Synsedimentary Structural Growth as a Control on Isolated Shelf Sandstone Bodies in the Cenomanian to Turonian Succession of the Western Cordilleran Foreland Basin*

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*Adapted from presentation at Tulsa Geological Society luncheon meeting, September 23, 2014. Please refer to related article, by the author and colleagues/students, entitled "Deltaic deposits formed under spatially and temporally variable accommodation regimes: A plausible alternative explanation for isolated shallow-marine sandstone bodies," AAPG Bulletin, v. 98/5, 2014, p. 893–909 (http://archives.datapages.com/data/bulletns/2014/05may/BLTN13054/BLTN13054.html) .

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Abstract

Although tectonic forcing of stratigraphic architecture in foreland basins is likely, evidence for such forcing is generally circumstantial owing to limitations imposed by the nature of surface and subsurface geological datasets. Herein, I illustrate two examples from surface exposures of Cenomanian-Turonian formations in the Cretaceous Western Cordilleran Foreland Basin (WCFB) of Utah and Wyoming that provide unequivocal evidence of synsedimentary fold growth. Such growth promoted differential subsidence and erosional truncation, facilitating the formation and preservation of elongate, isolated shelf sandstone bodies. The first example is from the Turonian Ferron Sandstone exposed in the Henry Mountains Syncline of south-central Utah. A 65 km long, depositional strike-parallel cross-section reveals a synsedimentary fold with an estimated wavelength of ~70 km and amplitude of at least 50 m, which is truncated by a regional erosion surface. Depositional dip-oriented outcrops on the flanks of this fold disclose the prominence of laterally discontinuous deltaic sands formed under strong forcing by repeated relative falls of sea level. The second example is from the Cenomanian-Turonian Frontier Formation in the northern Bighorn Basin, Wyoming. Here, along a depositional dip-oriented cross-section 35 km long, another synsedimentary fold with at least 35 m relief and a wavelength of 30 km is evident. Much of the Frontier Formation is incorporated into the fold, and is truncated by a more or less planar erosion surface in a similar manner to the Ferron Sandstone example. It can be shown that the elongate (digitate) shape of one sandstone member owes its origin largely to formation under a regime of both spatially and temporally varying accommodation. Both examples illustrate the importance of tectonic driving forces, likely related to forebulge migration, in the formation and preservation of the Cretaceous stratigraphic record of the WCFB.

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SYNSEDIMENTARY STRUCTURAL GROWTH AS A CONTROL ON ISOLATED SHELF SANDSTONE BODIES IN THE CENOMANIAN TO TURONIAN SUCCESSION OF THE WESTERN CORDILLERAN FORELAND BASIN

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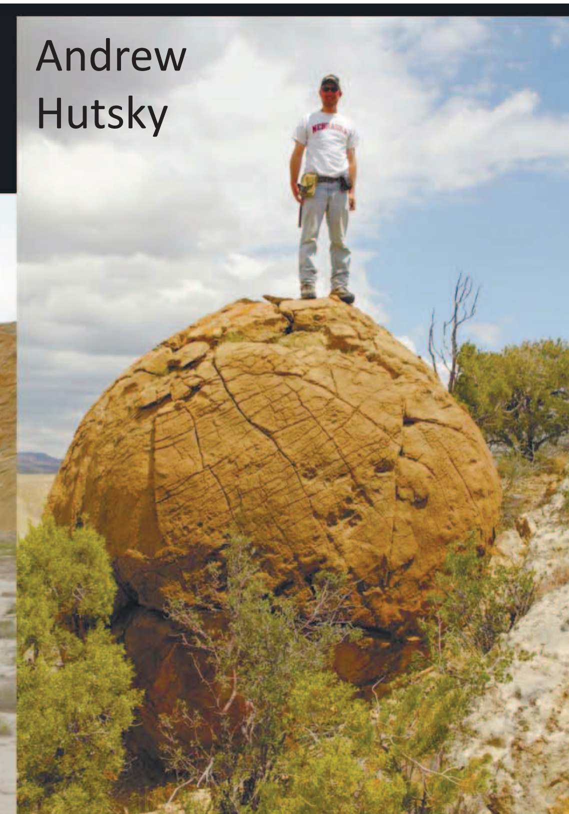
A presentation to the Tulsa Geological Society, September 23rd, 2014

Frontier Formation outcrop north of Greybull, WY

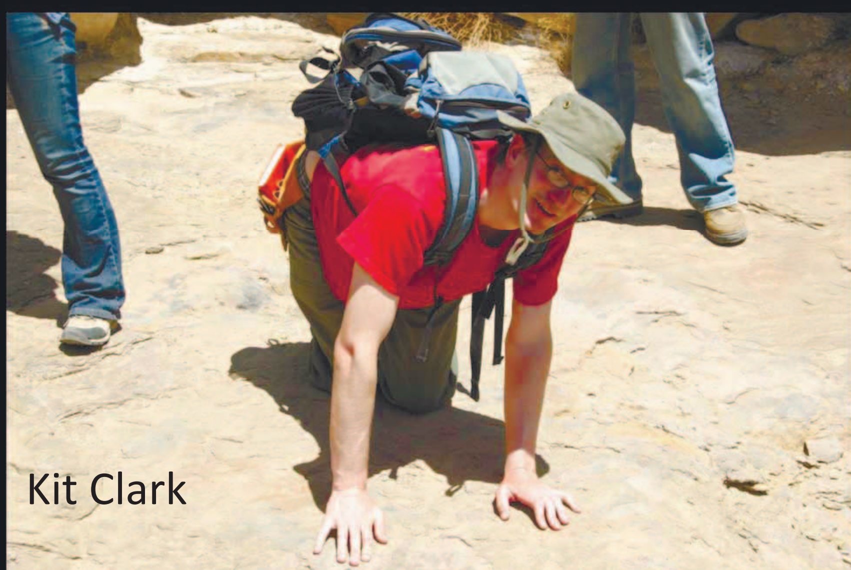
"THE USUAL SUSPECTS"

Trevor Hurd & Drew Seymour

Jesse Korus



Andrew Hutsky



Kit Clark

Fares Al-Aboud

OUTLINE OF TALK

IN THIS TALK, I SUMMARIZE RESULTS OF CURRENT RESEARCH
INTO DEPOSITIONAL SYSTEMS OF THE FRONTIER FORMATION IN
NORTHERN WYOMING and FERRON SANDSTONE IN SOUTHERN UTAH,

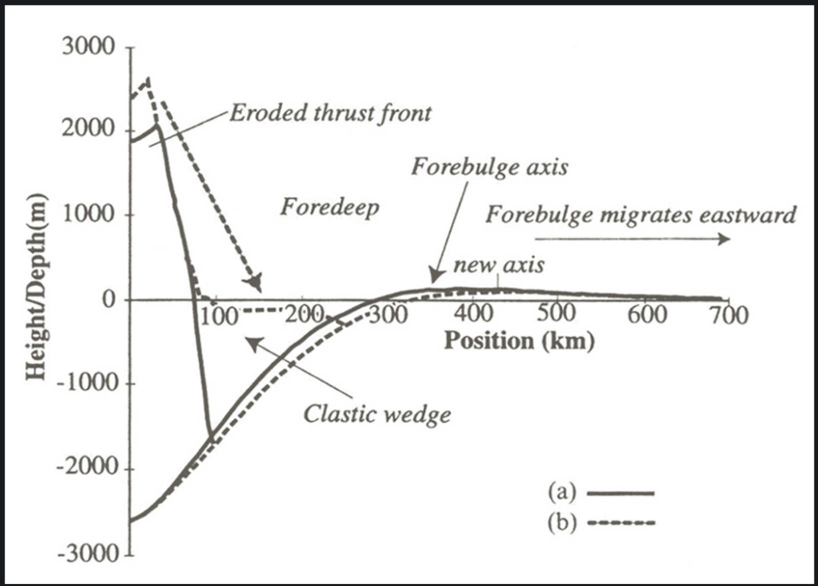
SHOW HOW SYNSEDIMENTARY STRUCTURAL GROWTH DURING
THE EARLY LATE CRETACEOUS CONTROLLED SEDIMENT BODY
GEOMETRY AND STRATAL STACKING PATTERNS IN THESE TWO UNITS,

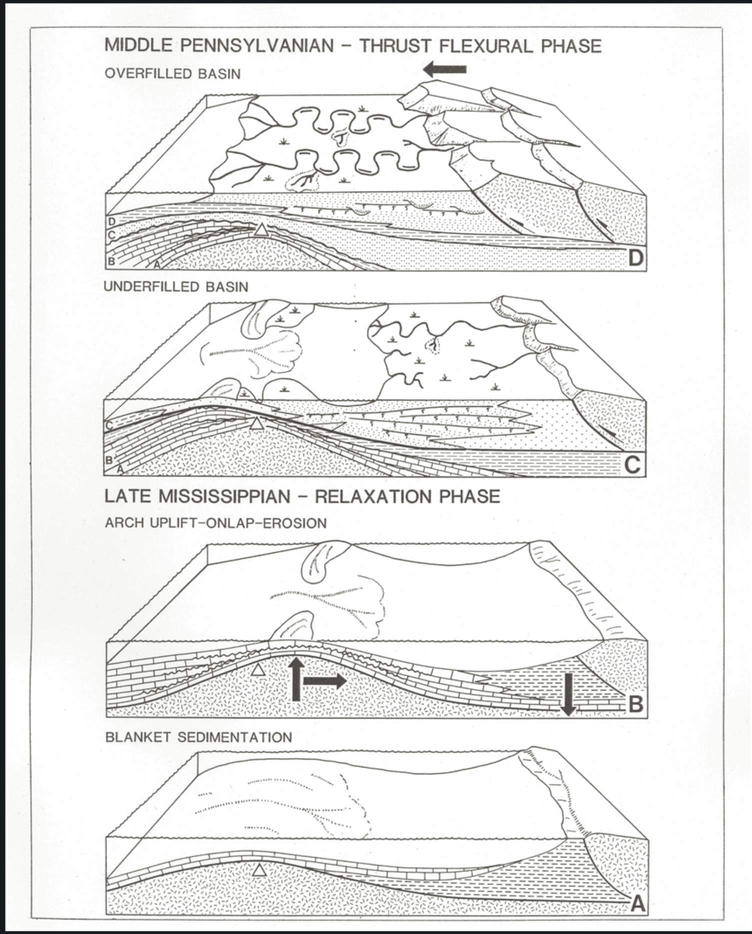
AND EXPLORE IMPLICATIONS FOR THE INTERPRETATION
OF ISOLATED SANDSTONE BODIES.

SYNSEDIMENTARY GROWTH STRUCTURES

- FORM IN A VARIETY OF CONTEXTS, BUT
- ARE PARTICULARLY COMMON IN FORELAND BASINS,
- ARE OFTEN RELATED TO FOREBULGE FORMATION.

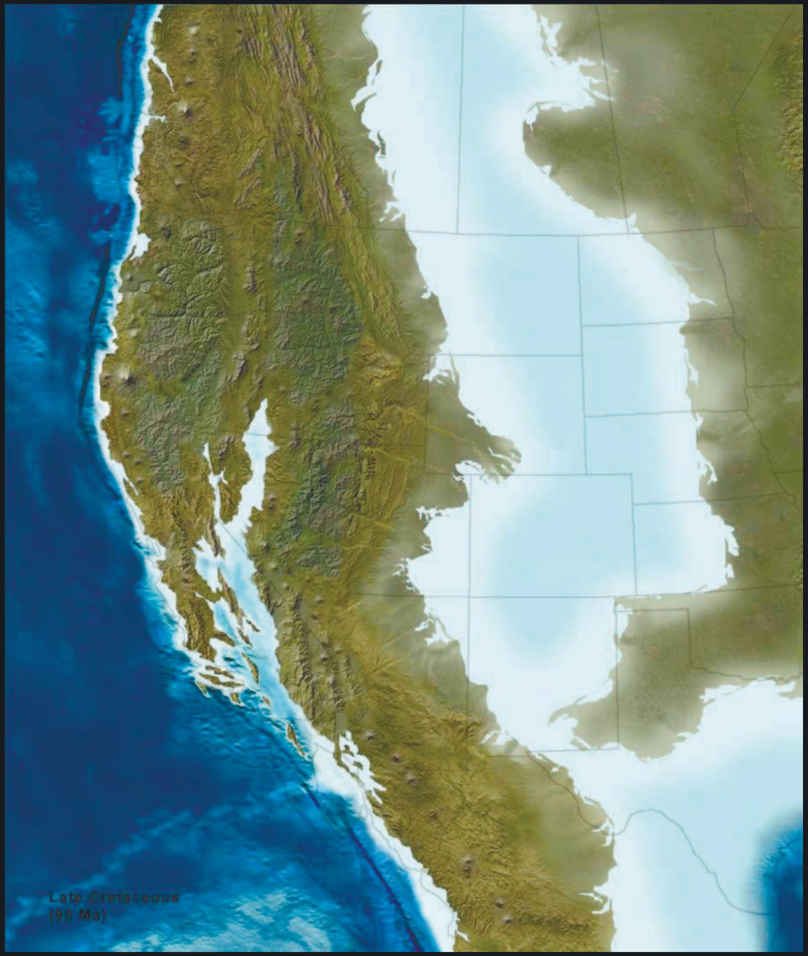
RECOGNITION OF GROWTH STRUCTURES TYPICALLY RESULTS FROM STRATAL THINNING AND ONLAP PATTERNS, EITHER INFERRED FROM SUBSURFACE DATA, OR VISIBLE IN EXCEPTIONALLY WELL-EXPOSED OUTCROP CASES.





(Diagrams from Tankard, 1986, AAPG Bull., 70, 853-868,
(White et al., 2002, Basin Research, 14, 43-54)

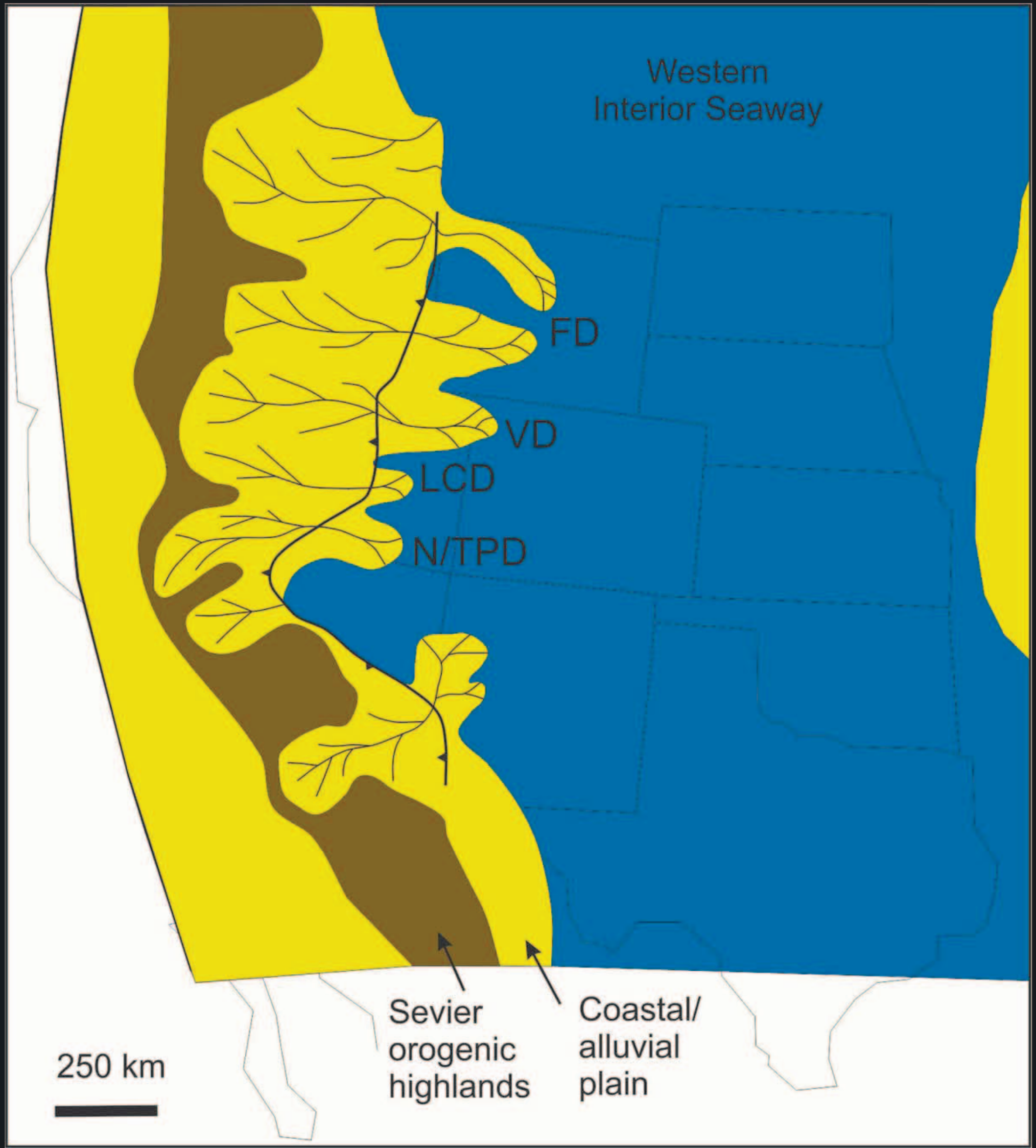
EARLY LATE CRETACEOUS EVOLUTION OF THE WESTERN CORDILLERAN FORELAND BASIN



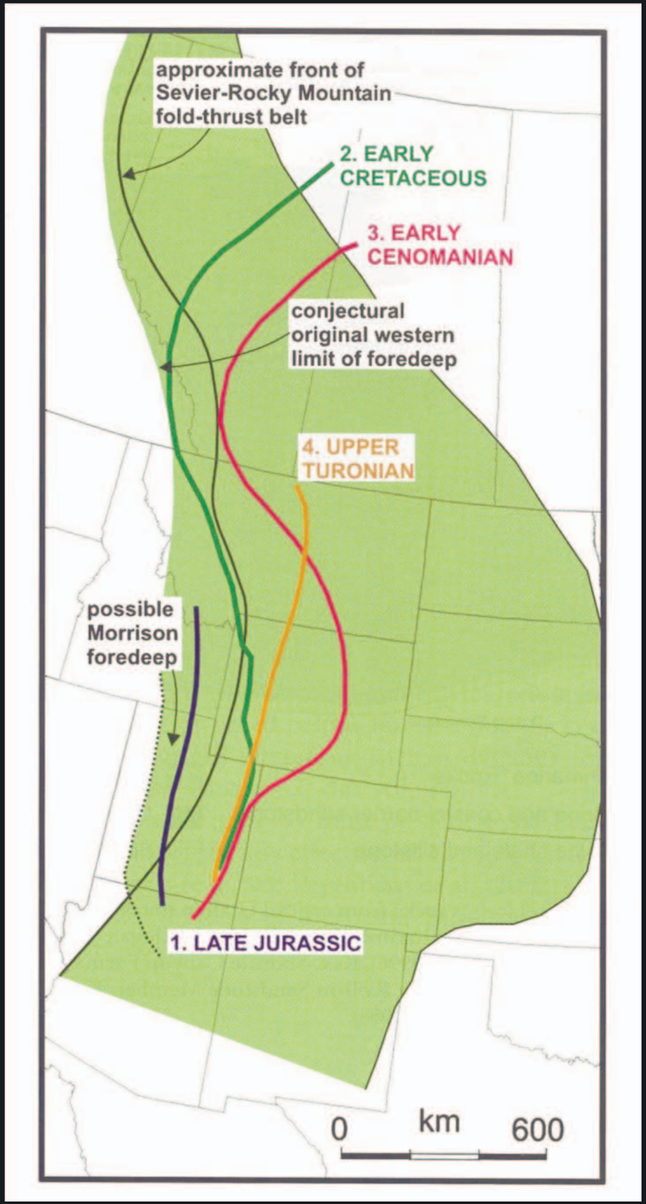
Albian/Cenomanian and Turonian paleogeographies by Ron Blakey

A SERIES OF DELTA COMPLEXES IS BELIEVED TO HAVE DISPERSED INTO THE BASIN FROM THE WEST,

DURING THE CENOMANIAN AND TURONIAN.



(Diagram from Fielding, 2011, Geology, 39, 1107-1110)

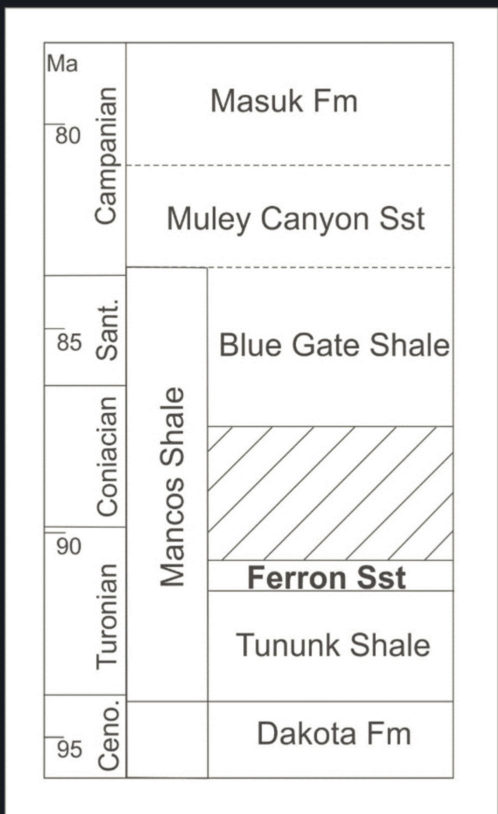


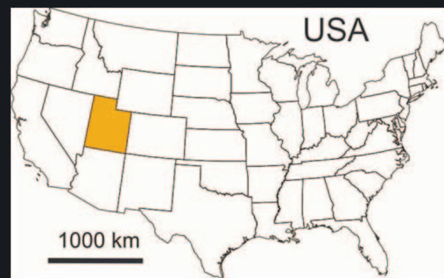
(Diagram from Miall et al., 2008,
In Sedimentary Basins of North America)

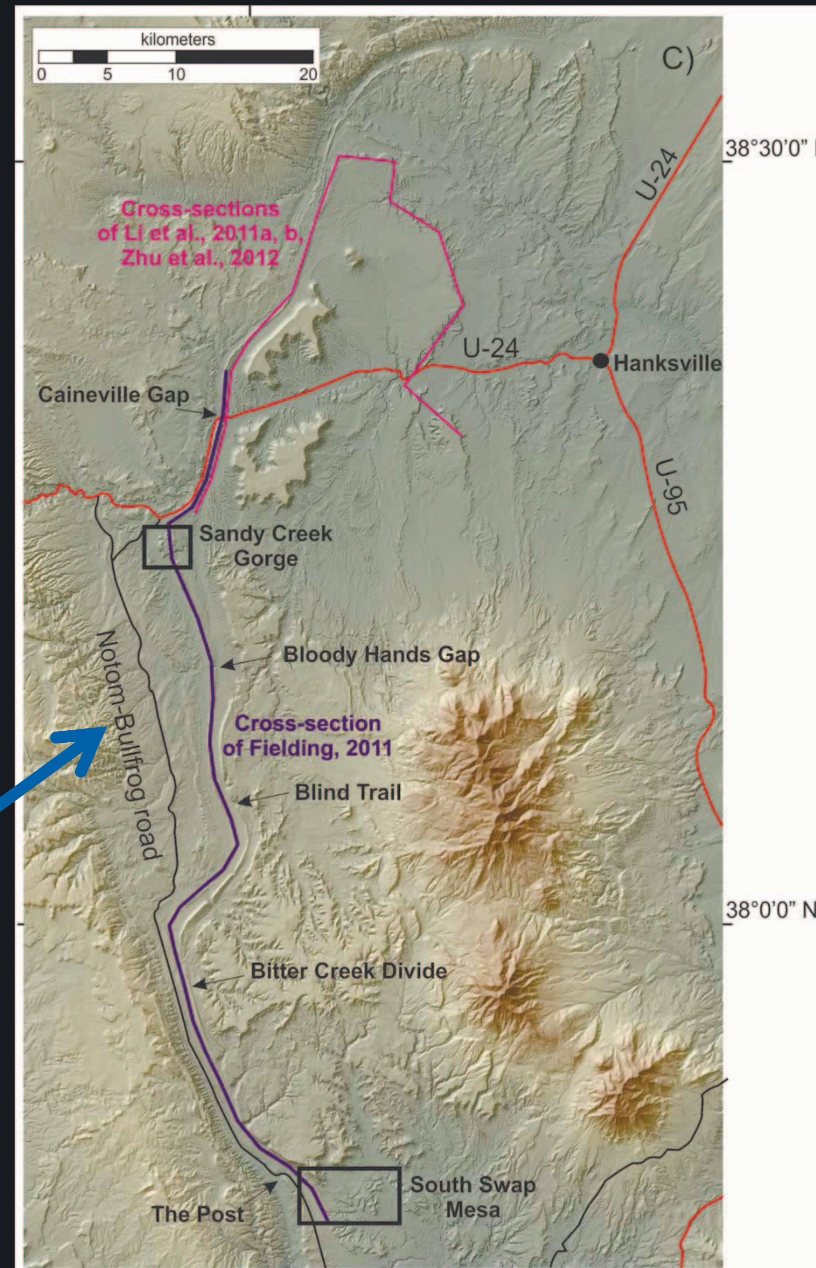
STUDY AREAS IN NORTH-CENTRAL WYOMING & SOUTH-CENTRAL UTAH LAY CLOSE TO THE INTERPRETED LOCATION OF THE FLEXURAL FOREBULGE DURING CENOMANIAN AND TURONIAN TIMES.

CENOMANIAN AND TURONIAN SUCCESSIONS IN THIS REGION ARE KNOWN FOR PRESERVING EVIDENCE OF SYNSEDIMENTARY TECTONIC ACTIVITY.

CASE STUDY 1: FERRON SANDSTONE, HENRY MOUNTAINS, UTAH



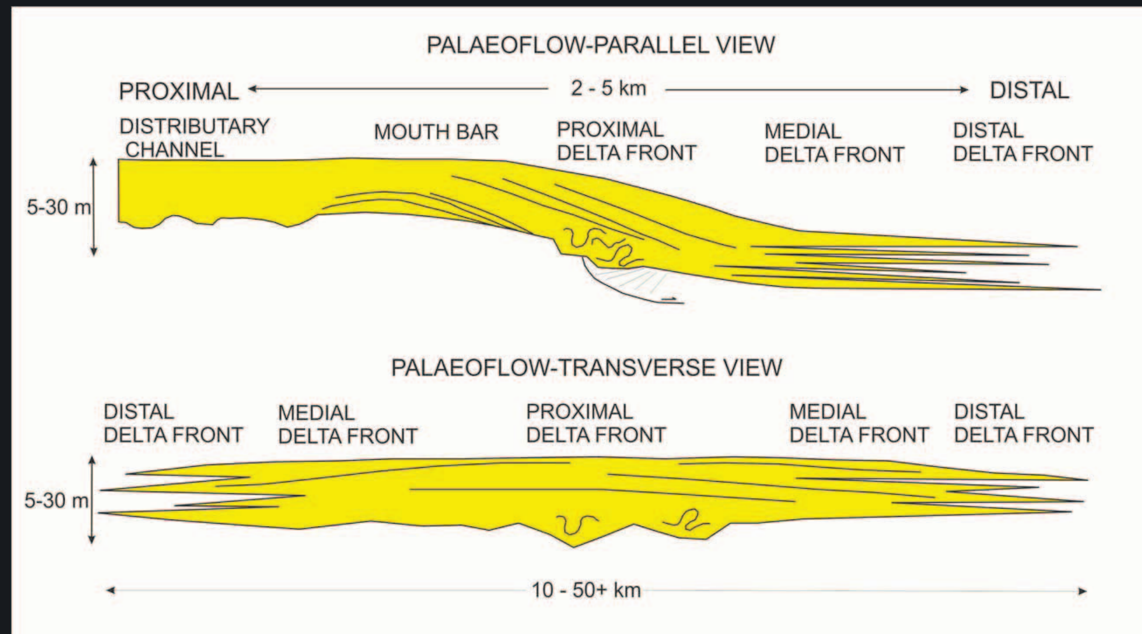




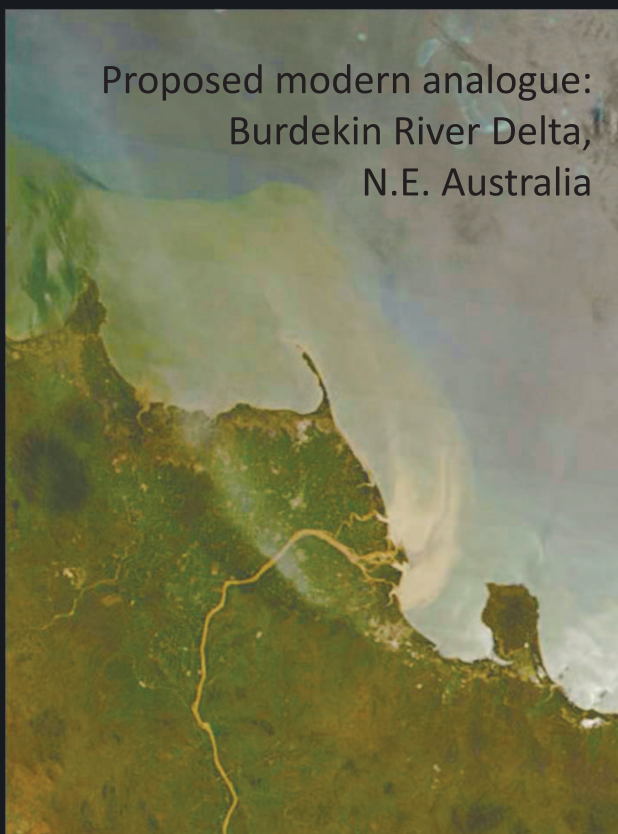
(Diagrams from Fielding, 2011, Geology, 39, 1107-1110; Fielding, in press, Sedimentology)

LOCAL FACIES MODEL FOR THE FERRON SANDSTONE, HENRY MTNS.

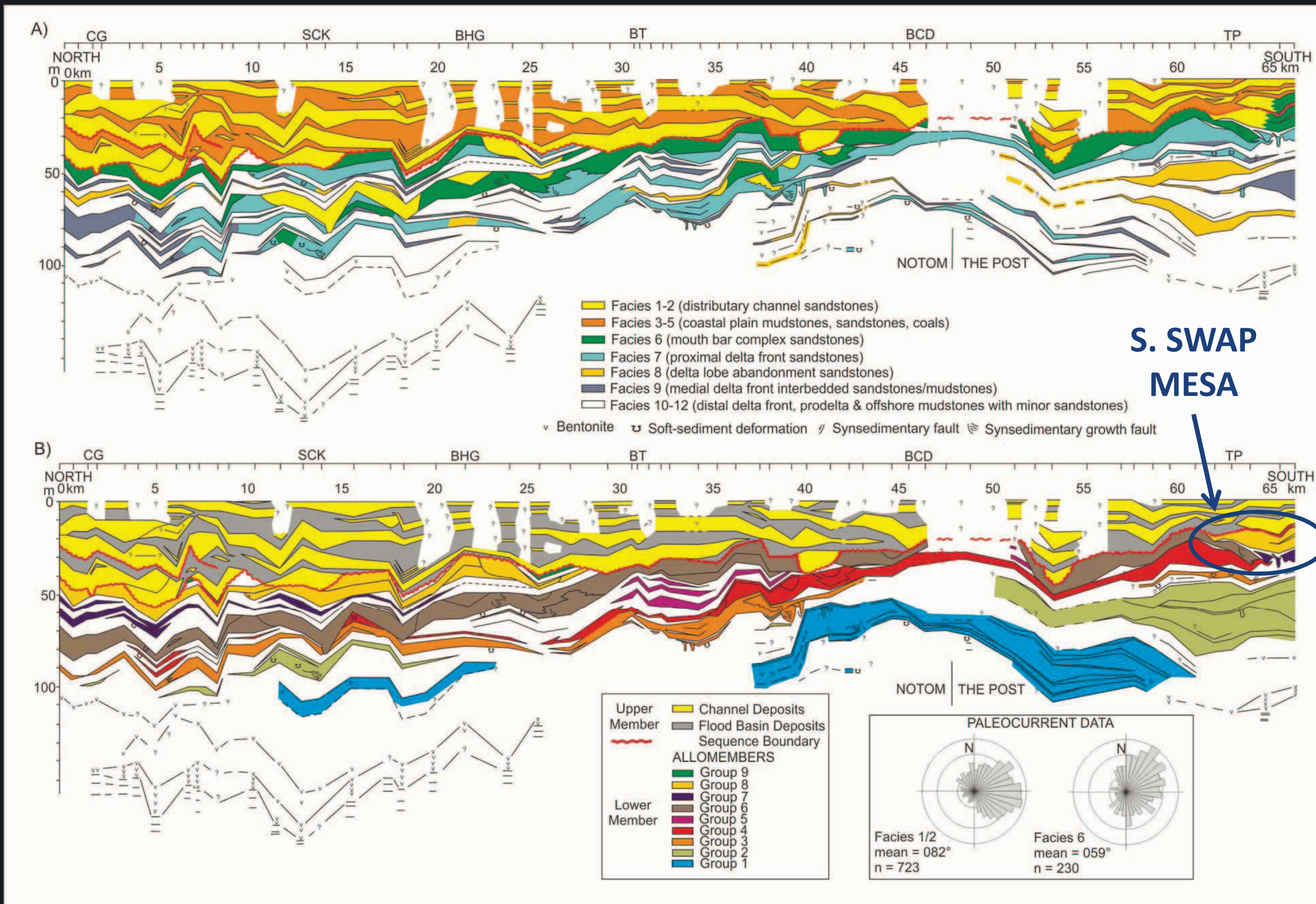
Series of modest-size (5-20 km wide, some laterally amalgamated), asymmetric, mixed-influence deltas that dispersed sediment eastward into the WCFB.



(Diagram modified from Fielding, 2010, J. Sed. Res., 80, 455-479)

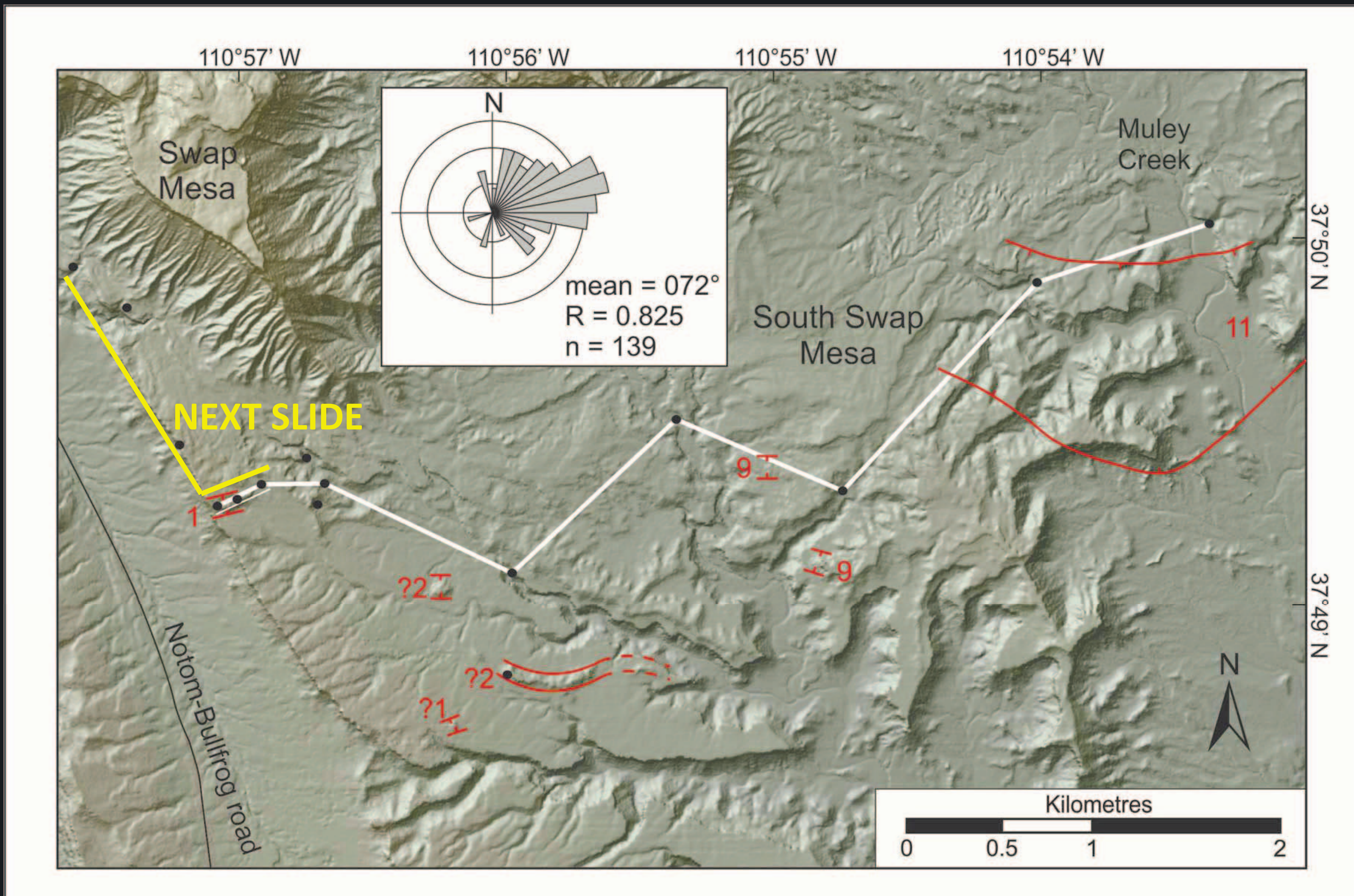


67 km LONG, DEPOSITIONAL STRIKE-PARALLEL CROSS-SECTION



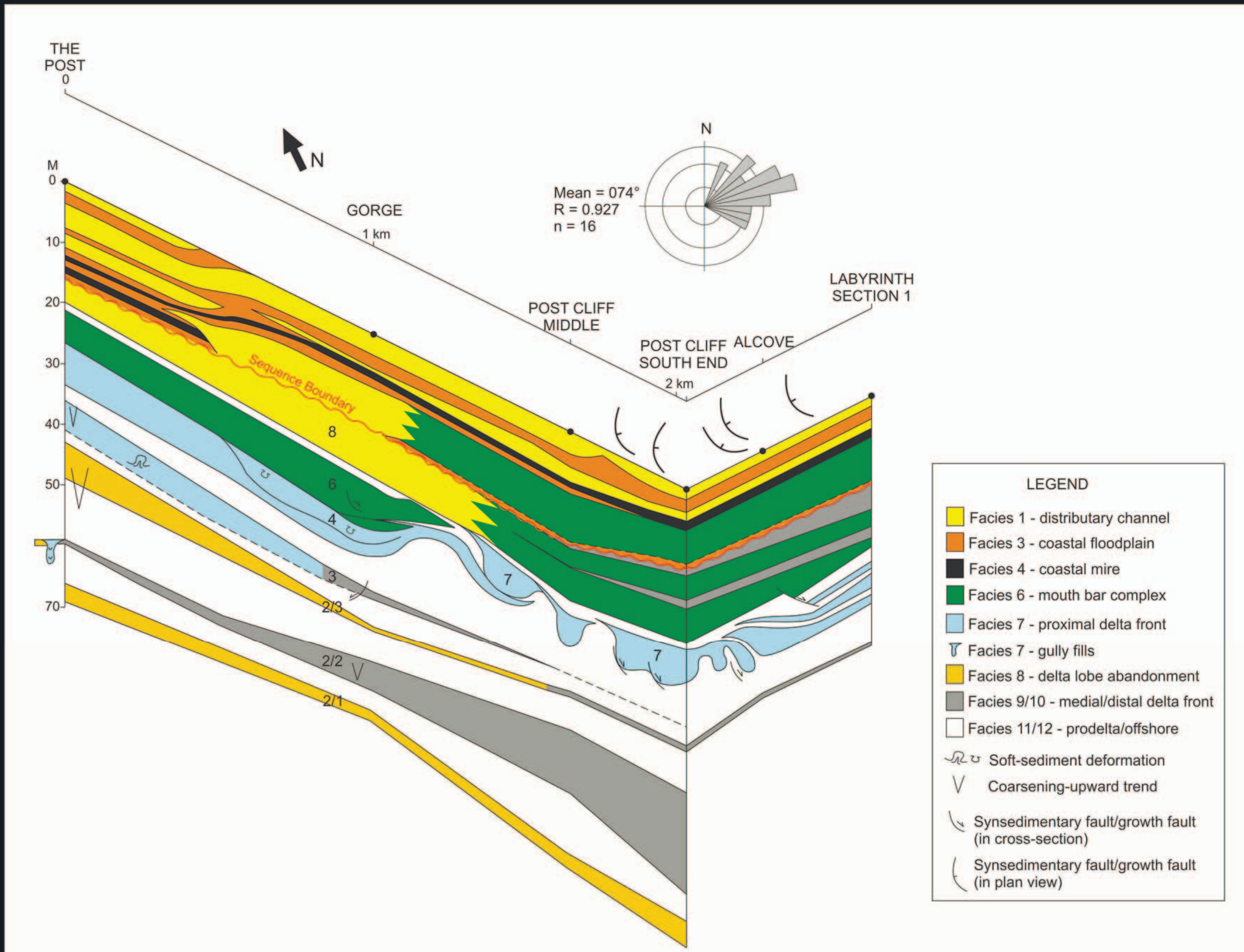
(Diagram modified from Fielding, 2011, Geology, 39, 1107-1110)

DIP TRANSECT STUDY AREA: SOUTH SWAP MESA



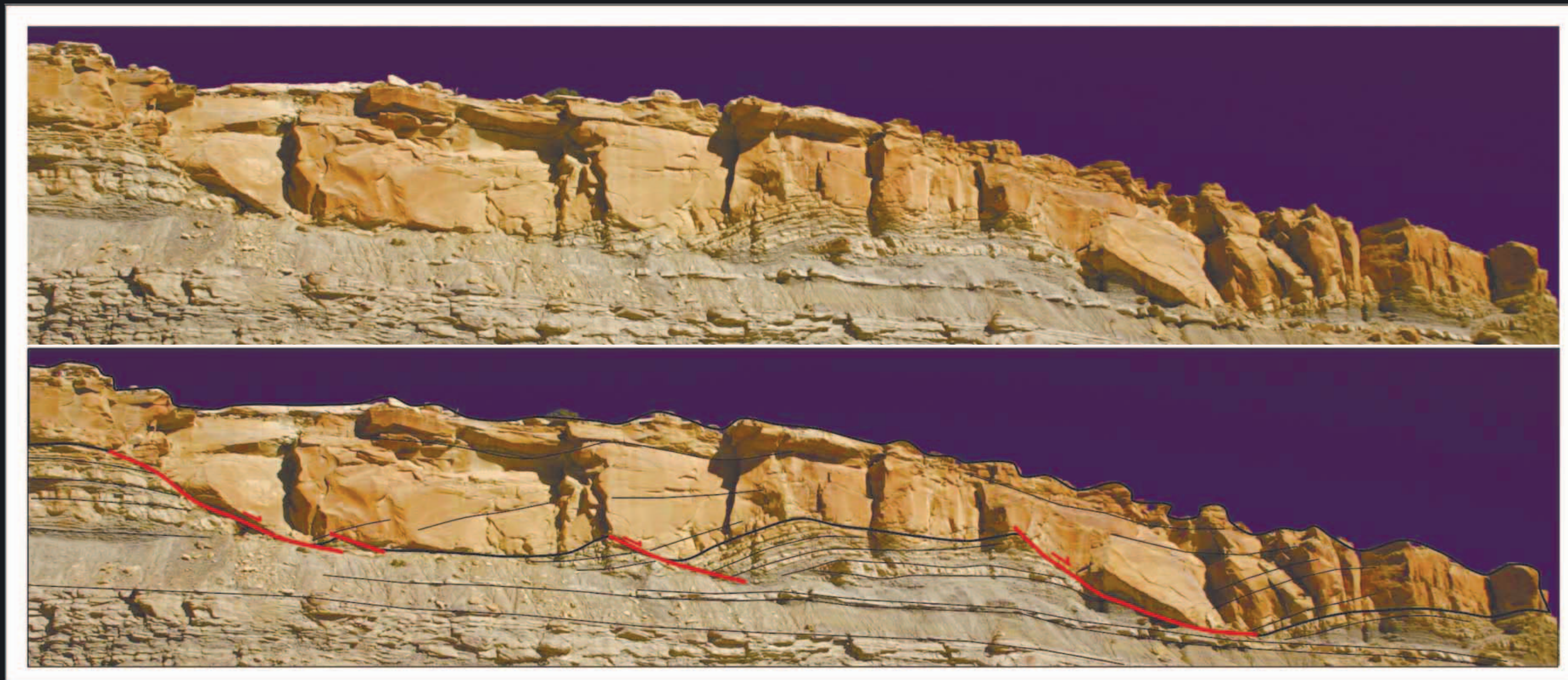
(Diagram from Fielding, in press, Sedimentology)

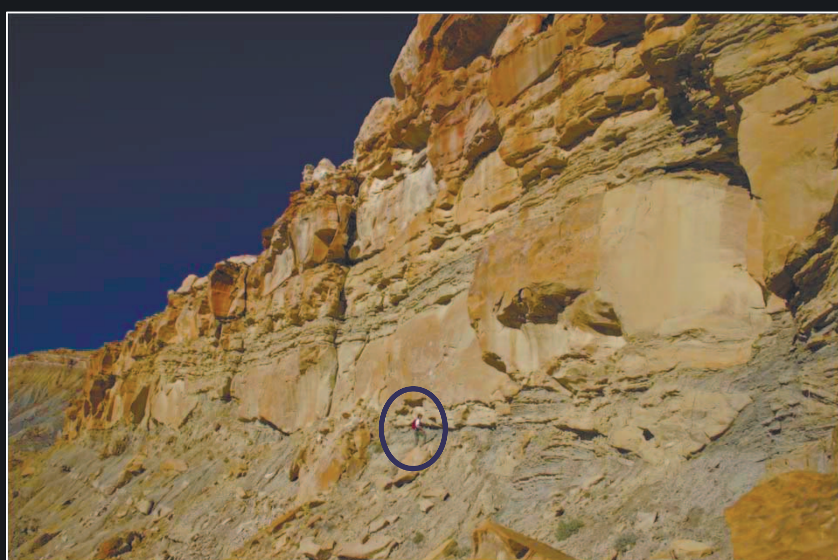
PERSPECTIVE DIAGRAM AT INTERSECTION OF STRIKE AND DIP TRANSECTS



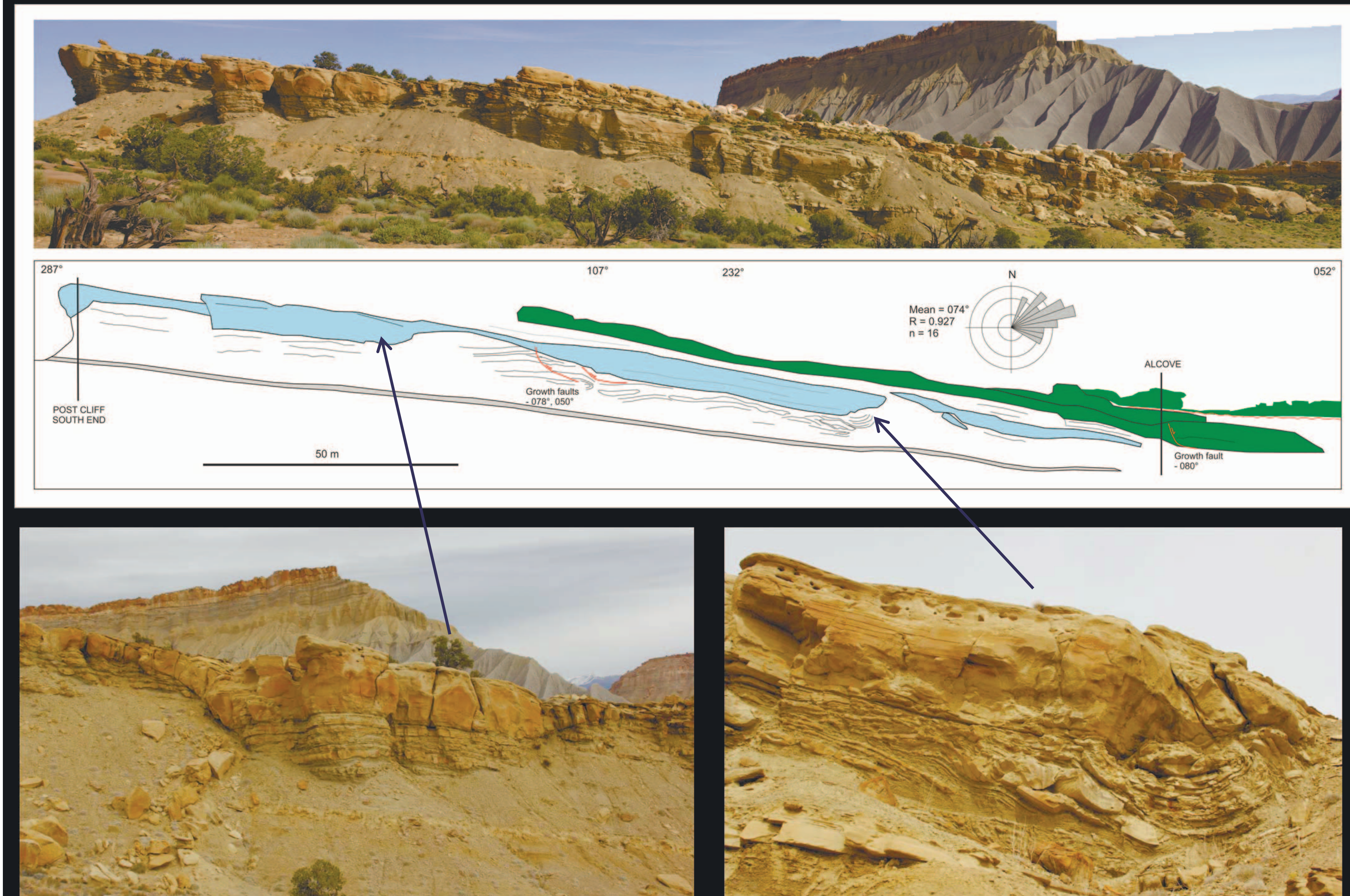
(Diagram from Fielding, in press, Sedimentology)

GROWTH-FAULTED GULLY FILLS AT SOUTH END OF STRIKE TRANSECT



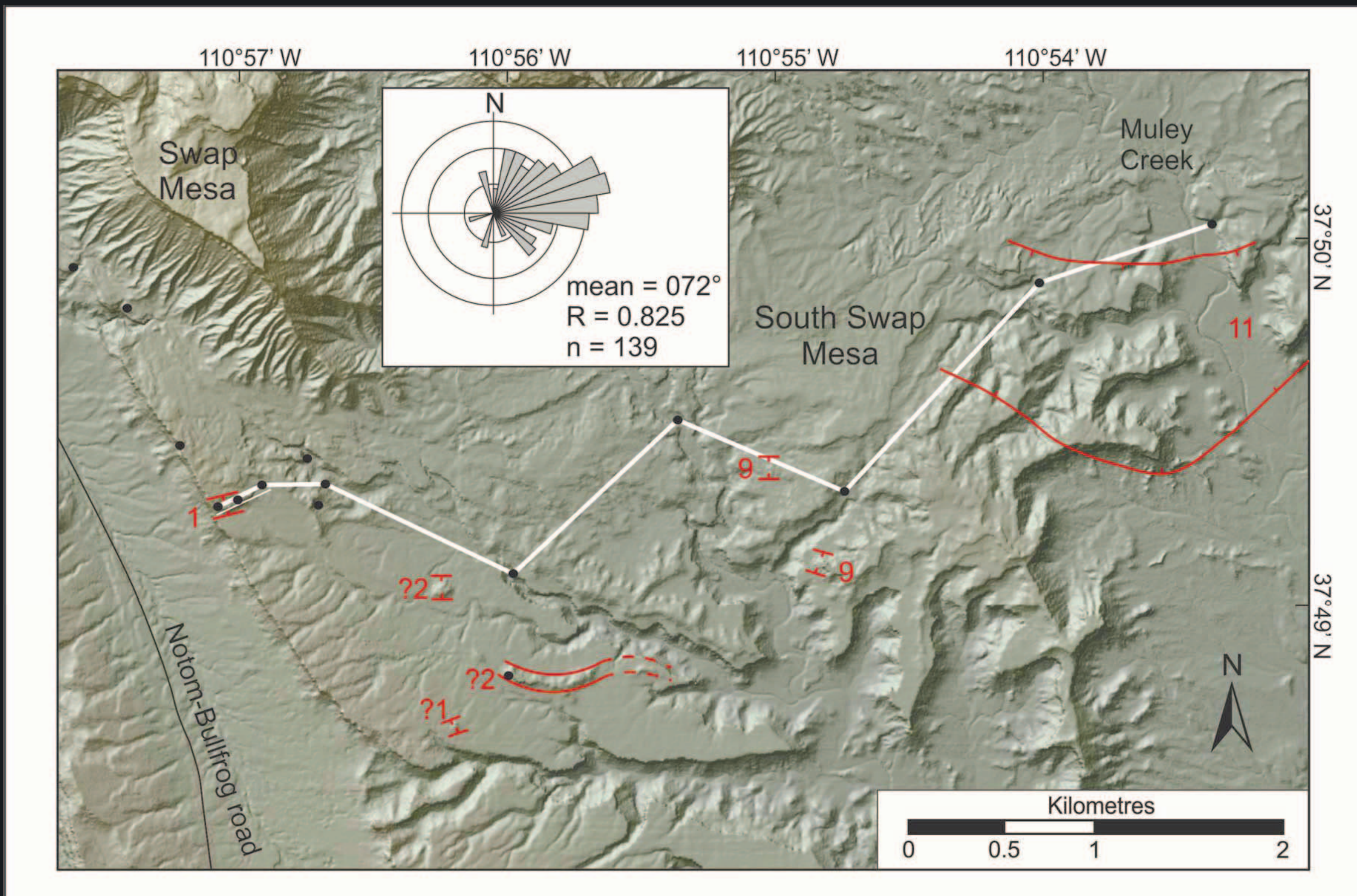


WESTERN END OF DIP TRANSECT

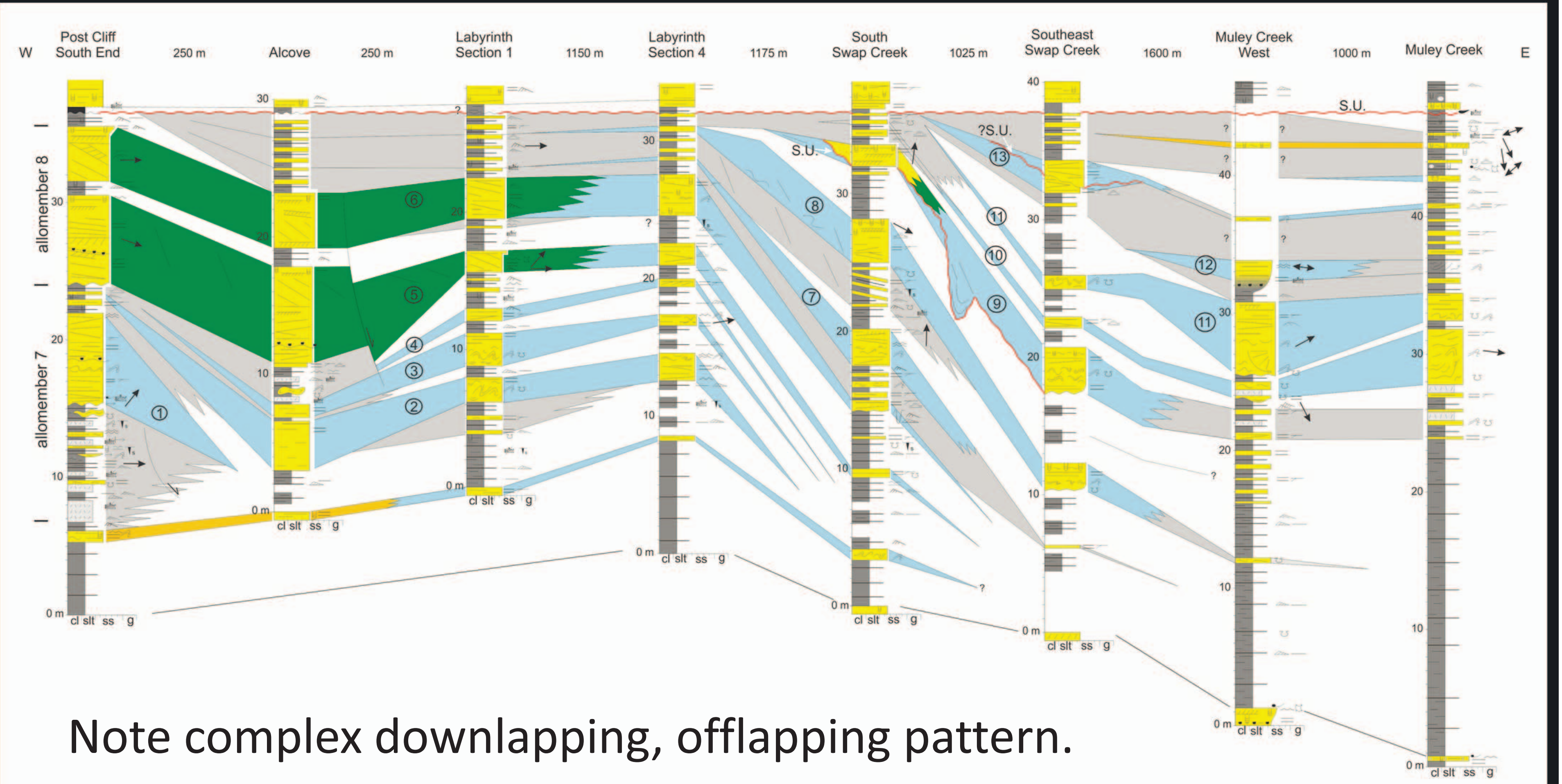


NOTE TRACK OF LONGER DIP-ORIENTED CROSS-SECTION, SHOWN IN FOLLOWING SLIDE

NOTE ALSO PRESENCE OF DELTA FRONT GULLY FILLS (RED)



CROSS-SECTION SHOWING STRATAL STACKING PATTERNS AT SOUTH SWAP MESA

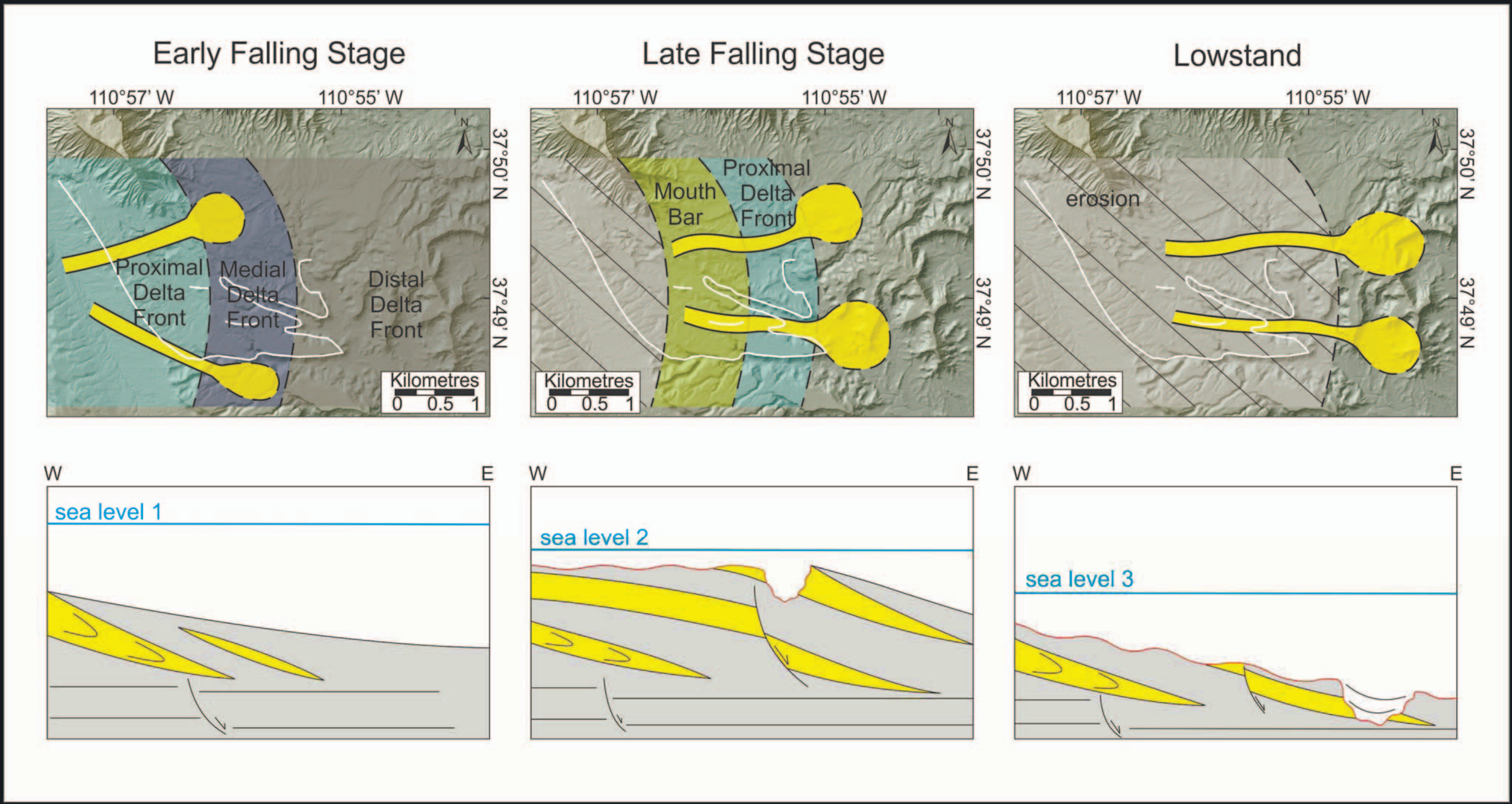


Note complex downlapping, offlapping pattern.

COMPLEX STACKING PATTERN, MULTIPLE EROSION SURFACES SUGGEST PRESERVATION OF SEVERAL SEQUENCES WITHIN THIS INTERVAL.

(Diagram from Fielding, in press, Sedimentology)

DEPOSITIONAL AND STRATIGRAPHIC MODELS TO EXPLAIN THE DEVELOPMENT OF A SEQUENCE AT SOUTH SWAP MESA

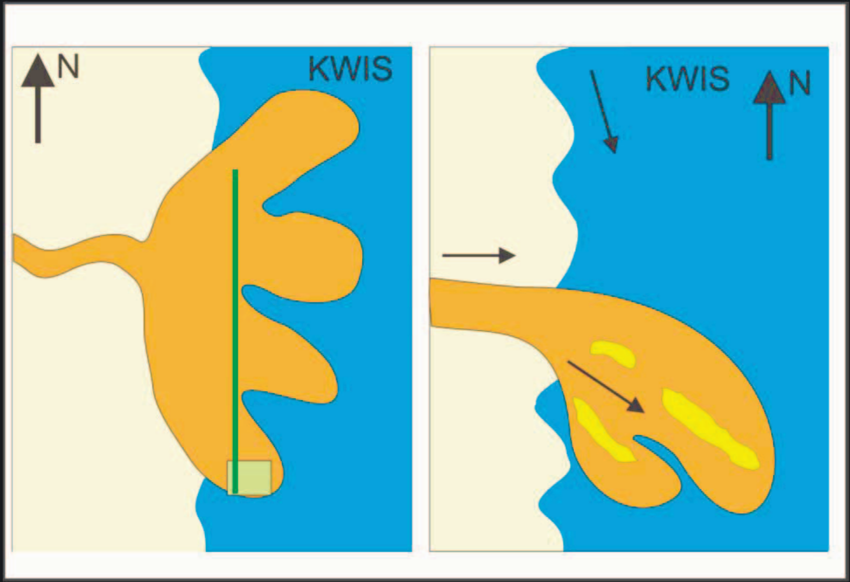


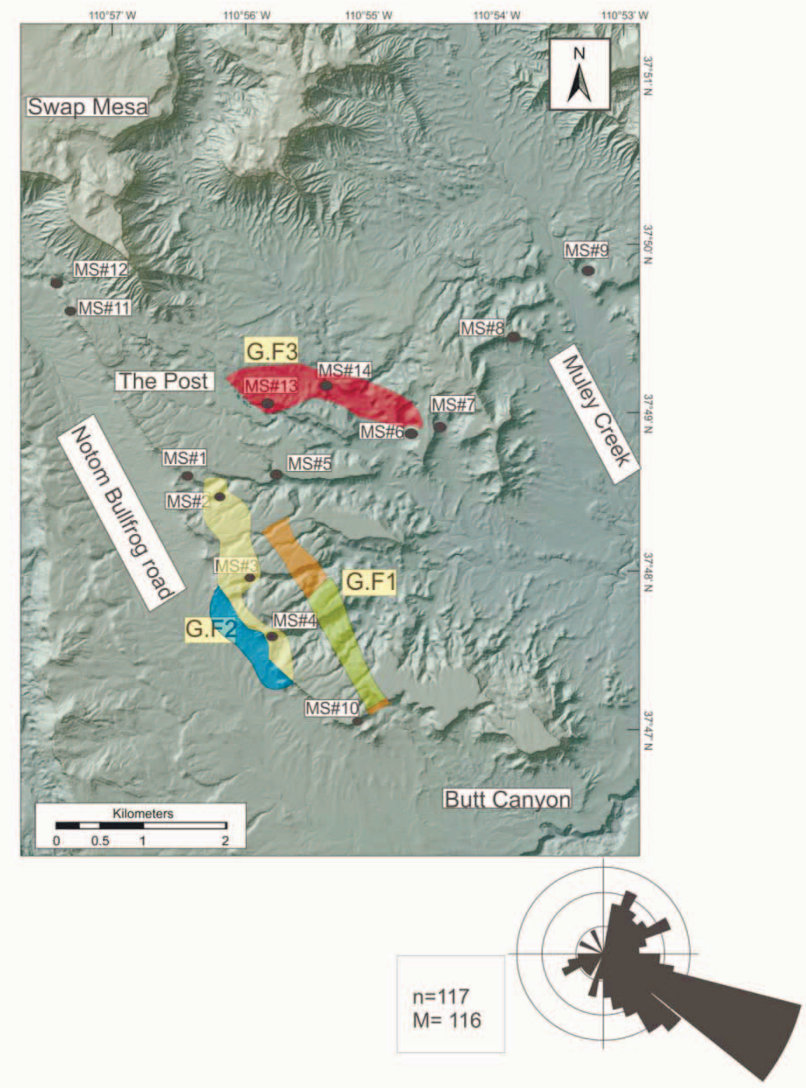
(Diagram from Fielding, in press, Sedimentology)

DATA FROM LOWER IN THE FERRON SST, MORE DISTAL DELTA FRONT FACIES, IMMEDIATELY TO THE SOUTH:

INCISED GULLY FILLS ARE ORIENTED TOWARDS SOUTHEAST, I.E. DEFLECTION TO THE RIGHT.

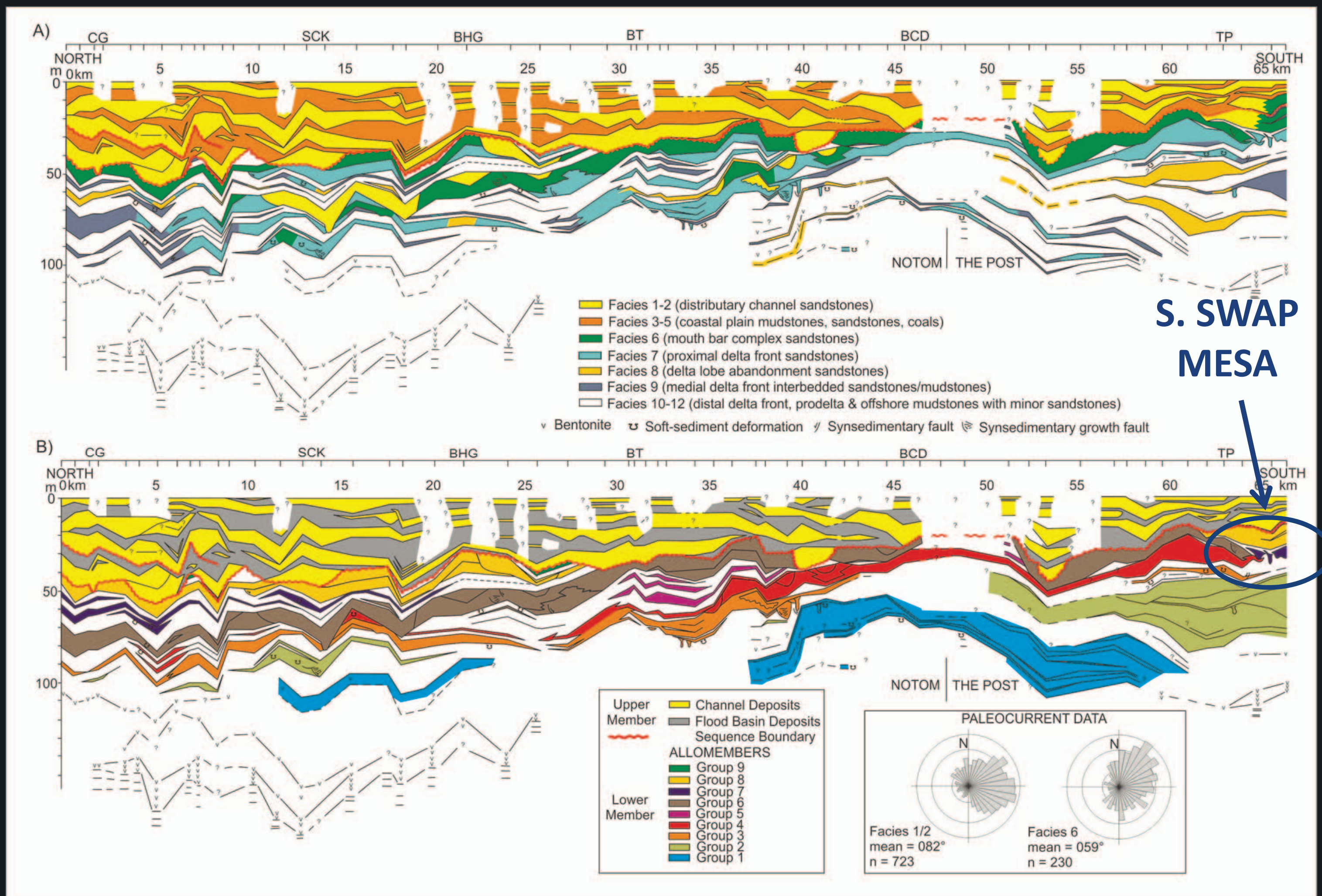
BELOW IS FARES' MODIFIED DEPOSITIONAL MODEL.





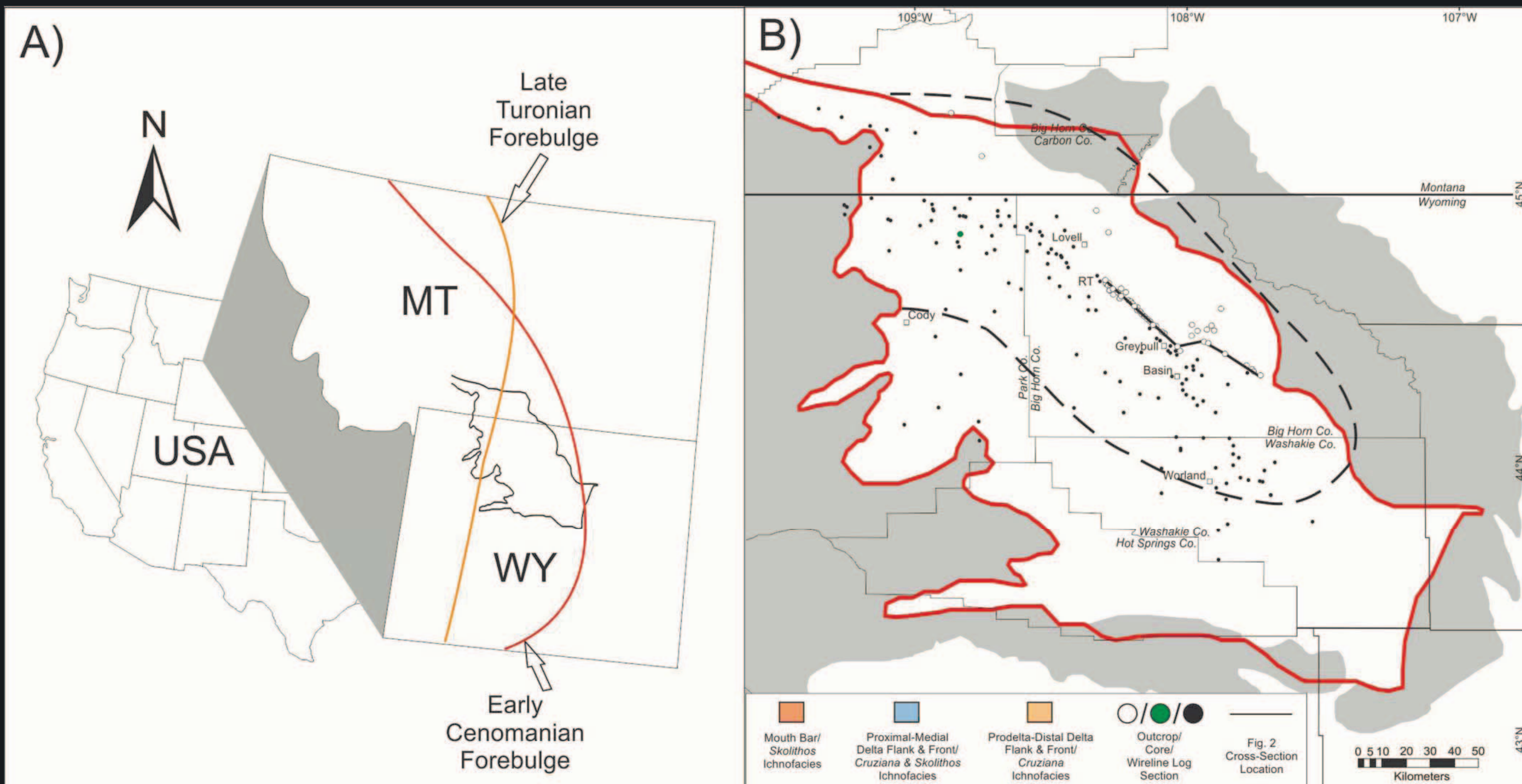
Diagrams from F. Al-Aboud MS thesis, UNL, 2014

EXTENSIVE DEFORMATION AND REPEATED FALLING-STAGE-DOMINATED SEQUENCES MAY BE DUE TO SUBSURFACE STRUCTURAL GROWTH



(Diagram modified from Fielding, 2011, Geology, 39, 1107-1110)

CASE STUDY 2: BIGHORN BASIN OF WYOMING AND MONTANA

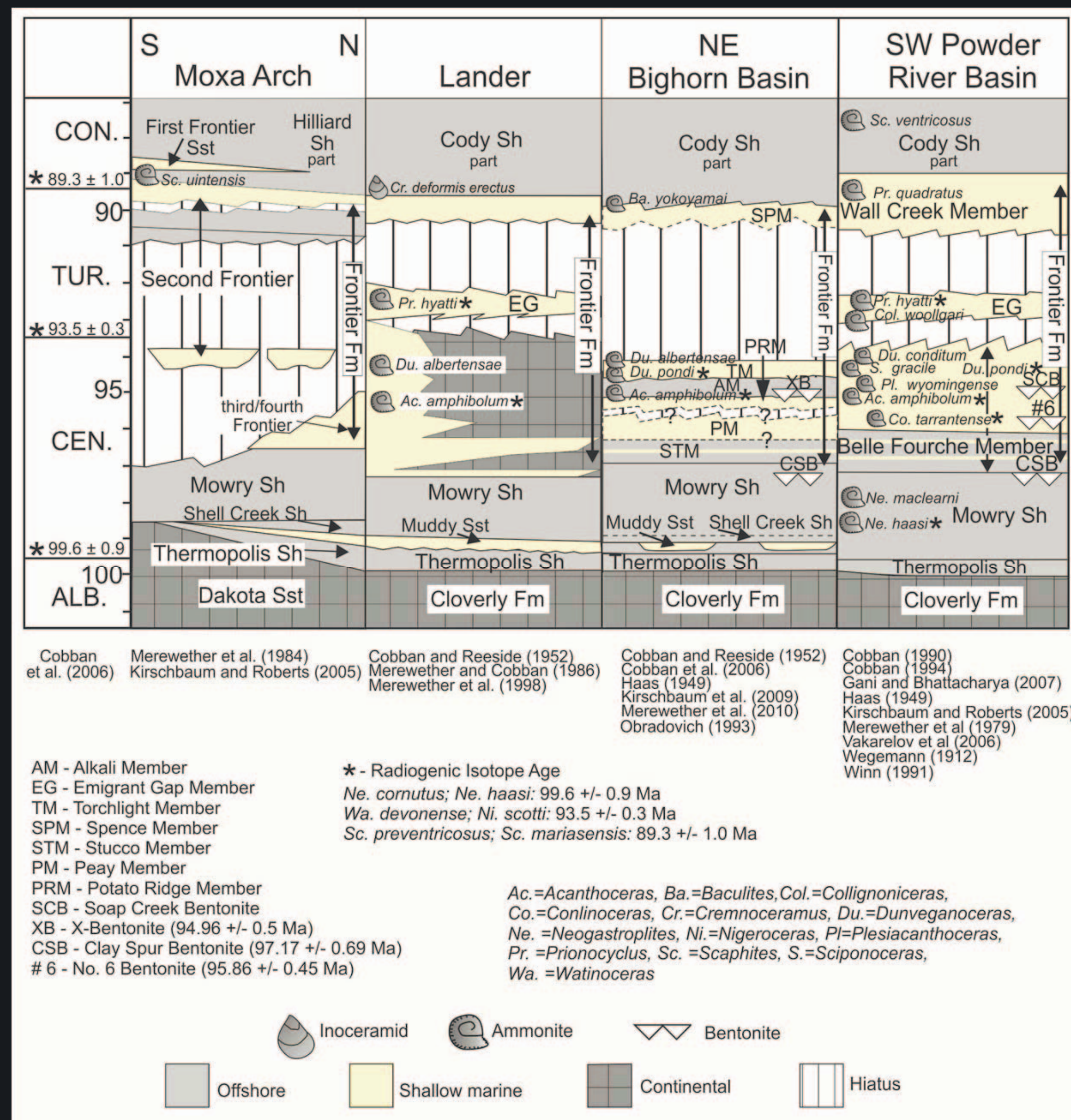


(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

STRATIGRAPHY OF THE FRONTIER FORMATION IN WYOMING

FRONTIER FM THOUGHT TO HAVE FORMED AS ONE OF A SERIES OF DELTAIC SYSTEMS THAT DISCHARGED EASTWARD INTO THE K.W.I.S. FROM THE WESTERN (OROGENIC) MARGIN.

WILL FOCUS HERE ON THE PEAY SANDSTONE MEMBER ("PM")

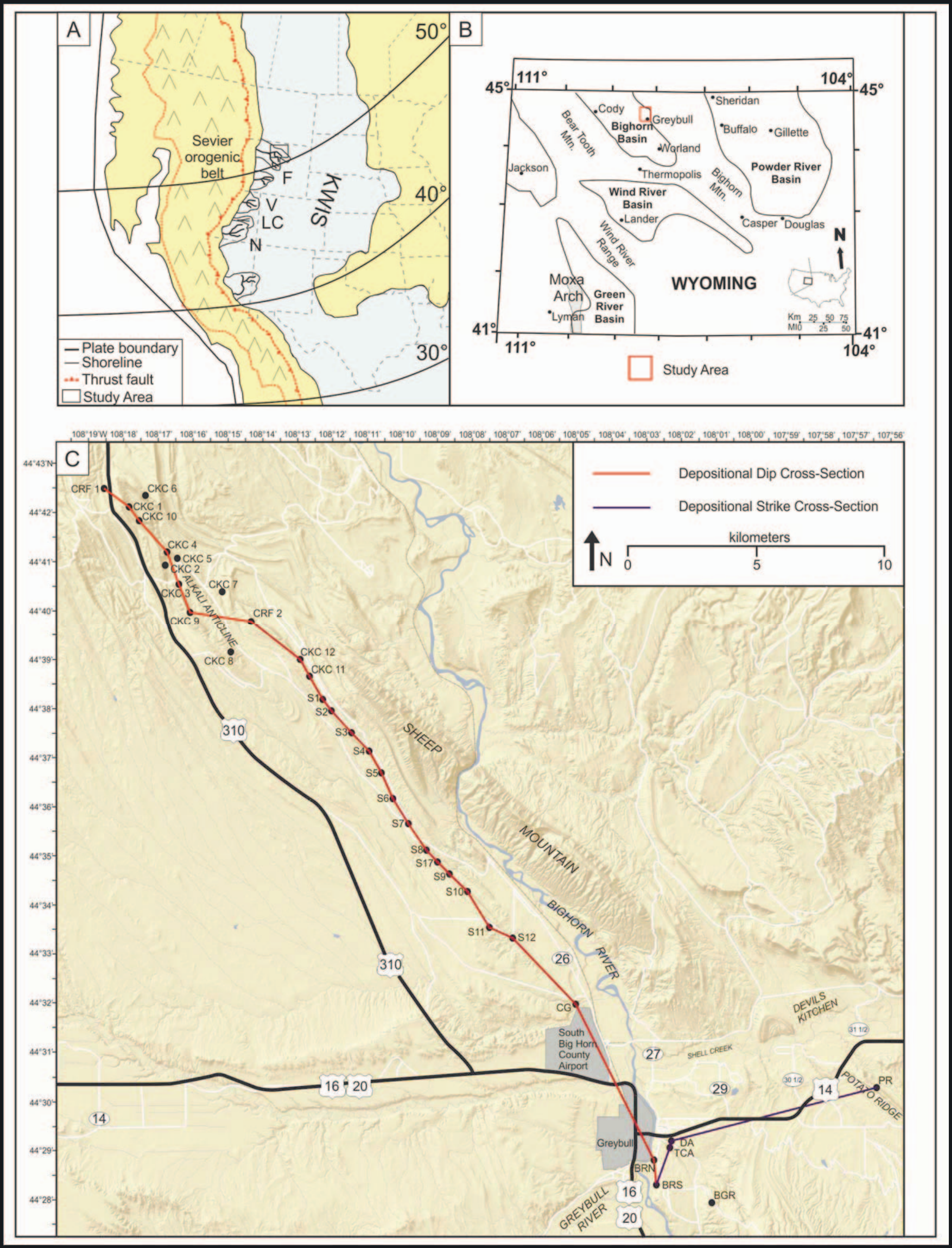


(Diagram from Hutsky et al., 2012, Mountain Geologist, 49, 77-98)

STUDY AREA INCLUDES A NW-SE TRENDING OUTCROP BELT ALONG THE FLANK OF SHEEP MTN. ANTICLINE.

VERTICAL SECTIONS MEASURED AT INTERVALS, CORRELATED PHYSICALLY TO ESTABLISH CONTINUITY OF BEDS.

(Diagrams from Hutsky et al., 2012, Mountain Geologist, 49, 77-98)

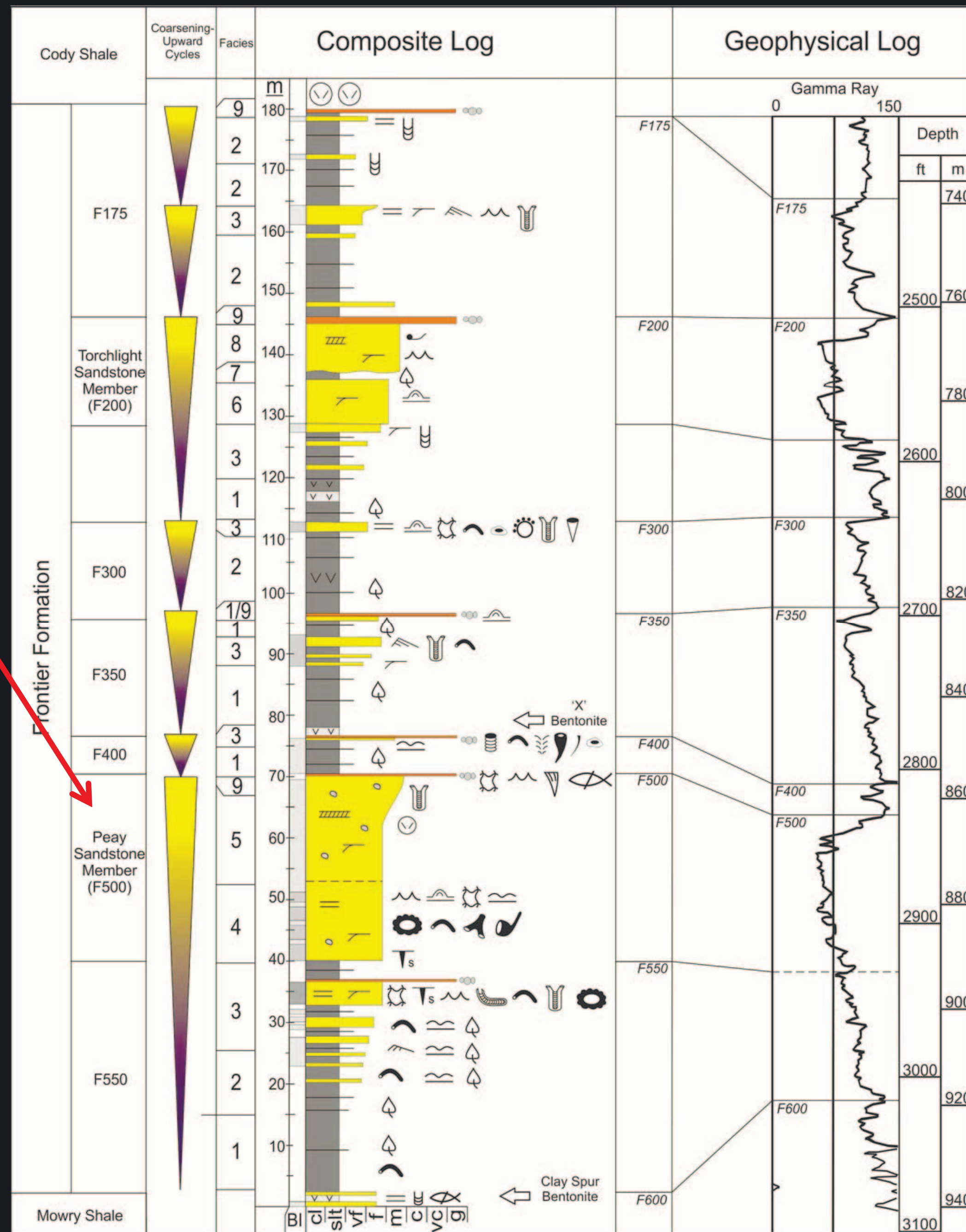


DEPOSITIONAL ENVIRONMENTS

COMPOSITE GRAPHIC LOG OF THE FRONTIER FORMATION IN THE STUDY AREA.

NOTE THE PEAY SANDSTONE MEMBER– COARSENING-UPWARD SUCCESSION,

INTERPRETED TO RECORD PROGRADATION OF A DELTA INTO THE BASIN.



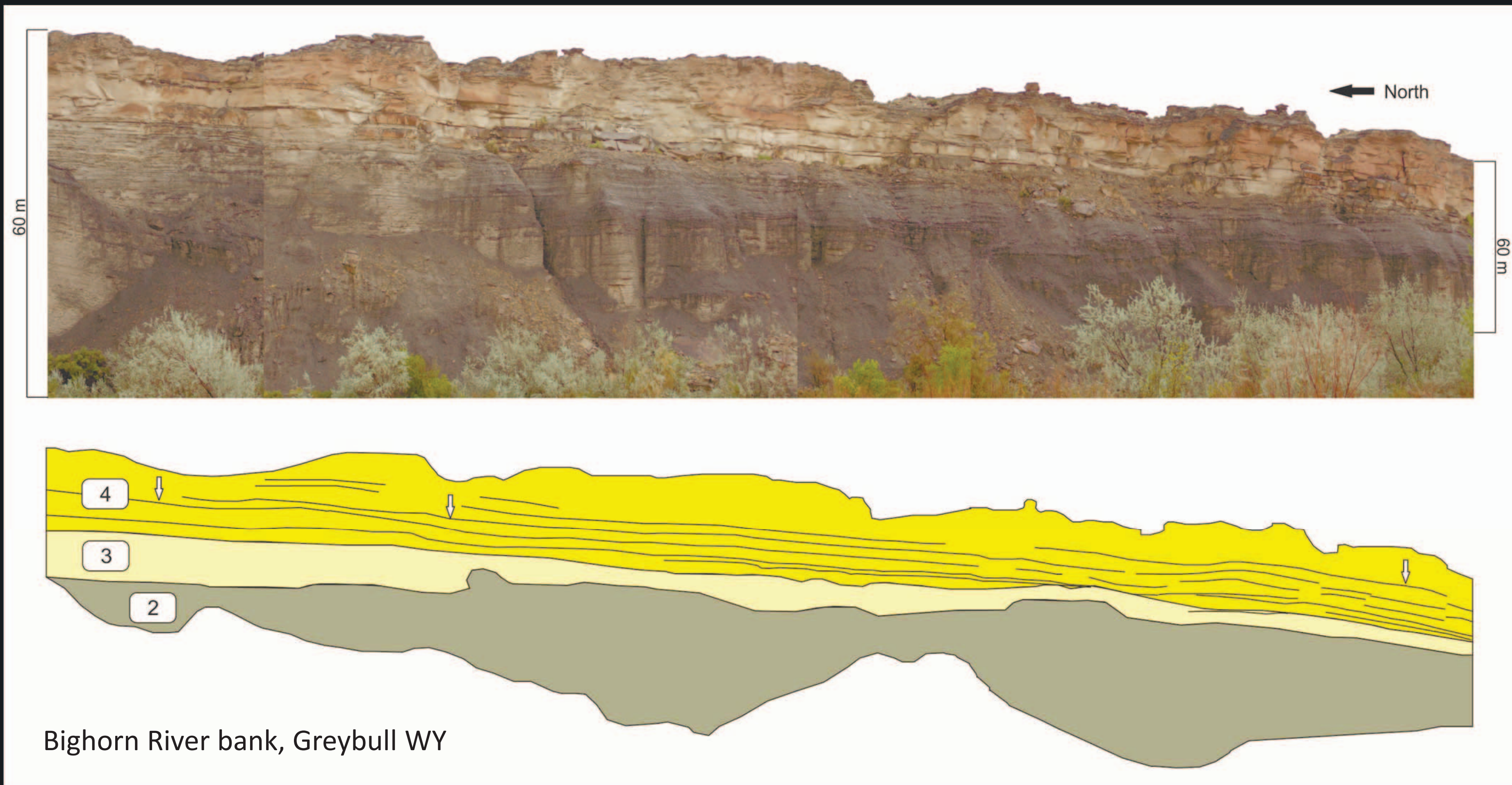
(Diagram modified after Hutsky et al., 2012, Mountain Geologist, 49, 77-98)

EXPOSURE OF PEAY SANDSTONE MEMBER IN BANK OF BIGHORN RIVER AT GREYBULL, WY ILLUSTRATES THE FULL PROGRADATIONAL CYCLE

Diagram from Hurd et al., 2014, J. Sed. Res., 84, 1-18

BEDDING STRUCTURE INDICATES IMPORTANCE OF FLUVIAL OUTFLOW, MODEST TIDAL INFLUENCE, VARIABLE WAVE INFLUENCE. DELTAIC CONTEXT SUPPORTED BY SPORADIC AND RESTRICTED NATURE OF TRACE ASSEMBLAGE, ABUNDANCE OF PLANT DEBRIS.

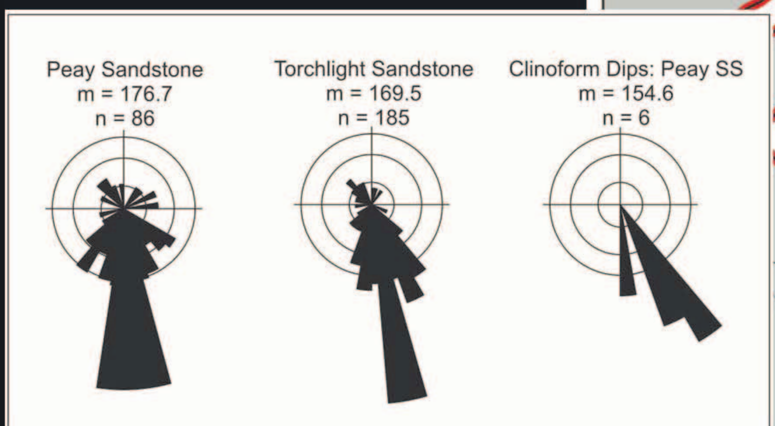
LATERALLY EXTENSIVE EXPOSURES REVEAL LOW-ANGLE CLINOFORM SETS IN MEDIAL-PROXIMAL DELTA FRONT FACIES

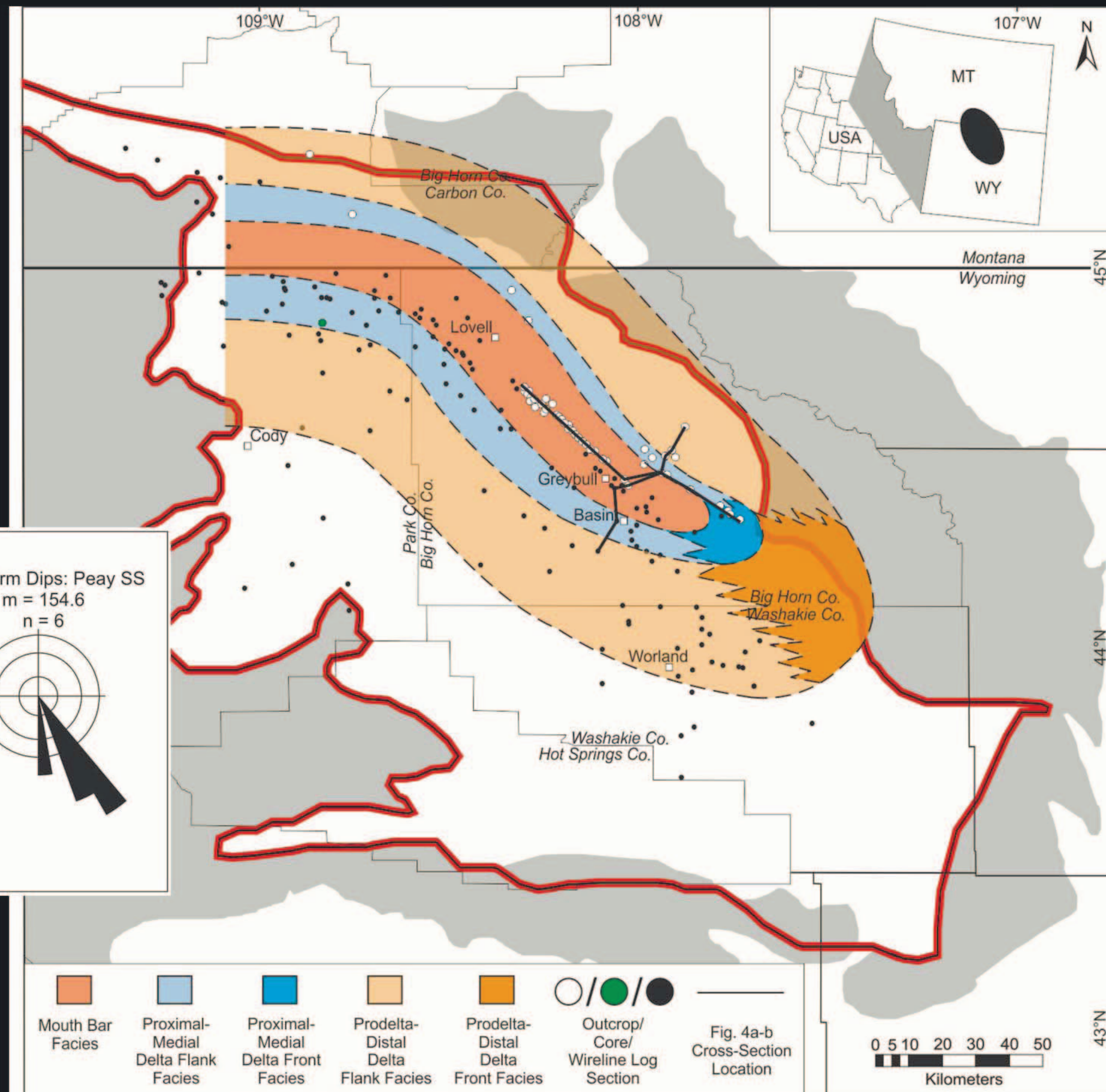


(Diagram from Hutsky et al., 2012, Mountain Geologist, 49, 77-98)

THIS MAP SHOWS THE INTERPRETED EXTENT OF VARIOUS DELTAIC FACIES IN THE STUDY AREA, IN PART DEFINED BY THE LIMITS OF THE BODY.

NOTE LACK OF COASTAL PLAIN FACIES.

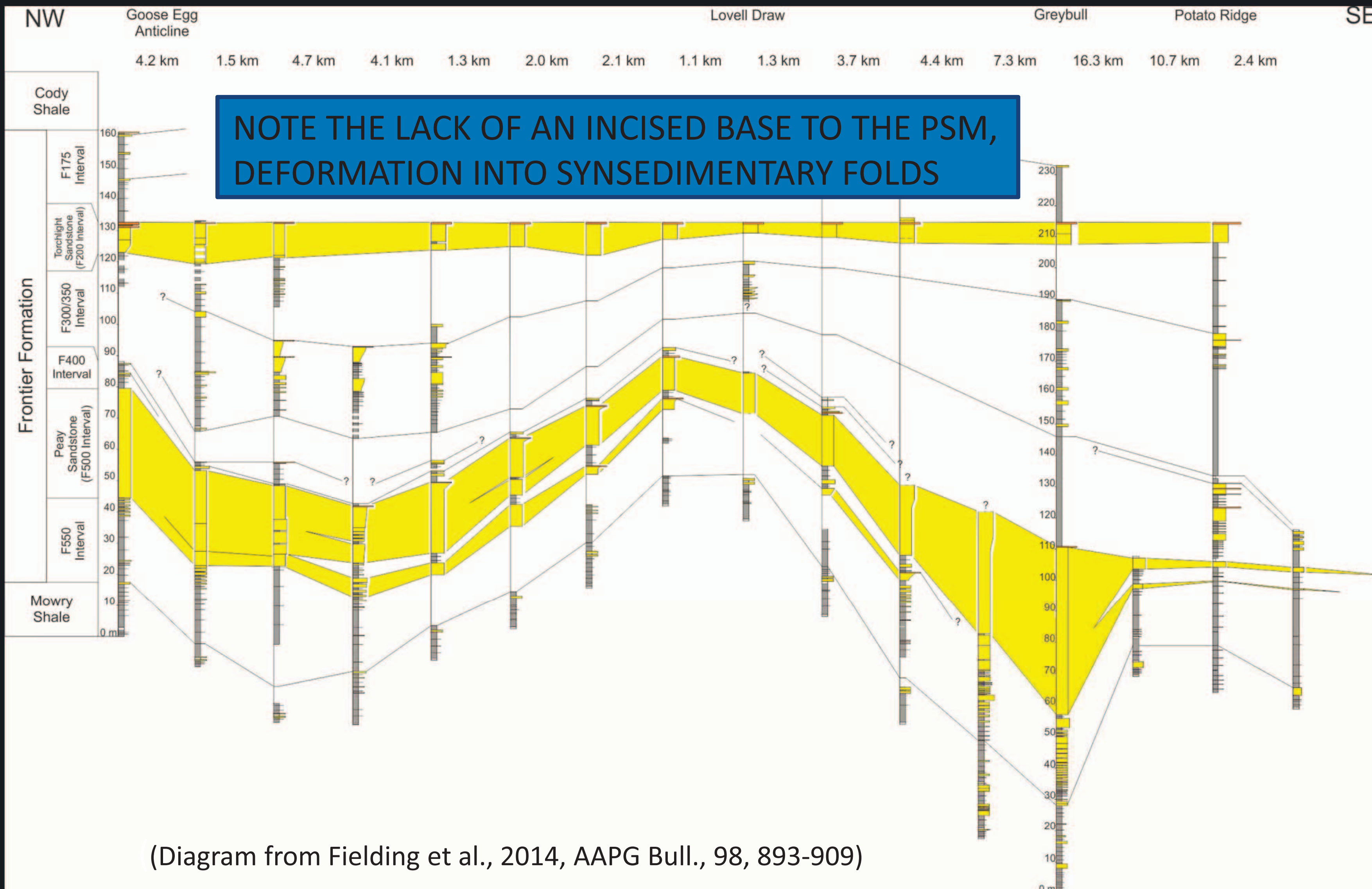




PALEOCURRENT DATA INDICATE SOUTHWARD SEDIMENT DISPERSAL.

(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

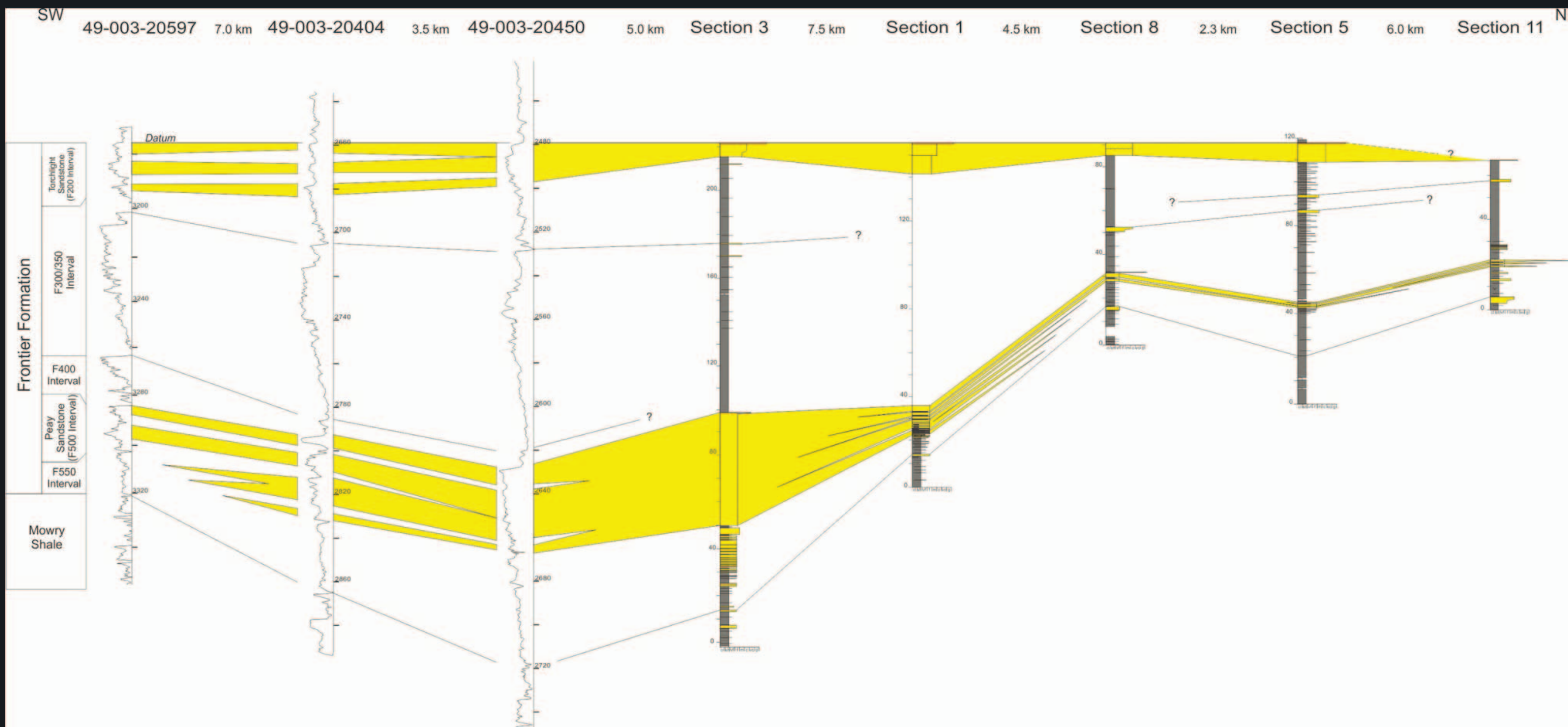
A DEPOSITIONAL DIP-ORIENTED CROSS-SECTION SHOWS THICKNESS CHANGES IN THE PEAY SANDSTONE MEMBER, AND ITS ABRUPT SOUTHWARD PINCHOUT SOUTH OF GREYBULL, WY.



(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

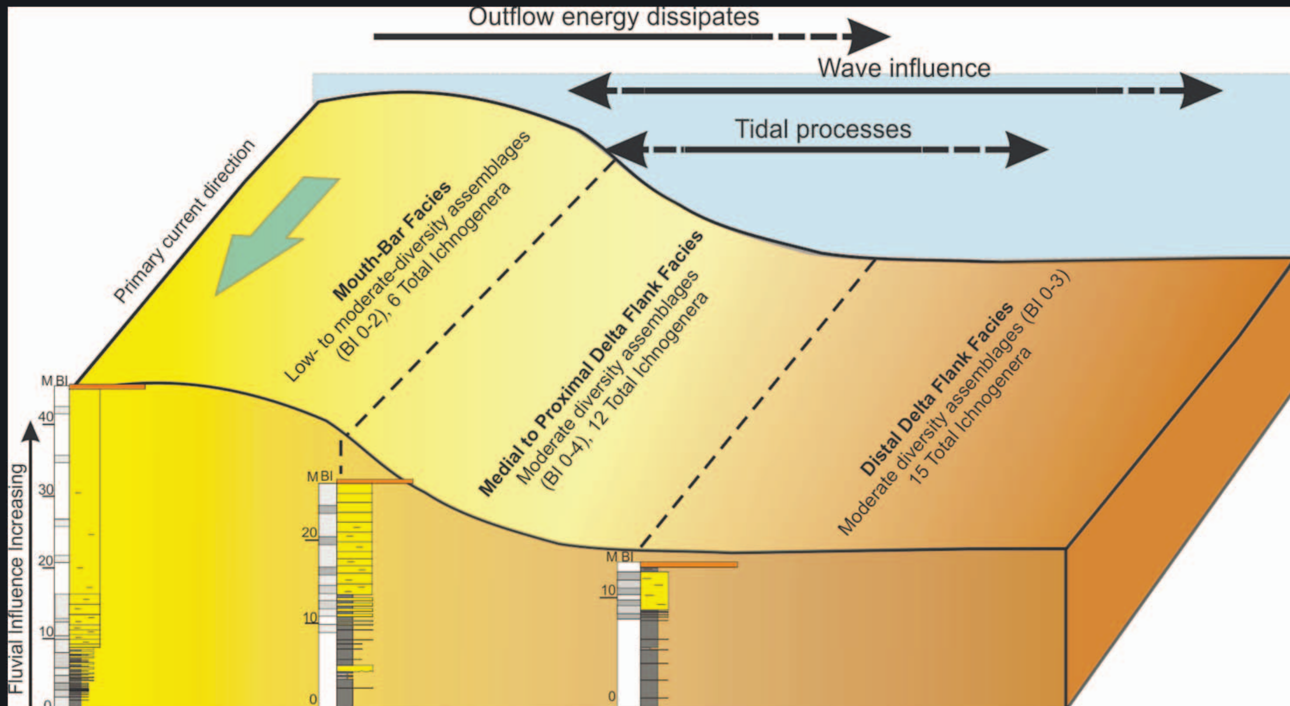
A DEPOSITIONAL STRIKE-ORIENTED CROSS-SECTION SHOWS THE CHARACTER OF LATERAL PINCHOUTS TO THE PEAY SST MBR.

NOTE THE LACK OF AN INCISED BASE TO THE PEAY, AND THE MAXIMUM IN THICKNESS OF UNDERLYING STRATA BENEATH THE AXIS OF THE DELTA BODY.



(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

DEPOSITIONAL MODEL FOR THE NORTHEASTERN PEAY DELTA FLANK

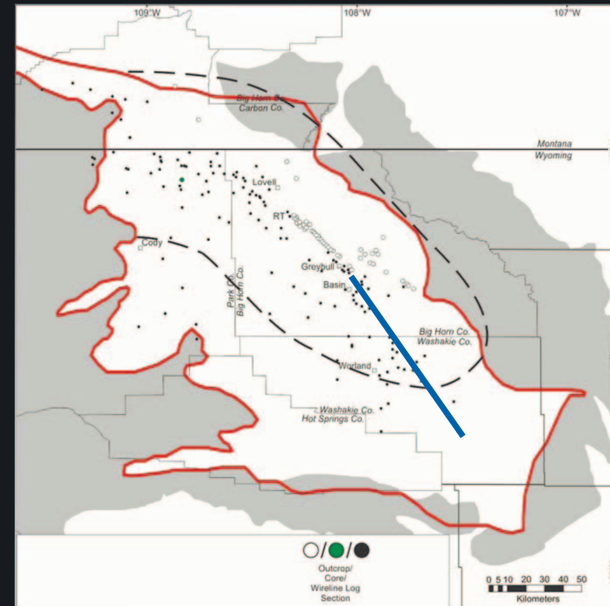


1	*Skolithos*, reduced diversity	Proximal *Cruziana* with reduced diversity, elements of *Skolithos*	Archetypal *Cruziana*
2	Mouth Bar	Medial to Proximal Delta Flank	Distal Delta Flank
3	Fluvial influence	Mixed tidal, storm, & wave influence	Wave & storm influence

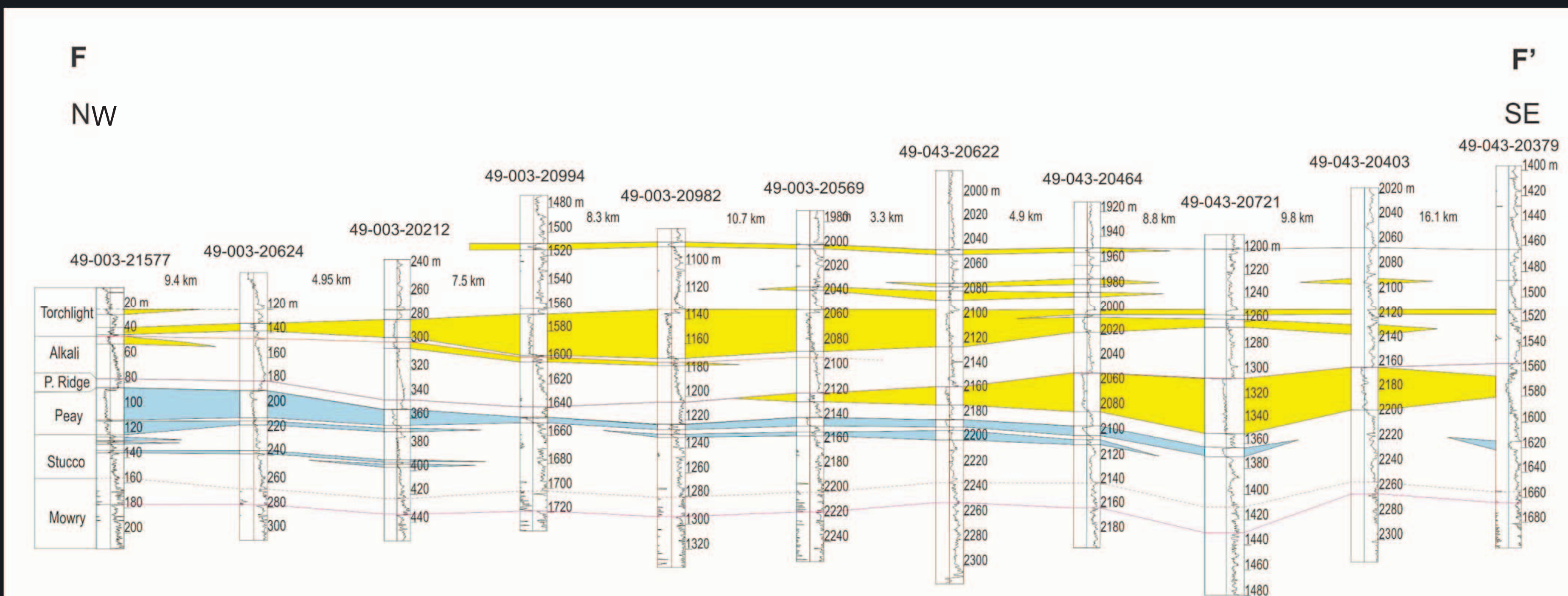
1. Ichnofacies
2. Interpreted Depositional environment
3. Dominant Depositional Process

(Diagram from Hurd et al., 2014, J. Sed. Res., 84, 1-18)

SUBSURFACE CORRELATION OF SANDSTONE BODIES ILLUSTRATES LENSOID GEOMETRIES, COMPENSATIONAL STACKING PATTERN.

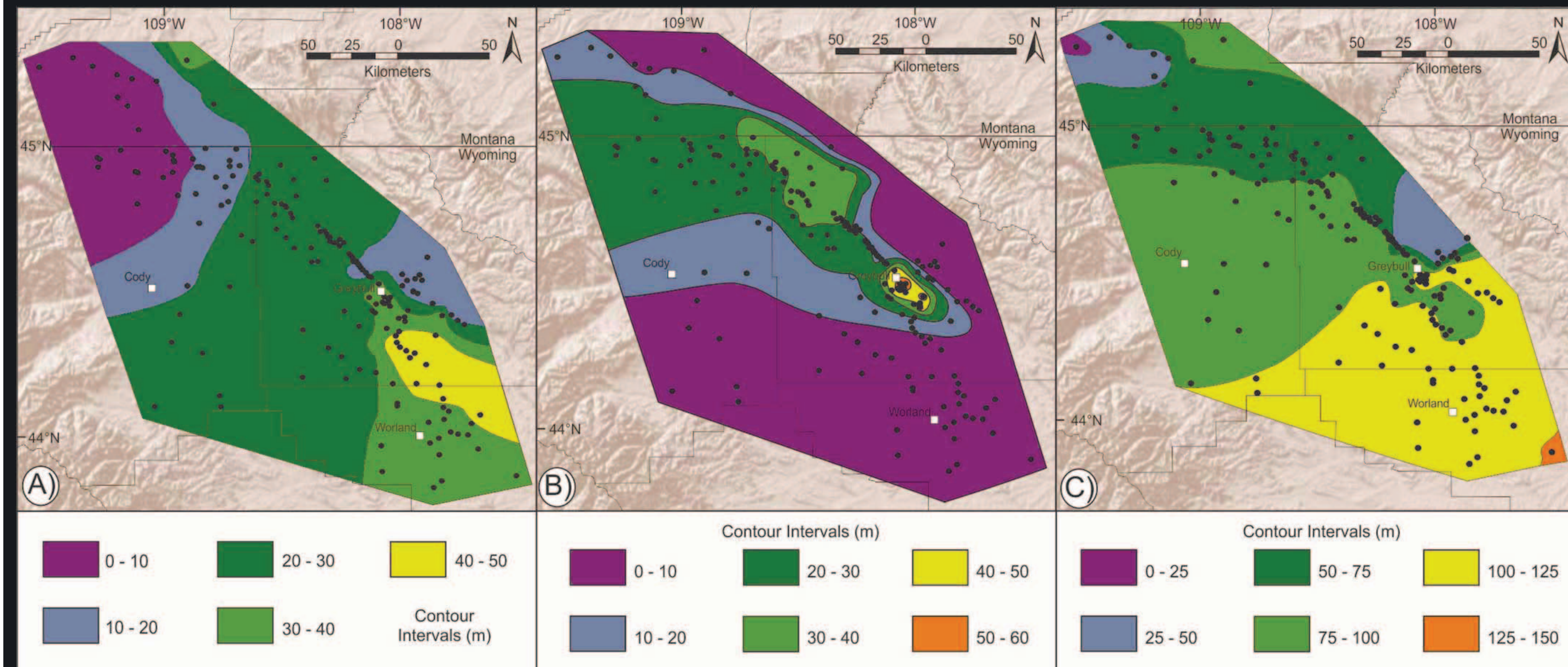


NW-SE CROSS-SECTION FROM GREYBULL TOWARDS THERMOPOLIS, WY



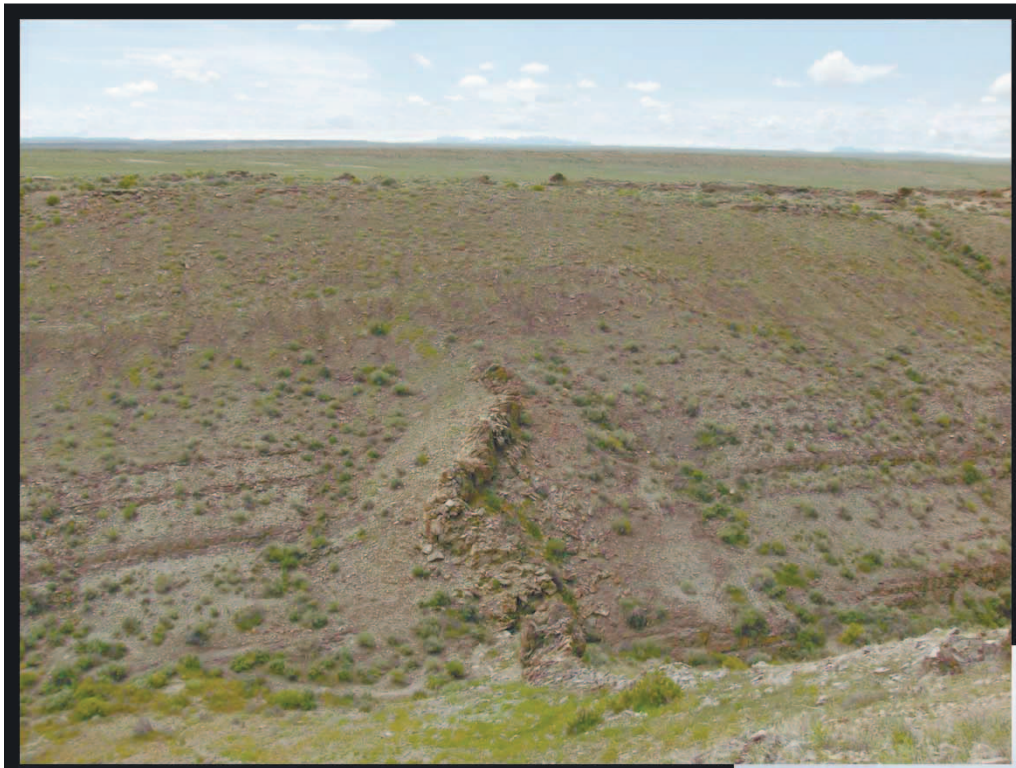
(Diagram from T. Hurd MS thesis, UNL 2012)

ISOPACH MAPS FOR
A) TOP MOWRY TO BASE PEAY MBR,
B) PEAY MBR,
C) TOP PEAY TO TOP TORCHLIGHT MBR



NOTE THE LOCATION OF ZONES OF MINIMAL ACCUMULATION

(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)



BELOW THE CORE OF THE GROWTH ANTICLINE, A SIGNIFICANT NUMBER OF SANDSTONE DYKES ARE PRESERVED, PENETRATING UNDERLYING MUDROCK UNITS.

Sandstone in the dykes is indistinguishable from that of the Peay Mbr., margins display shear fabrics and other evidence of forceful intrusion.

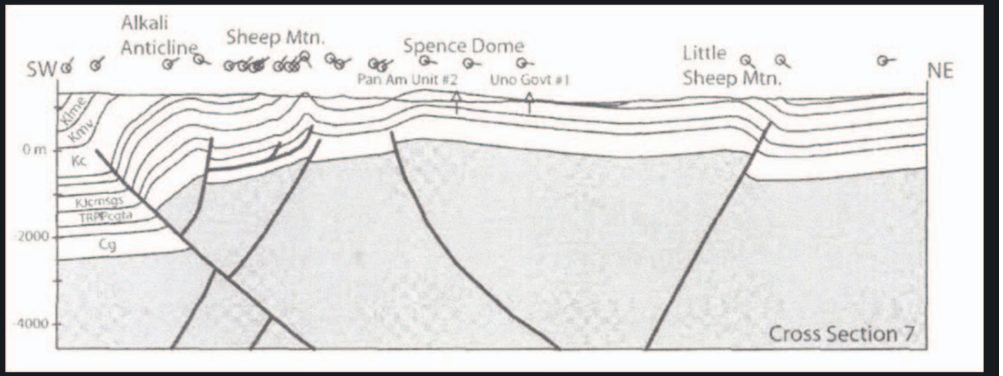
Many dykes trend 030-040°, and are somewhat sinuous.

THIS MAP SHOWS THE LOCATIONS AND ORIENTATIONS OF KNOWN SANDSTONE DYKES.

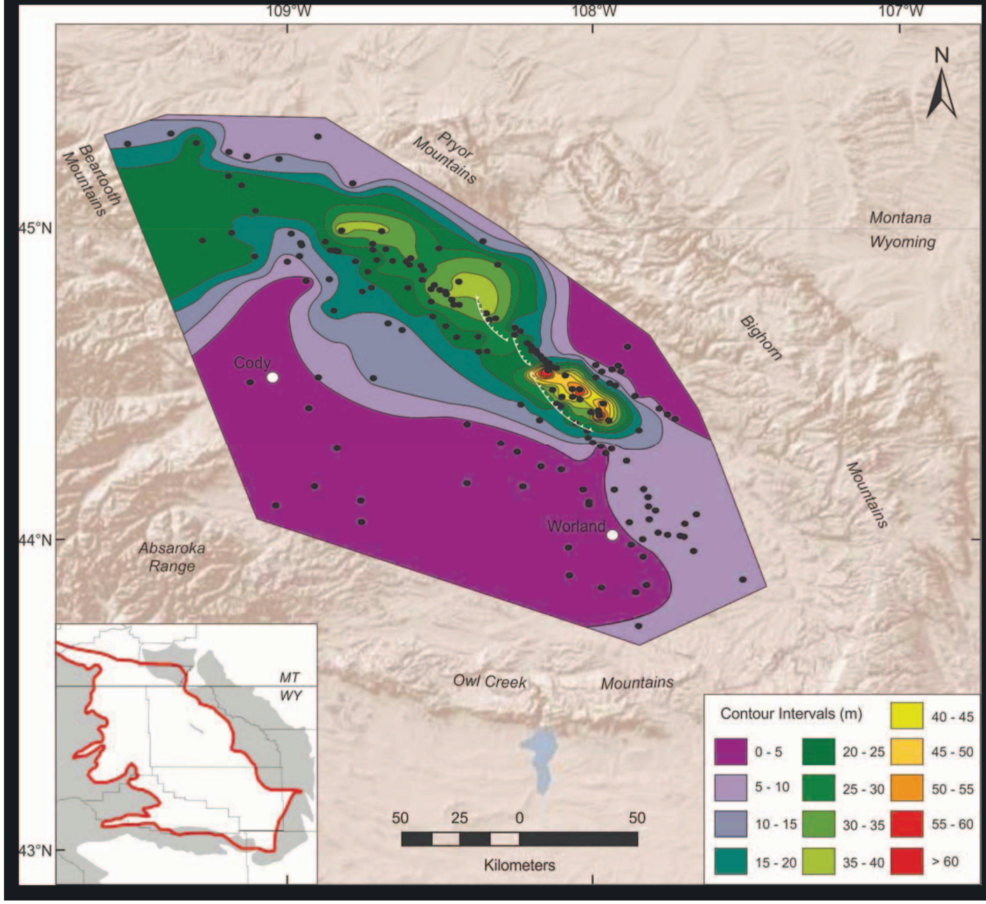
THE GREATEST CONCENTRATION OF DYKES COINCIDES WITH THE LOCATION OF THE SYNSEDIMENTARY ANTICLINE SHOWN IN THE DEPOSITIONAL DIP CROSS-SECTION.

(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

STRONG COINCIDENCES ARE EVIDENT AMONG THE TREND AND PLANFORM GEOMETRY OF PEAY SANDSTONE MEMBER BODY, SURFACE TRACE OF RIO THRUST, AND SANDSTONE DYKES (PERPENDICULAR
TO MAIN S.E. TREND).

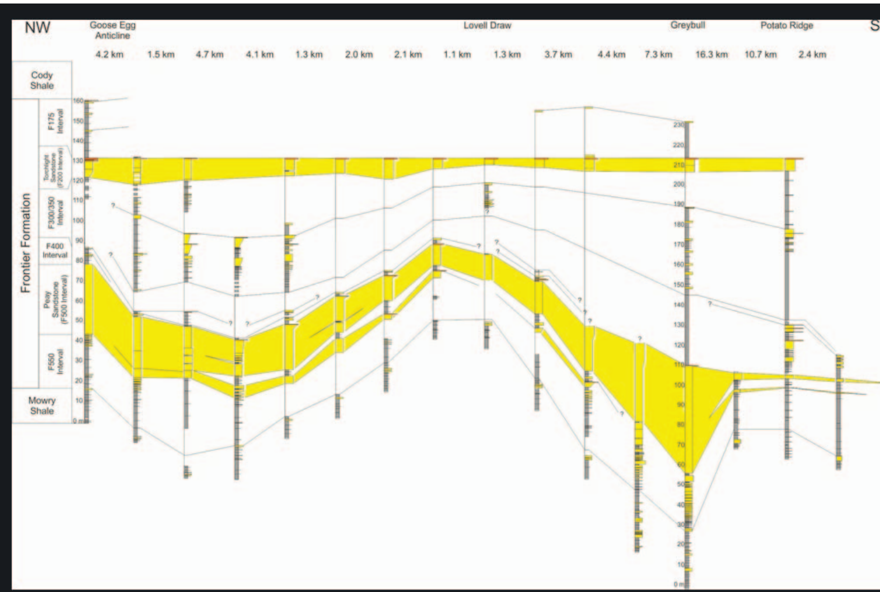


(Diagram from Stanton & Erslev, 2002, WGA Field Conference Guidebook)



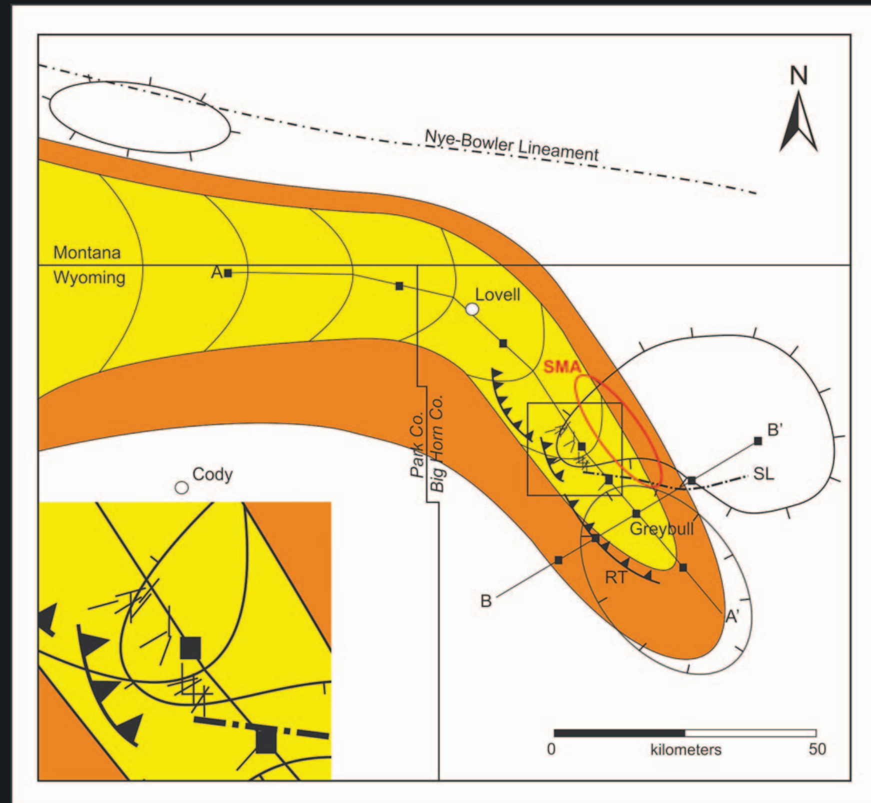
A CAUSAL RELATIONSHIP CAN BE INFERRED.

THE ENIGMATIC CHARACTERISTICS OF THE P.S.M. ARE EXPLAINED IN THIS DEPOSITIONAL MODEL.



ACCUMULATION OF THE P.S.M. WAS FORCED BY BOTH SPATIALLY AND TEMPORALLY VARIABLE, LIMITED ACCOMMODATION, DRIVEN BY STRUCTURAL GROWTH.

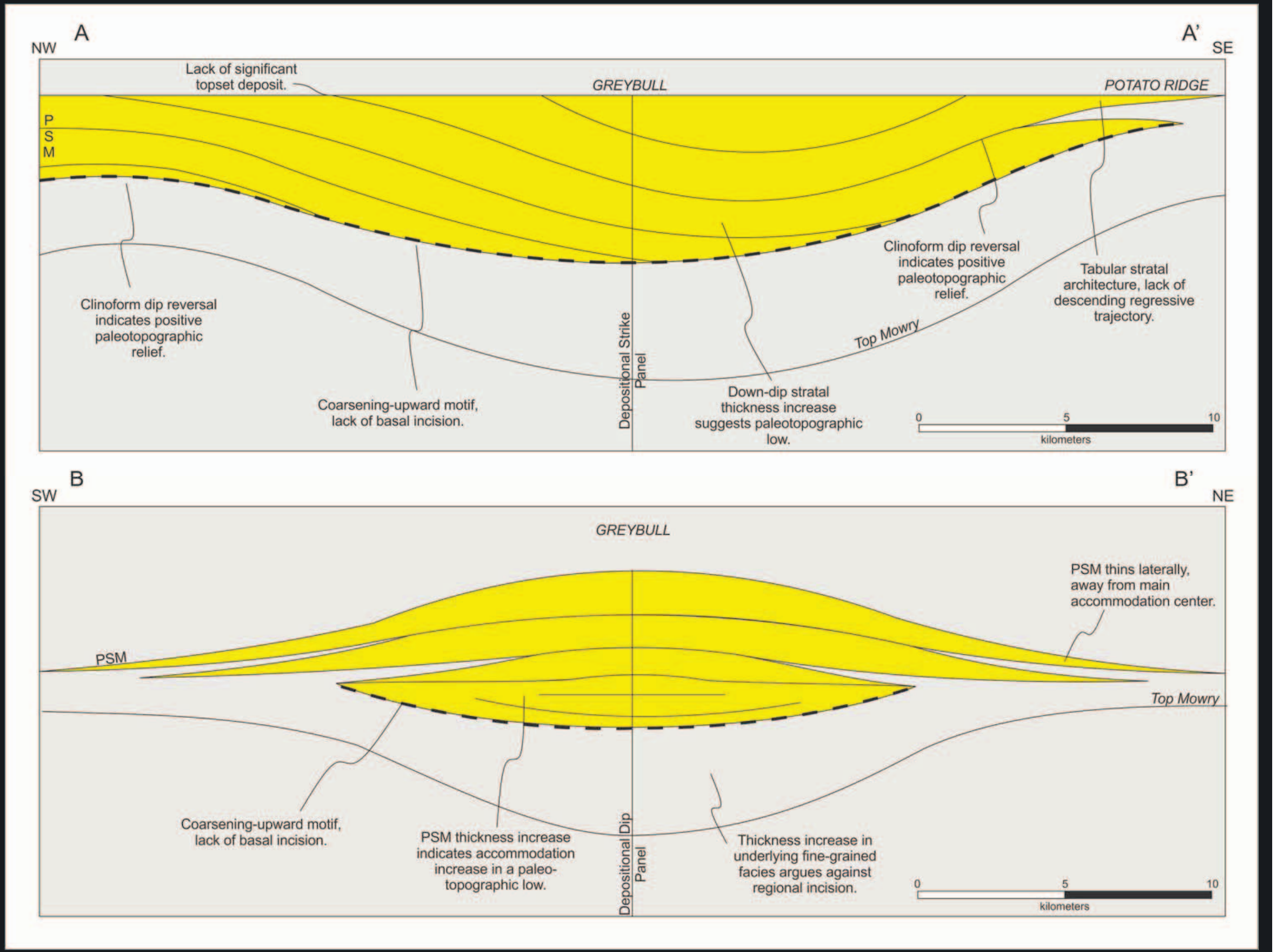
THE SEDIMENT DISPERSAL SYSTEM EXPLOITED ZONES OF GREATER ACCOMMODATION, BYPASSING ZONES OF MINIMAL ACCOMMODATION.



(Diagrams from Fielding et al., 2014, AAPG Bull., 98, 893-909)

THE P.S.M. RESEMBLES LOWSTAND AND FALLING STAGE DELTAIC SYSTEMS, IN THAT IT EXTENDS A LONG DISTANCE INTO THE BASIN, LACKS A COASTAL PLAIN TOPSET, BUT

IT ALSO LACKS AN INCISED BASE, DOES NOT SHOW A DESCENDING REGRESSIVE TRAJECTORY, AND PRESERVES A MAXIMUM THICKNESS OF UNDERLYING STRATA BELOW THE DELTA AXIS.



(Diagram from Fielding et al., 2014, AAPG Bull., 98, 893-909)

SYNTHESIS

MANY SANDSTONE BODIES IN THE K.W.I.S. SHOW NORTH-SOUTH ELONGATION AND/OR EVIDENCE OF SOUTHWARD DISPERSAL.

MANY ARE APPARENTLY ENCASED IN MARINE MUDROCKS –

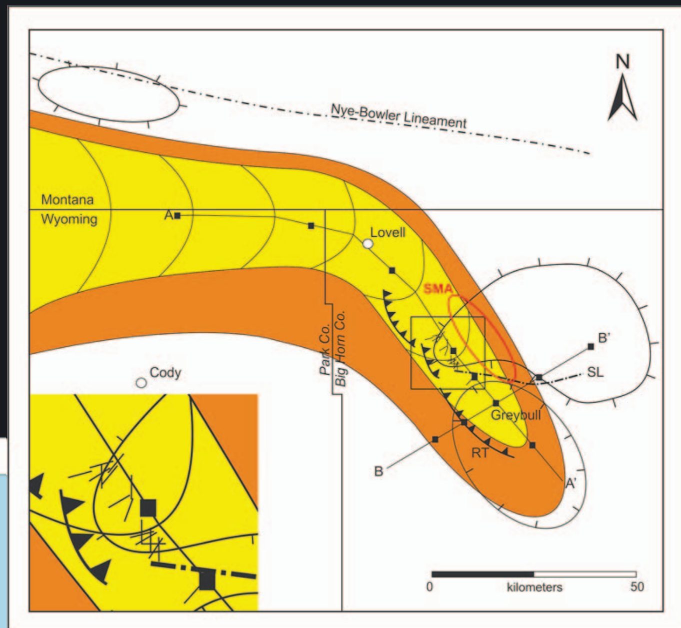
“ISOLATED SANDSTONE BODIES”

Unit	Age	Depositional Environments and Paleocurrent Data
1. Tocito Ss.; northwestern New Mexico (Van Wagoner, et al., 1991)	Coniacian	Transgressive shelf sand ridge or incised estuarine valley: offshore unimodal large-scale cross-strata dip to SE; large wave-ripple crests trend NW-SE; shore parallel sediment transport to the SE on a transgressive restricted shelf or SE transport in a shore-parallel estuary
2. Kenilworth Mbr., Blackhawk Fm.; Book Cliffs, Utah (Taylor and Lovell, 1995)	Campanian	Upper shoreface: “Trough cross-bed orientations...in the upper shoreface deposits...have a dominant southerly component and suggest that there were strong shore-parallel currents.”
3. Shannon Ss., east-central Wyoming (Tillman and Martinsen, 1984)	Campanian	Shelf ridge complex: “Transport directions determined from high-angle cross-beds indicate a southwest transport direction.”
4. Dunvegan Fm.; northwestern Alberta (Bhattacharya and Walker, 1991)	Cenomanian	Barrier bar: “A major distributary channel probably fed this barrier bar at its northeastern end and sand was transported to the southwest by longshore drift.”
5. Burnstick Mbr., Cardium Fm.; Alberta (Pattison and Walker, 1992)	Turonian	Incised shoreface: “We interpret the alongstrike trends as the result of ... southwestward sediment transport in the shoreface.”
6. Virgelle Mbr, Eagle Fm.; Bighorn Basin, Wyoming (Fitzsimmons, 1995)	Campanian	Incised estuarine valley: bipolar N-S dipping trough cross-strata fill a N-S trending, shore parallel, incised valley
7. Baytree Mbr., Cardium Fm.; northwestern Alberta (Hart and Plint, 1989)	Turonian	Shoreface: “The dominant southeast (i.e. shore-parallel) cross-bedding, in both sandstones and conglomerates indicates a strong longshore component to sediment transport.”
8. Rusty Mbr., Ericson Ss.; SW Wyoming (Martinsen et al., 1997)	Campanian	Valley-fill sandstones: “In contrast to surrounding delta plain sediments, where paleoflow was to the ESE, the paleocurrents within valley-fill sandstones are directed to the SSW.”
9. Duffy Mtn. Ss., Mancos Shale; Northwestern Colorado (Boyles and Scott, 1982)	Campanian	Shore-parallel shelf bars: “ The sediment was probably derived from....southwestern Wyoming.”
10. Eagle Ss.; north-central Montana (Rice, 1980)	Upper Cretaceous	Delta-front: “The sand was probably deposited as river-mouth bars that were redistributed by dominately southward-flowing marine longshore currents...”
11. Gallop Ss.; northwestern New Mexico (Campbell, 1971)	Upper Cretaceous	Elongate, shore-parallel, northwest-southeast trending, offshore bar: Cross-laminae dip to the southeast.
12. Ferron Ss.; Castle Valley, Utah (Cotter, 1975)	Upper Cretaceous	Low energy coast: “Sediment....was derived from the large Vernal Delta, located north and west of the Castle Valley outcrops, and was transported generally southwestward, parallel with the coast.”
13. Hygiene Ss.; northern Colorado (Kitely and Field, 1984)	Late Campanian	Mid-outer shelf sand ridges: “The sand was derived from the west, transported eastward, and then redistributed by southward-flowing storm and oceanic currents.”

(Table from Slingerland & Keen, 1999)

PUBLISHED EXPLANATIONS FOR APPARENTLY ISOLATED, NORTH-SOUTH-ELONGATE SANDSTONE BODIES IN THE WESTERN INTERIOR SEAWAY BASIN INCLUDE

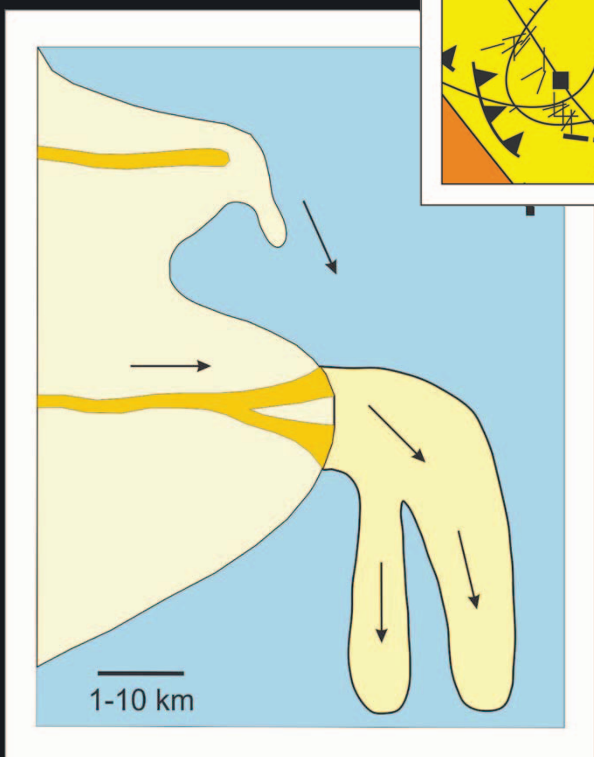
Frontier Fm.,
Bighorn Basin



- Mid-shelf bars,
- Tidal sand ridges,
- Falling-Stage nearshore wedges,
- Spit deposits,
- Longshore drift deposits,
- Incised valley fills,

- AND NOW

- **Deflected digitate deltas**



Ferron Sandstone,
Henry Mountains

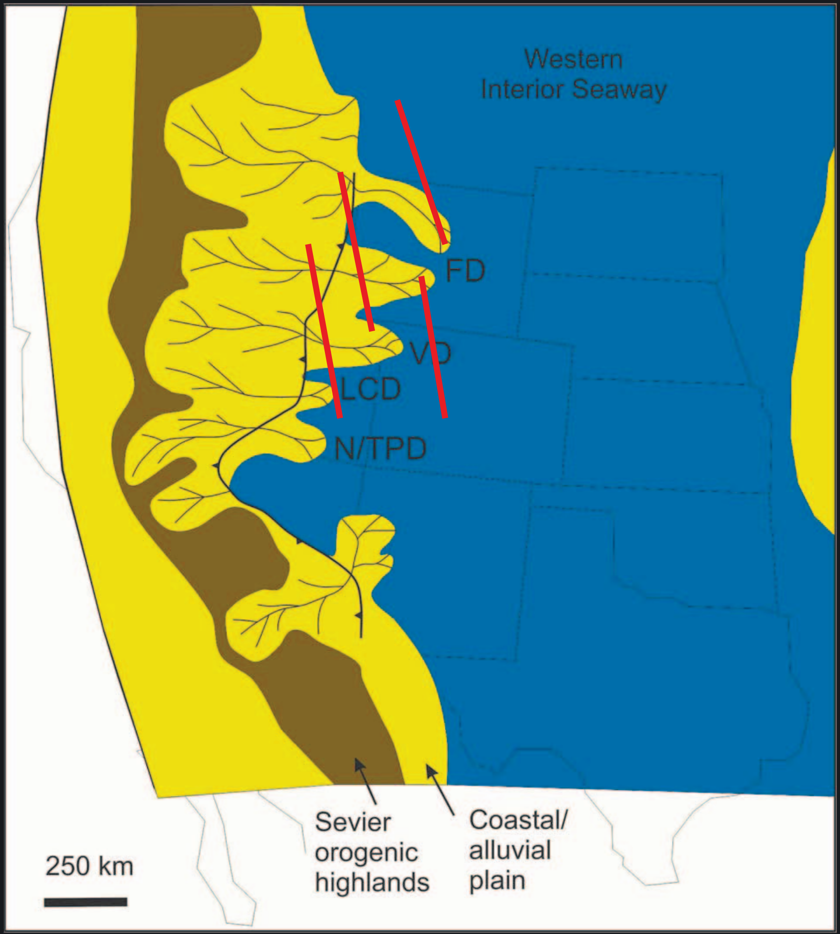
CONCLUSIONS

THE PSM AND FERRON SST WERE DEPOSITED AS DIGITATE, SOUTHWARD-PROJECTING, FLUVIALLY-DOMINATED DELTAS.

BOTH MEMBERS SHOW PERSUASIVE EVIDENCE OF FORCING BY SPATIALLY AND TEMPORALLY VARIABLE, LIMITED ACCOMMODATION.

THE NATURE OF THE IMPLIED SPATIAL DISTRIBUTION OF ACCOMMODATION SUGGESTS THAT THE NOTION OF A SINGLE, LINEAR FOREBULGE IS PROBABLY UNREALISTIC.

THE DATA AND INTERPRETATIONS PRESENTED HERE MAY CONSTITUTE A PLAUSIBLE ALTERNATIVE EXPLANATION FOR SOME “ISOLATED SANDSTONE BODIES” WITHIN THE WESTERN CORDILLERAN FORELAND BASIN.




THANK YOU FOR YOUR INTEREST