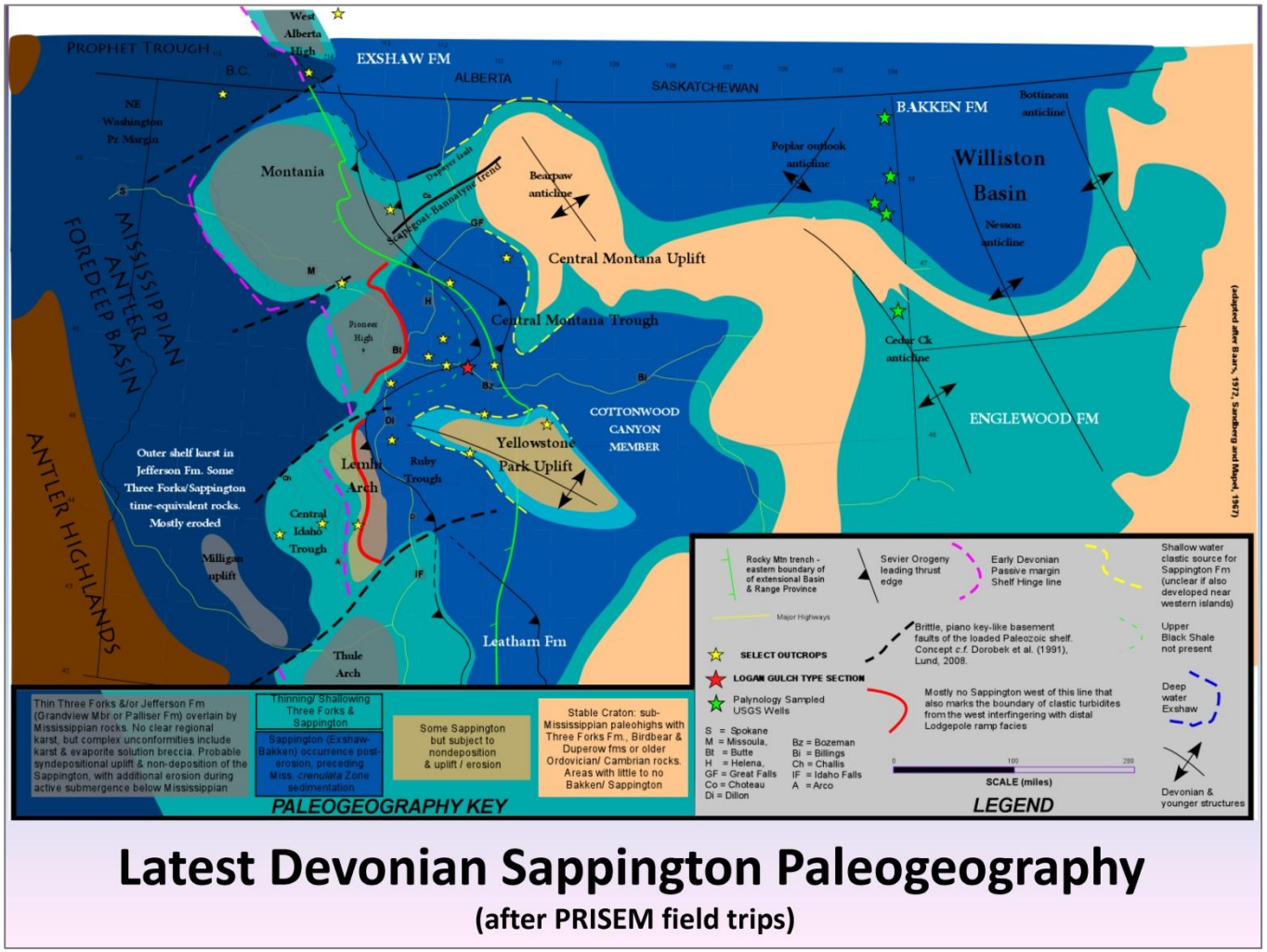


Presenter's notes: Correlation from Swimming Woman In the Big Snowys west through Three forks Area out to the West.

1) Cyclicity of the Jefferson Low Accomodation cycles.
2) Ingle last Birdbear cycle (Basal Sappington . Mississippian undivided overlies the Birdbear to the West.
3) CMT preserves upper D formation and sequence boundaries.

Sappington and overlying Scallion

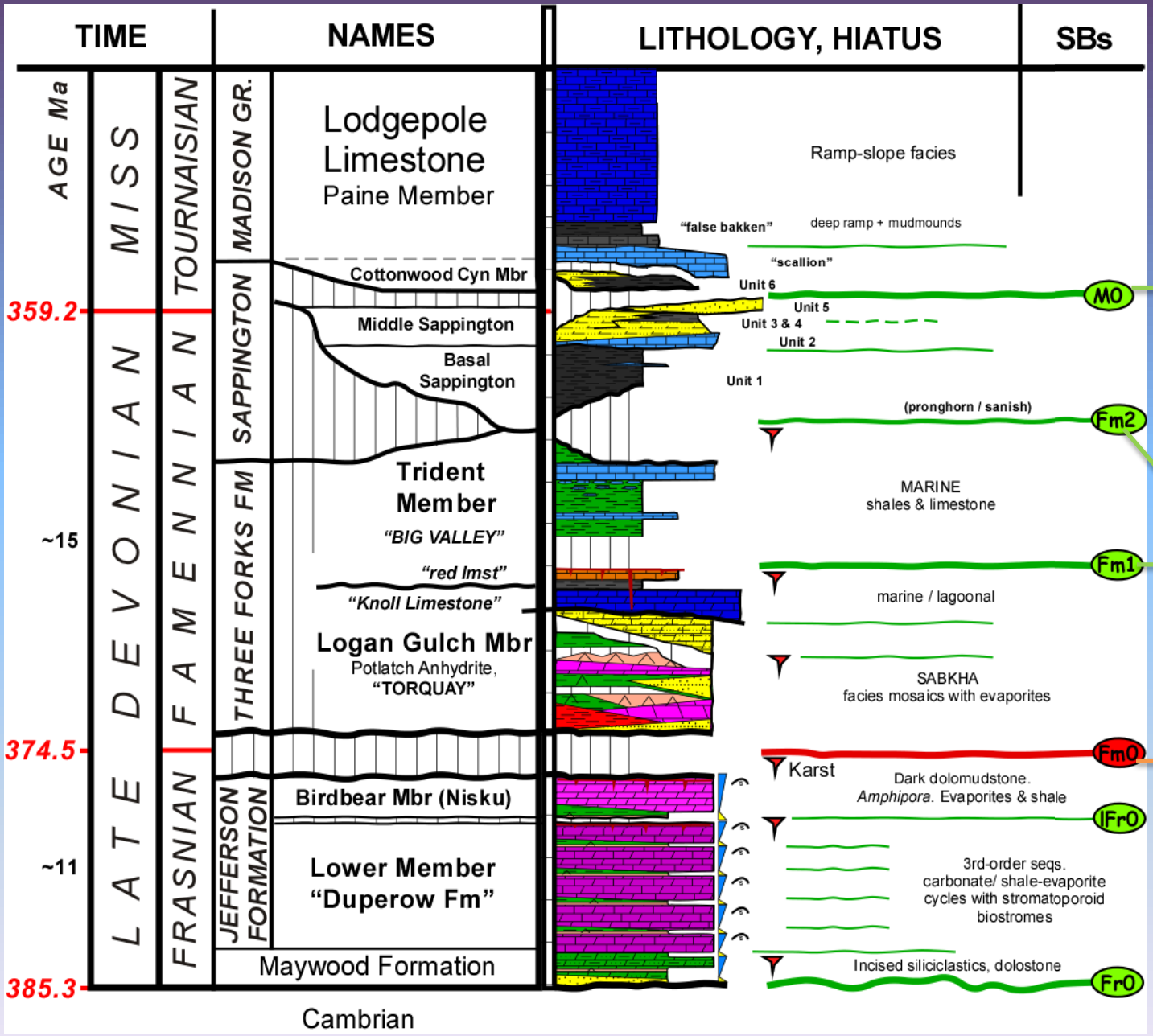


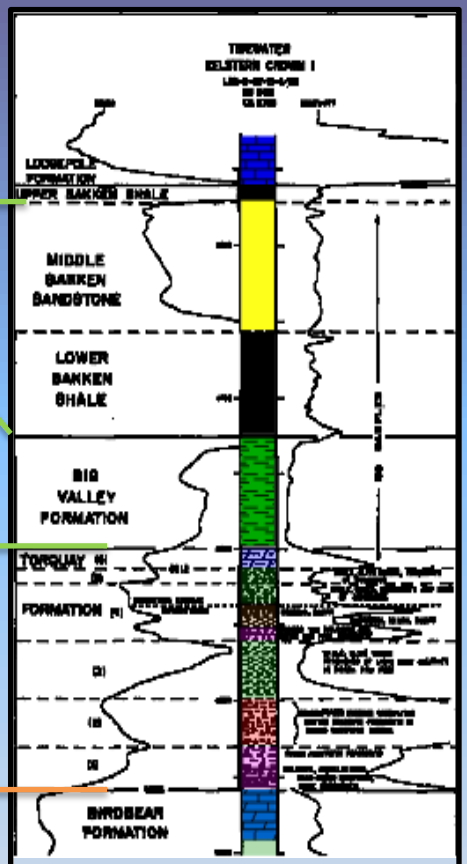


Latest Devonian Sappington Paleogeography

(after PRISEM field trips)

Presenter's notes: Sappington Depositional area in CMT should be pointed towards (note the Cottonwood Cyn Mbr (eastern CMT) deposited concurrently with the Sappington before some western uplift of the CMT (ergo the upper black shale tongue thins to the west and thickens to the east toward the Cotton Wood Cyn Fm depocenter.





Saskatchewan Williston Basin lay down?
(from Christopher 1961)

Three Forks Area / Central Montana Trough Stratigraphy Summary

Broad ID-MT Overview

Idaho Jefferson & Three Forks equivalents west of Lemhi Arch show middle to latest Devonian high accommodation.

Upper Grandview = evaporitic lower Famennian intra-shelf basin matching MT Craton strata (i.e. 3 Forks Potlatch / Logan Gulch Mbr.)

Major sequences boundaries are regional

Frasnian Jefferson (and Nisku/Birdbear) low accommodation MT craton sequences

Three Forks and Sappington were involved with complex craton edge tectonic adjustments and glacioeustasy

Want to see more of the Bakken equivalent facies in outcrop???
contact PRISEM Geoscience Consulting to arrange a field trip

Presenter's notes: This talk is a broad overview of units that were mostly dated and discussed in the 1960-1980s (e.g. Johnson, Sandberg).
ID-MT Devonian shelf lithostrat & mappable formations are dominated by dolostones, are difficult to date & ID. Ergo ID Devonian strata remain primitively described.