Evaluating the Roles of Sediment Supply and Tectonics Using Growth-strata Analysis, Sequence Stratigraphy, Forward Stratigraphic Modeling and Sediment Volume Calculations: An Example from the Cordilleran Foreland Basin, USA*

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Abstract

Although the importance of sediment supply is widely accepted, most studies of the ancient must assume constant supply because it is difficult to quantify or model. Because changes in sediment supply or tectonics can result in similar architectures, it is not possible to know the exact stratigraphic response to specific tectonic processes without assessing drivers independently. We present a comprehensive analysis of two contrasting stratigraphic architectures within a Campanian low-aspect-ratio (LAR) clastic wedge in the Cordilleran Foreland basin (CFB) that 1) quantifies sediment supply for onlapping and offlapping sequence sets within the LAR wedge, 2) tests limits of diffusion-based, forward stratigraphic modeling (Dionisos) to calculate supply and 3) uses growth-strata correlation to disentangle structural drivers. Previous correlations of Aschoff and Steel (2011) were extended using a database of 78 well-logs and 30 stratigraphic profiles. The new correlation and isopachs provide the 3D perspective needed to quantify supply and highlight affects of Laramide uplifts, using growth-strata and thinning. Stratal volumes were calculated for offlapping and onlapping parts of the LAR wedge, using the regional sequence-stratigraphic framework and isopach maps covering ~600,000 km^2 of the CFB; stratal volumes were decompacted and converted to sediment flux, using biostratigraphic age-control. Volume calculations yielded sediment fluxes of 63,049 km^3My-1 for the offlapping and 65,859 km^3My-1 for the onlapping sequence set. Forward stratigraphic modeling, using numerous known input variables, yielded sediment fluxes of 27,217 km^3My-1 for offlapping and 27,308 km^3My-1 for onlapping sequence set. Both methods yielded similar sediment fluxes, indicating little variation in supply despite contrasting stratal architecture. Uplift of the Uinta Mountains was constrained to upper Campanian, based on new isopach maps showing an east-west-trending depozone along the southern Uinta Mountains and correlation of growth-strata to basin-fill. Backstripping by Liu et al. (2011) suggest that dynamic subsidence migrated far eastward, away from the main depozone of the LAR wedge during the Sevier-Laramide transition. Migration of dynamic subsidence may have catalyzed the 3rd-order LAR wedge, but higher frequency architectural changes within the wedge were likely due to local Laramide structures, such as the San Rafael Swell (SRS) and the Uinta Uplift, not sediment supply.

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Evaluating the Roles of Sediment Supply and Tectonics using Growth-strata Analysis, Sequence Stratigraphy, Forward Stratigraphic Modeling and Sediment Volume Calculations: An Example from the Cordilleran Foreland Basin, USA

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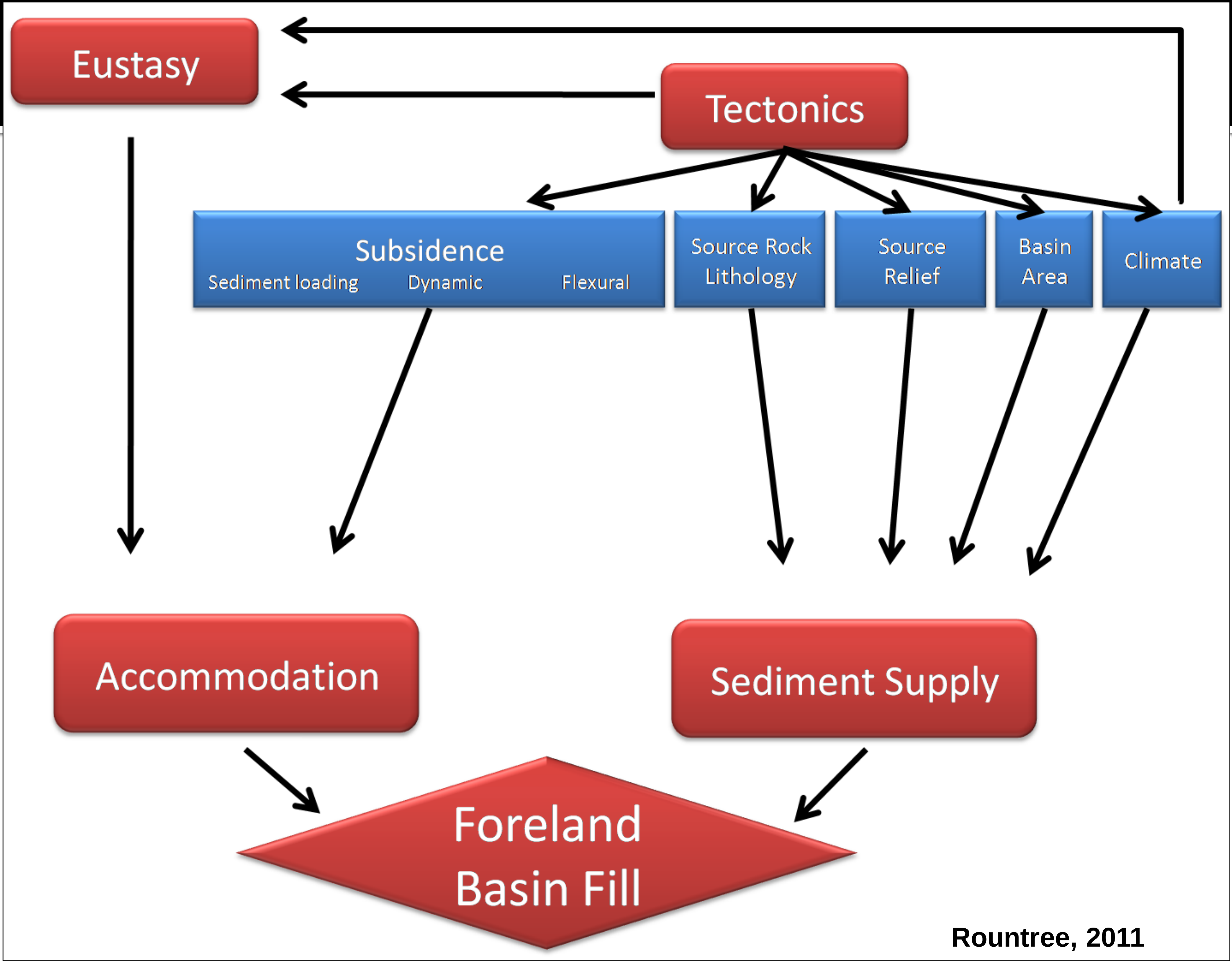
Outline

- External Stratigraphic Drivers
- Problems
- Scientific Questions
- Cordilleran Foreland Basin- Geologic Context
- Part 1-Growth-strata Analysis+ Tect. Controls
- Part 2- Sediment Supply
  - Mega-regional Correlation
  - Sediment Volume Calculations
  - Forward Stratigraphic Modeling
- Conclusions

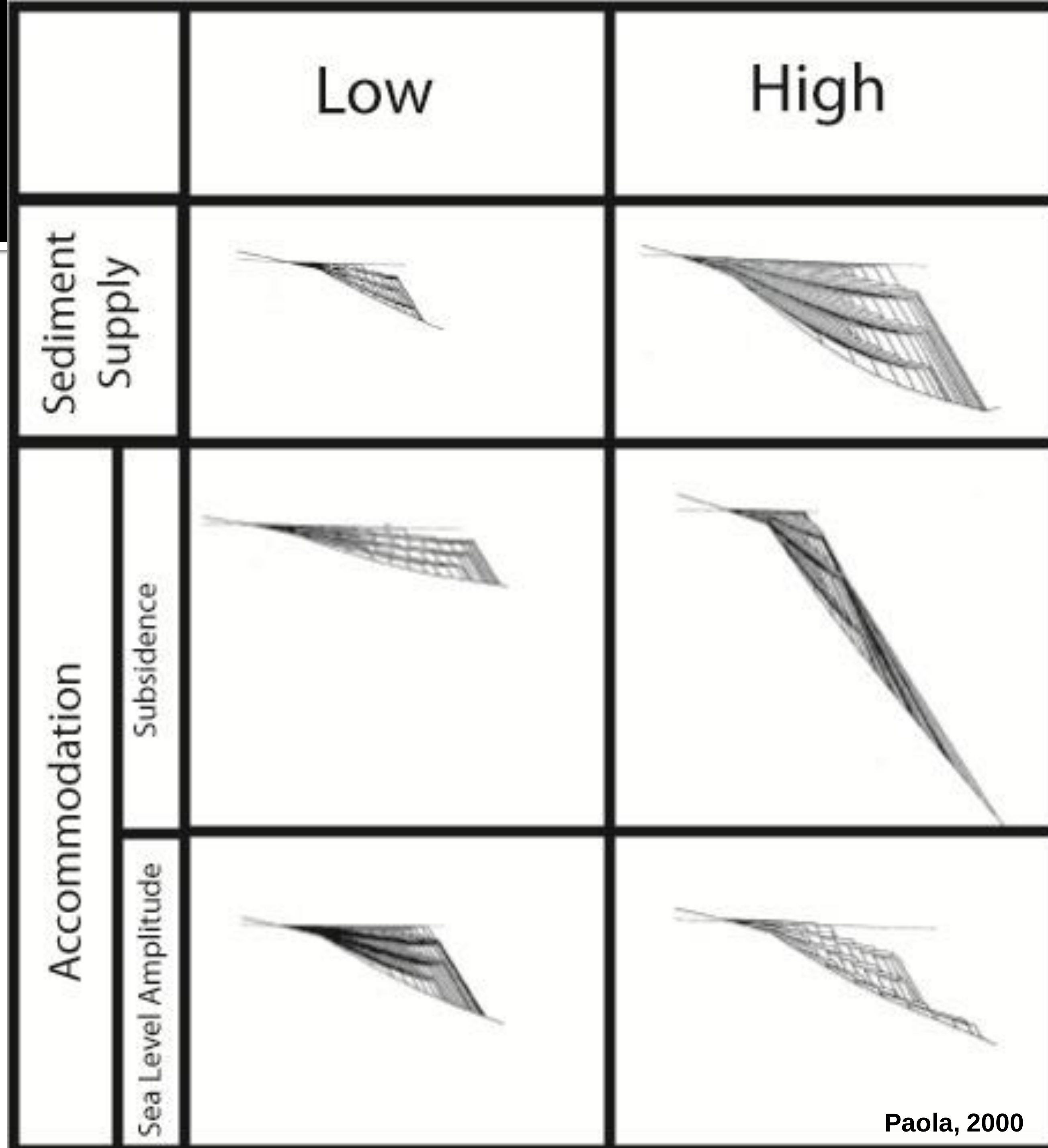
External Stratigraphic Controls



Predicted Stratigraphic Architecture

Climate
Drainage Basin Size/Geometry
Uplift of Rocks
Sediment Source Lithology

Sea-level
Regional Subsidence
Local Structural Uplift



Current Problems- Sediment Supply

Numerical and Physical Models

- Difficult to up-scale to ancient sedimentary systems and basins
- Assumptions about sea-level, tectonics, stratal preservation, etc.

Quantifying in the Ancient

- Requires detailed, basin-wide correlation
- Must encompass entire "container" of sediment
- Requires good age control
- Assumptions with decompaction

Best Approach- Integration

Objectives and Approach

Evaluate Role of Tectonics

(see Aschoff and Steel, 2011 GSAB; Valora and Aschoff, 2012 UGS Report)

- Growth-strata analysis- local thrust-belt structures
- Regional Correlation with Sequence Stratigraphy and Biostratigraphic Control

Quantify Sediment Flux for End-member Strat Geometries

- Construct regional outcrop-subsurface connection for 4D view of basin-fill
- Calculate stratal volumes for select 4^{th} and 5^{th} order depositional sequences
- Convert to sediment volumes using decompaction

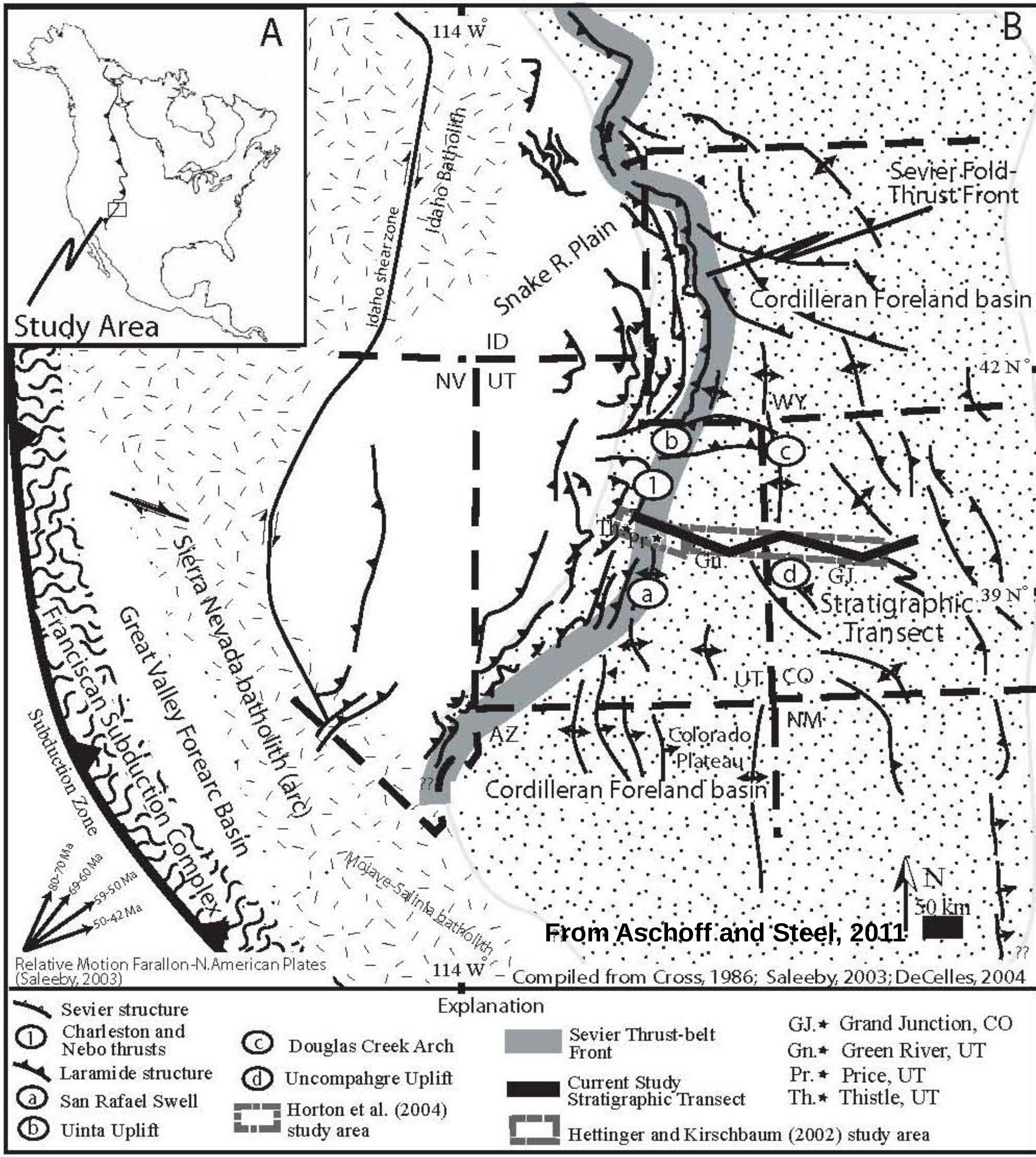
Forward Stratigraphic Model of End-member Strat Geometries

- Dionisos- diffusion-based forward stratigraphic model
- Input well known basin geometry, subsidence, sea-level curve, time-lines and stratigraphy
- Test the limit of Dionisos by modeling contrasting 4^{th}-order sequences as well as 5^{th}-order stratigraphic sequences

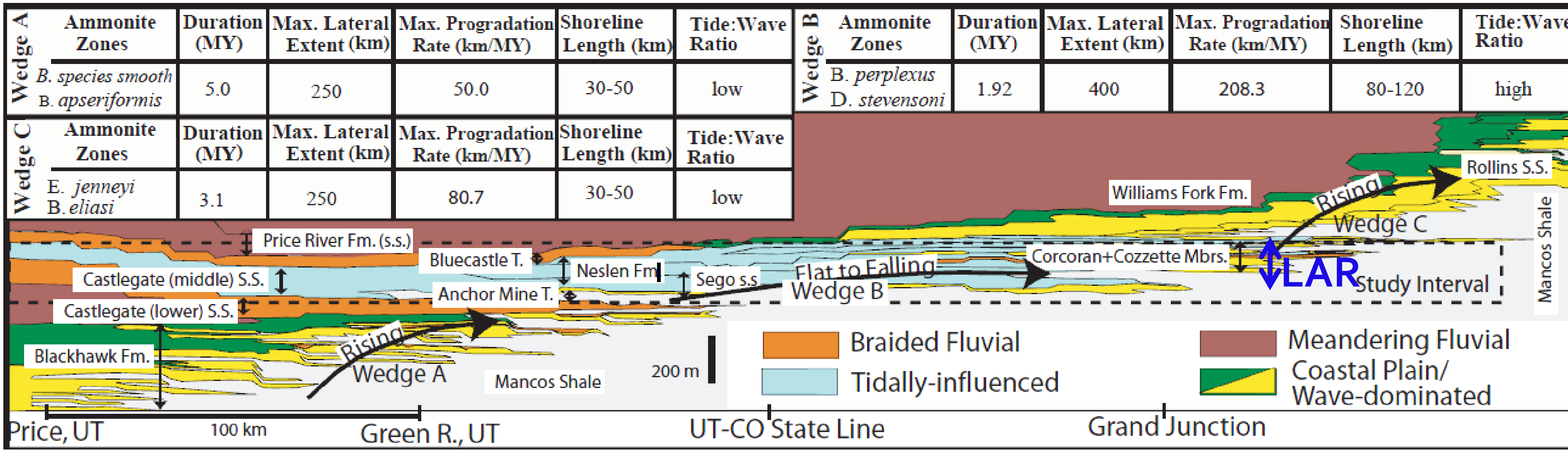
NA Cordilleran Foreland Basin Western USA

Best-studied Foreland Basin

- High-resolution Ammonite Zones
- Radiometric Dates
- Bentonites/ashes
- Extensive outcrop exposure
- Hundreds of public well logs



Foreland Basin Fill



Wedge A Ammonite Zones	Duration (MY)	Max. Lateral Extent (km)	Max. Progradation Rate (km/MY)	Shoreline Length (km)	Tide:Wave Ratio
B. species smooth *B. apseriformis*	5.0	250	50.0	30-50	low

Wedge B Ammonite Zones	Duration (MY)	Max. Lateral Extent (km)	Max. Progradation Rate (km/MY)	Shoreline Length (km)	Tide:Wave Ratio
B. *perplexus* D. *stevensoni*	1.92	400	208.3	80-120	high

Wedge C Ammonite Zones	Duration (MY)	Max. Lateral Extent (km)	Max. Progradation Rate (km/MY)	Shoreline Length (km)	Tide:Wave Ratio
E. *jenneyi* B. *eliasi*	3.1	250	80.7	30-50	low

Recent work…

-Hettinger and Kirschbaum (2002) Provided a regional stratigraphic synthesis

-Horton et al., (2004) showed that extensive (~200 km) Castlegate progradation was coeval with thrust-belt development

-Aschoff, (2008) and Aschoff and Steel, (GSA Bulletin,2011) highlighted an interval (the LAR Wedge) with *2x as much progradation as Castlegate Ss.* developed coeval with both thin- and thick-skinned deformation

-Aschoff and Steel (Sed Geol, 2011) identified two types of clastic wedges:

High aspect ratio wedges

A low aspect ratio wedge

Part 1: Role of Tectonics

Local Structural Influence

- Uplift of a single, localized (10's km) structure
- Reduces local(?) subsidence, diverts depositional systems and creates local unconformities

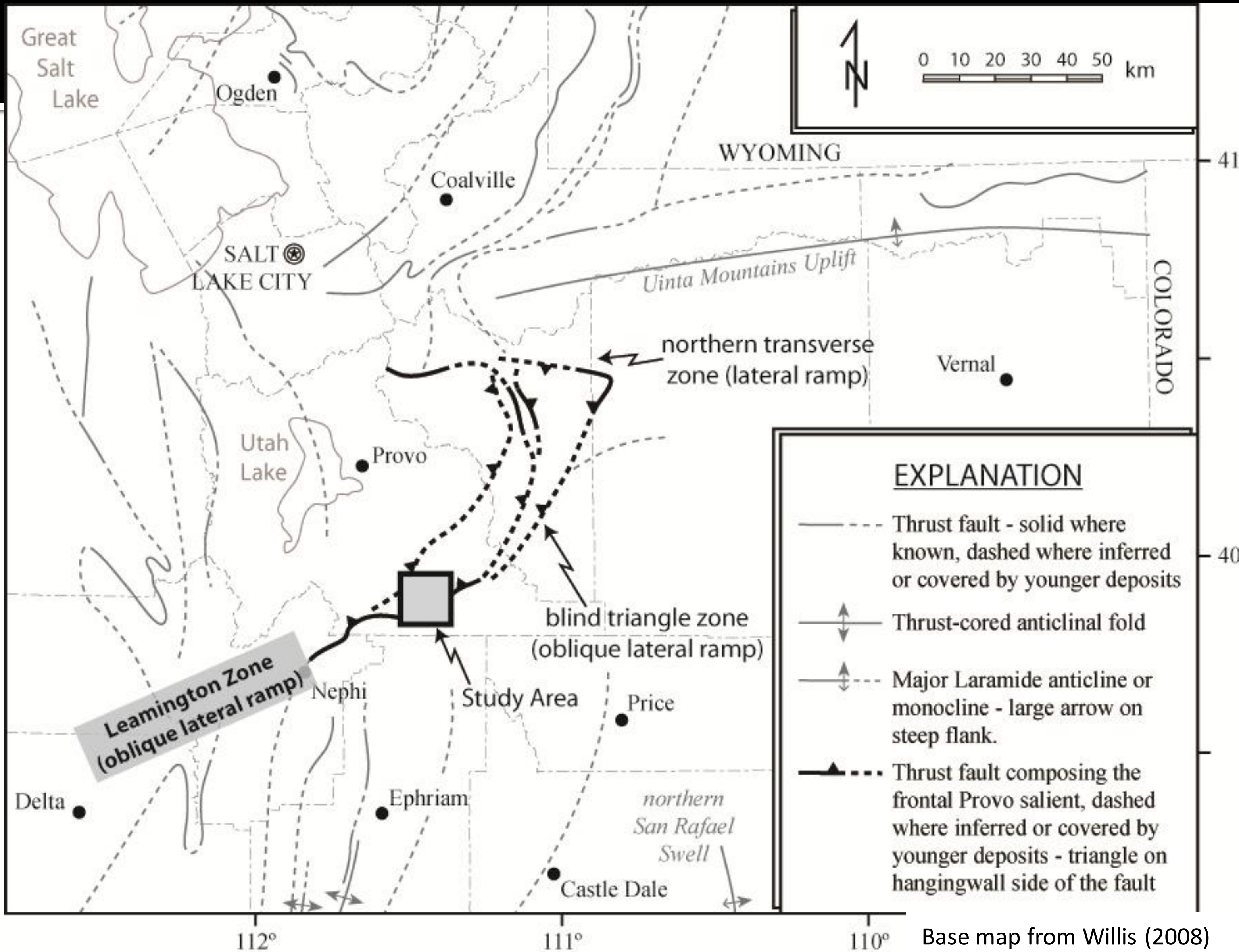
Regional Structural Influence

- Uplift of a thrust-belt
- Sinuosity of thrust-front (i.e., salients, reentrants, transverse zones) and its control on major sediment entry points
- Flexural subsidence of crust adjacent to thrust-belt
- Isostatic rebound

"Mega-regional" Tectonic Influence

- Subduction-related asthenospheric corner-flow
- Dynamic subsidence predicted when subduction angles are flat
- Creation of dynamic topography (uplift) when subduction angles are steep

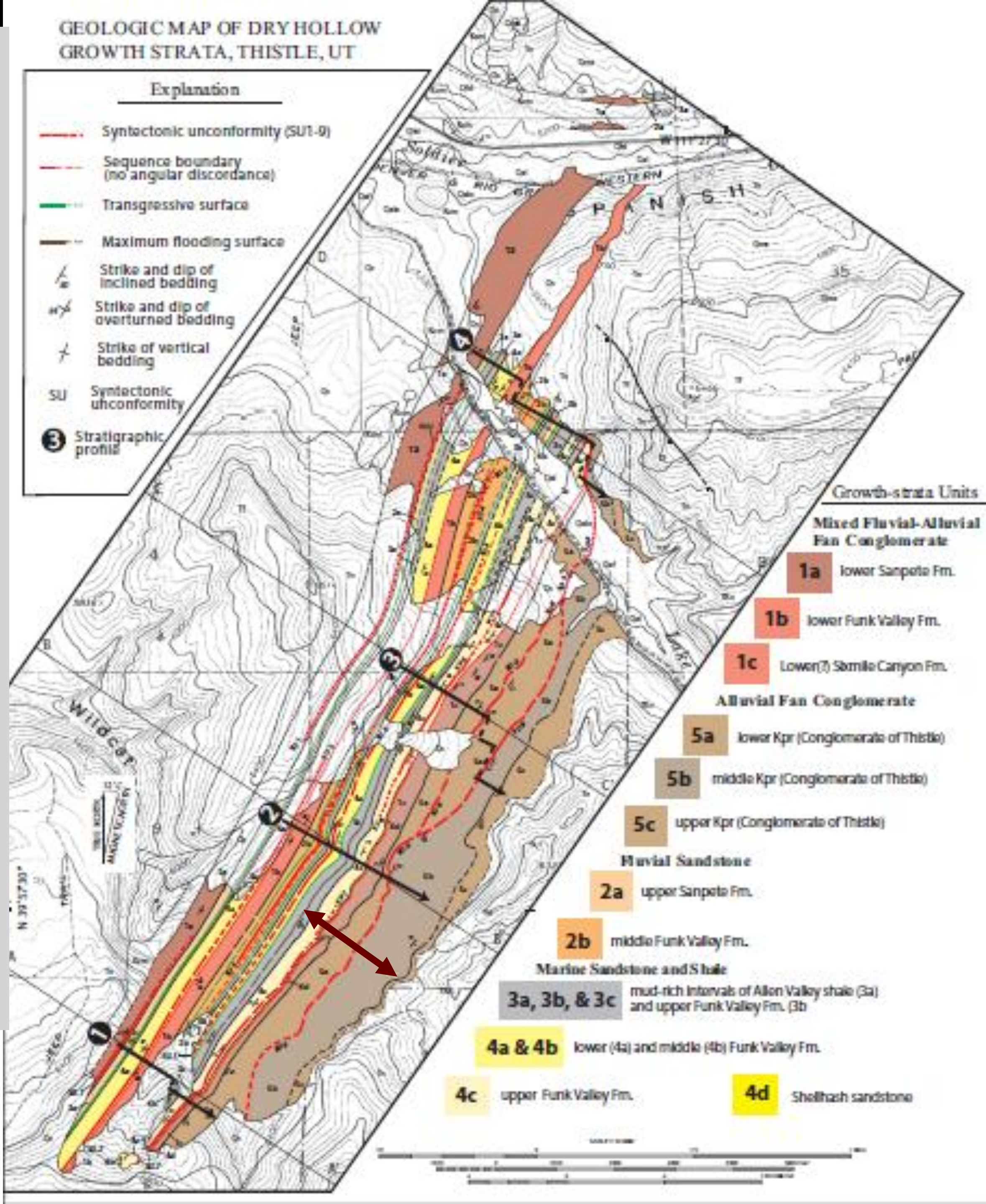
Part 1: Role of Tectonics

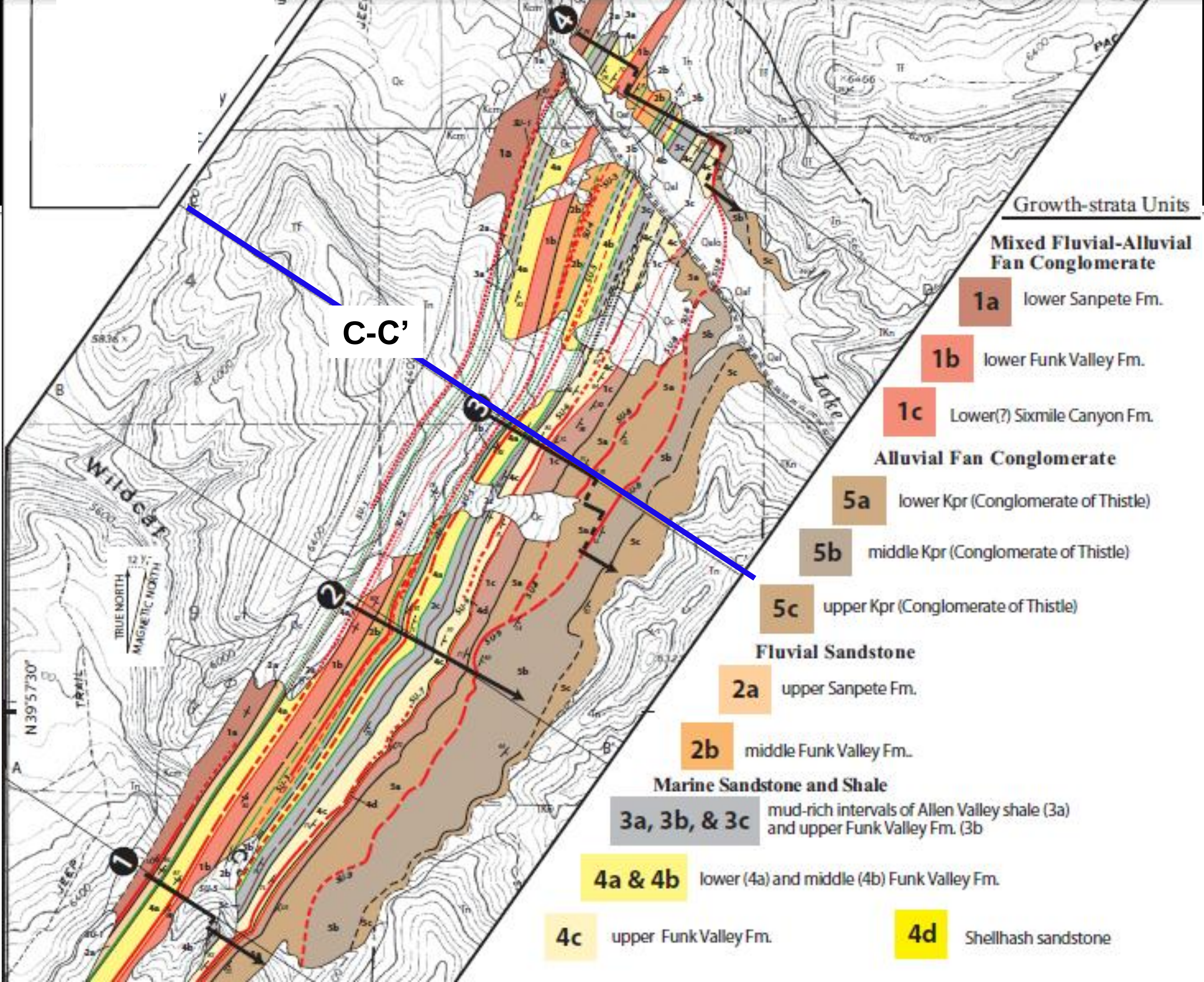


Base map from Willis (2008)

Summary:

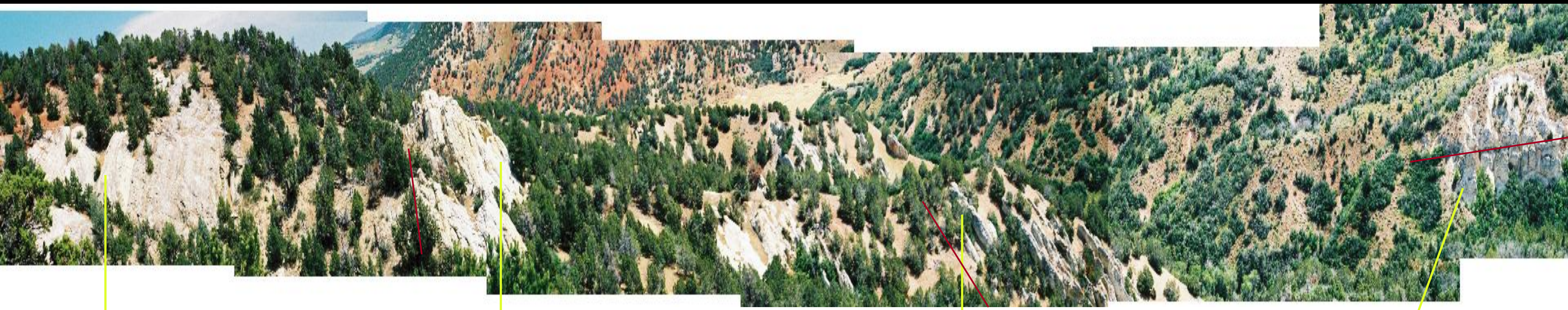
- 9 Syntectonic Unconformities
- 4 Main Unconformity-bound packages (2 upper and 2 lower)
- Upper Growth-strata packages correlate to LAR Wedge
- Major Transgressive Surface correlates with the base of the Anchor Mine Tongue



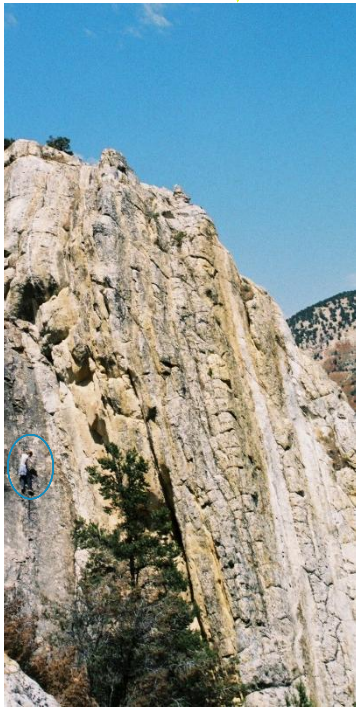


C-C'
Growth-strata Units
Mixed Fluvial-Alluvial Fan Conglomerate
1a lower Sanpete Fm.
1b lower Funk Valley Fm.
1c Lower(?) Sixmile Canyon Fm.
Alluvial Fan Conglomerate
5a lower Kpr (Conglomerate of Thistle)
5b middle Kpr (Conglomerate of Thistle)
5c upper Kpr (Conglomerate of Thistle)
Fluvial Sandstone
2a upper Sanpete Fm.
2b middle Funk Valley Fm.
Marine Sandstone and Shale
3a, 3b, & 3c mud-rich intervals of Allen Valley shale (3a) and upper Funk Valley Fm. (3b
4a & 4b lower (4a) and middle (4b) Funk Valley Fm.
4c upper Funk Valley Fm.
4d Shellhash sandstone
Wildcat
Lake
TRUE NORTH
MAGNETIC NORTH
N39°57'30"

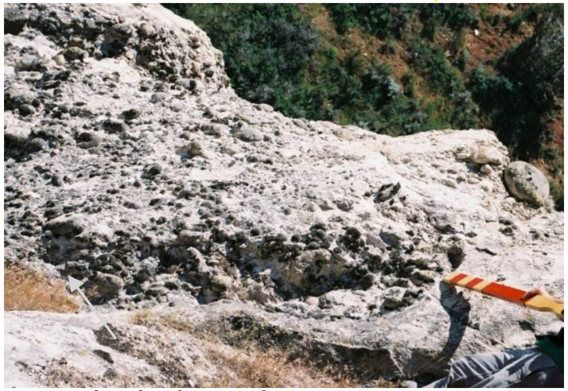
Growth Strata



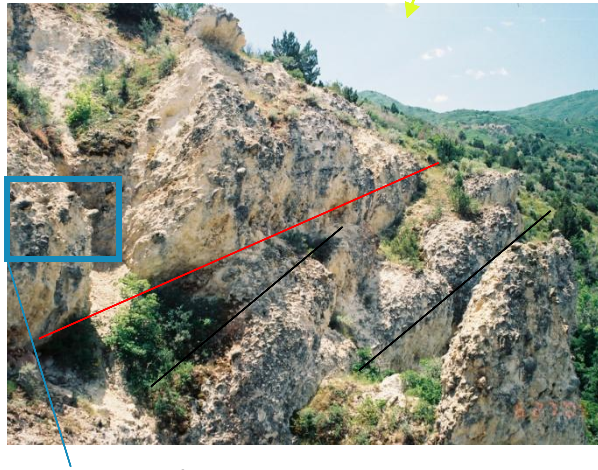
Slightly overturned
Sixmile Canyon Fm.



Near-vertical
Sixmile Canyon Fm.



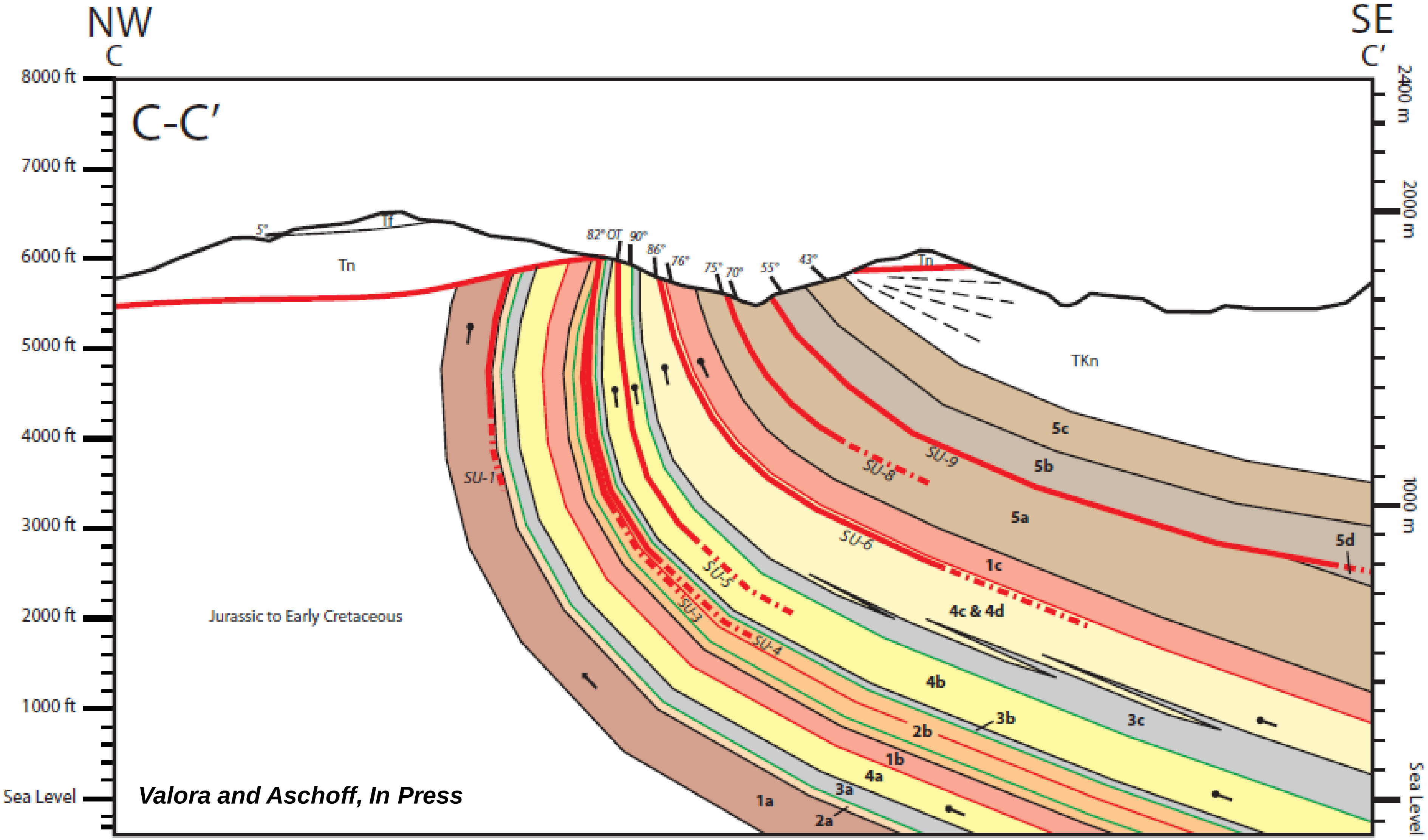
Braided Fluvial
Price River Fm.
(Castlegate Ss. Equiv).



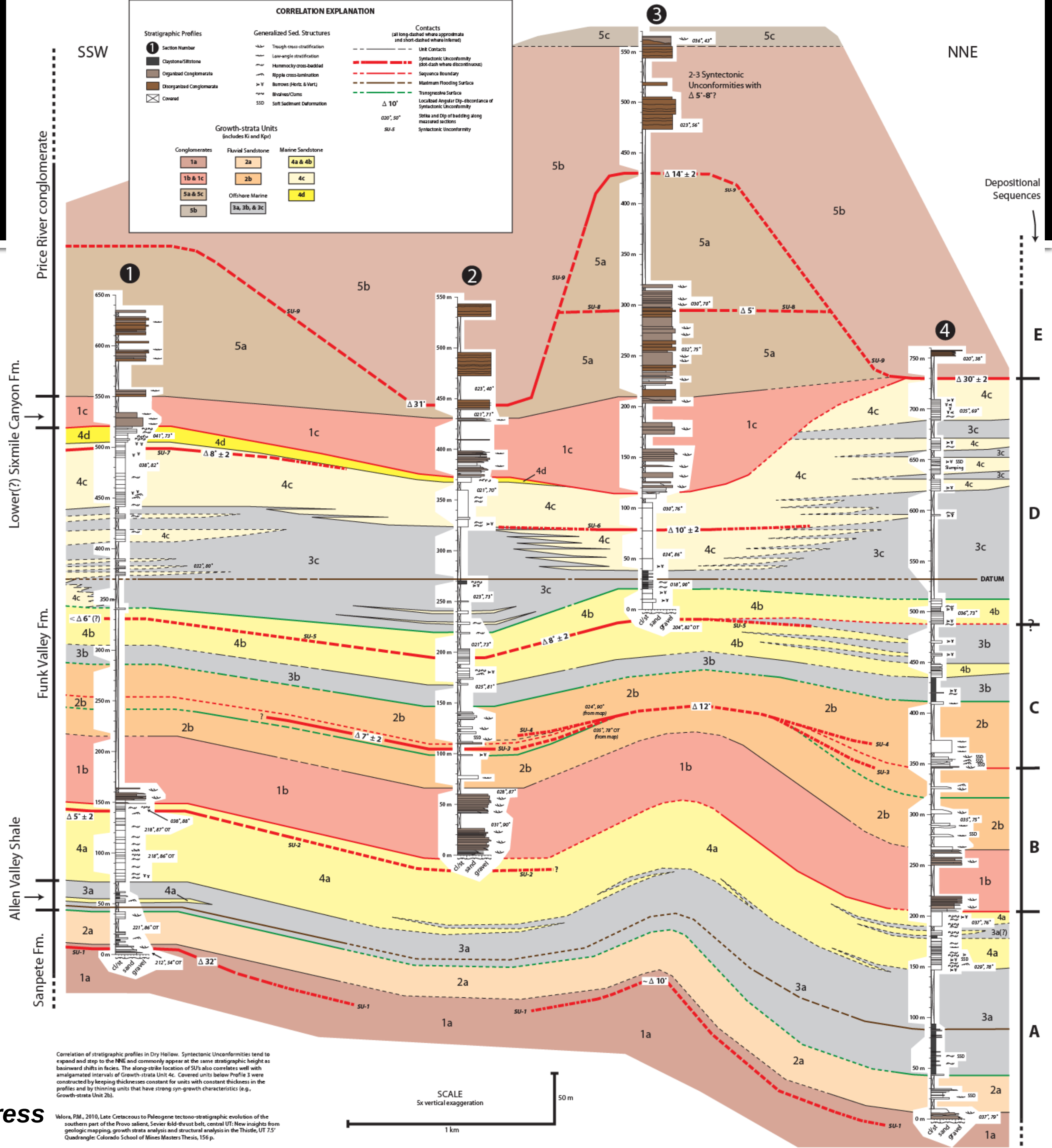
Debris-flow Alluvial Fan
Price River conglomerate

Summary:

- 9 Syntectonic unconformities
- Uppermost 3 SU-bound packages correlate to forced regressive and onlapping sequence sets



NW
C
SE
C′
C-C′
8000 ft
7000 ft
6000 ft
5000 ft
4000 ft
3000 ft
2000 ft
1000 ft
Sea Level
2400 m
2000 m
1000 m
Sea Level
5°
Tf
Tn
82° OT
90°
86°
76°
75°
70°
55°
43°
Tn
TKn
5c
5b
5a
5d
1c
4c & 4d
4b
3b
3c
2b
1b
4a
3a
1a
2a
SU-1
SU-3
SU-4
SU-5
SU-6
SU-8
SU-9
Jurassic to Early Cretaceous
Valora and Aschoff, In Press

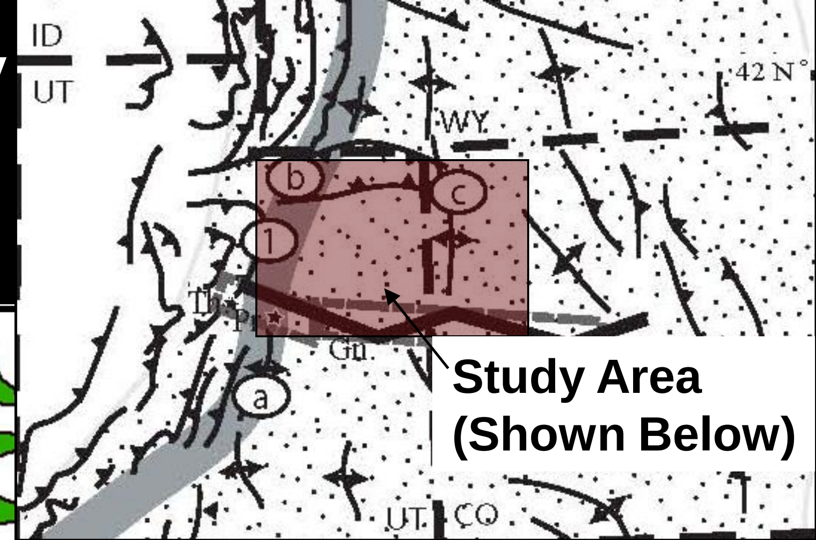


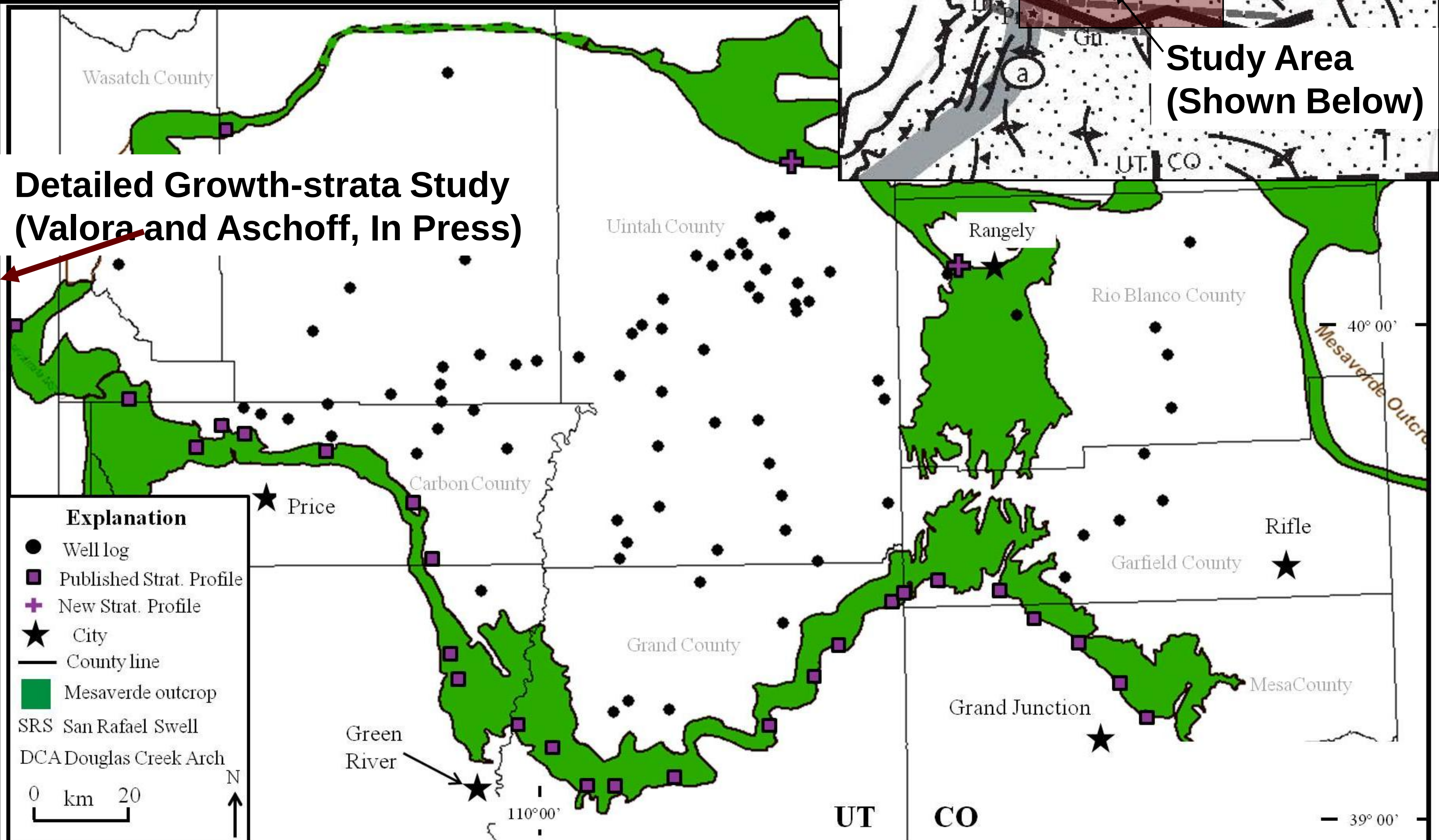
Correlation of stratigraphic profiles in Dry Hollow. Syntectonic Unconformities tend to expand and step to the NNE and commonly appear at the same stratigraphic height as basinward shifts in facies. The along-strike location of SU's also correlates well with amalgamated intervals of Growth-strata Unit 4c. Covered units below Profile 3 were constructed by keeping thicknesses constant for units with constant thickness in the profiles and by thinning units that have strong syn-growth characteristics (e.g., Growth-strata Unit 2b).

Valora, P.M., 2010, Late Cretaceous to Paleogene tectono-stratigraphic evolution of the southern part of the Provo salient, Sevier fold-thrust belt, central UT: New insights from geologic mapping, growth strata analysis and structural analysis in the Thistle, UT 7.5' Quadrangle: Colorado School of Mines Masters Thesis, 156 p.

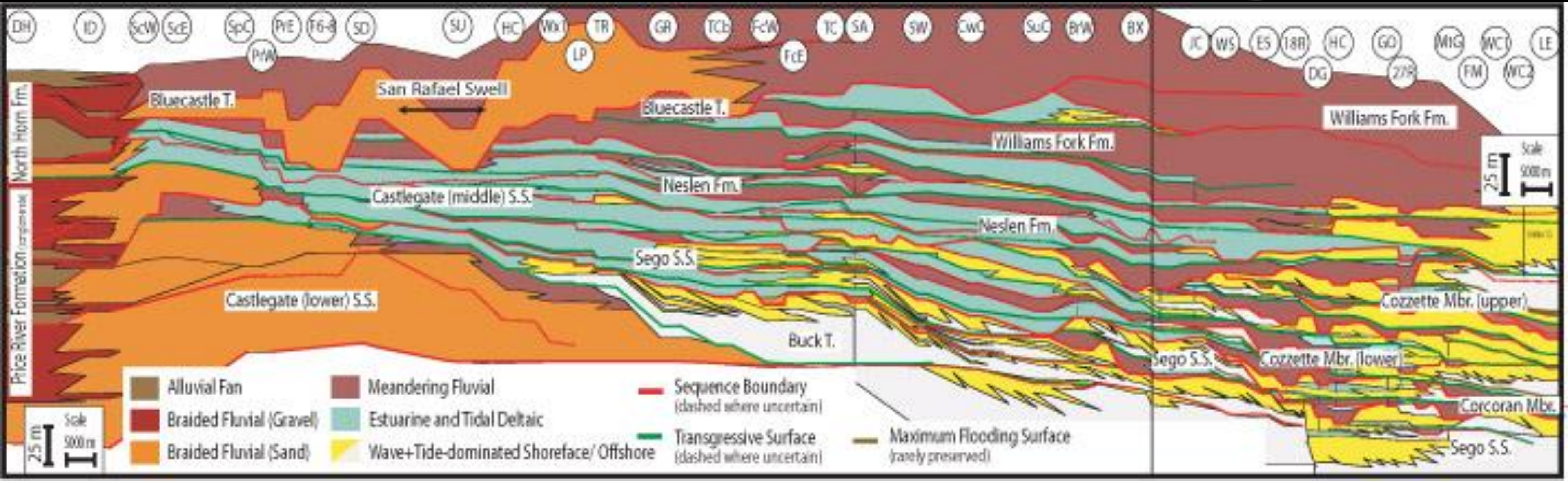
Valora and Aschoff, In Press

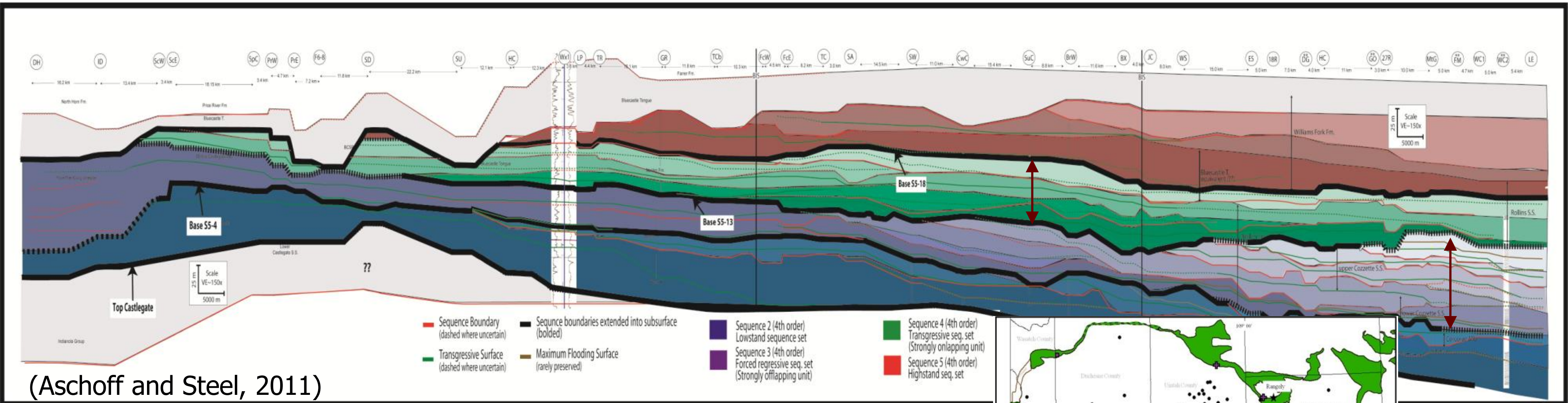
Part 2: Role of Sediment Supply Dataset



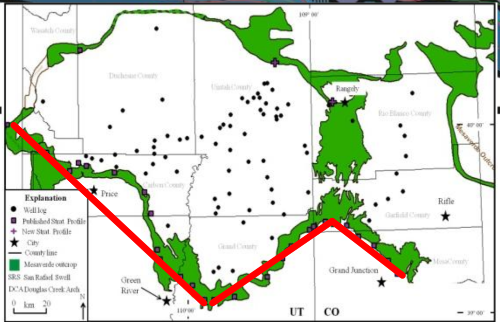


Architecture of the LAR wedge

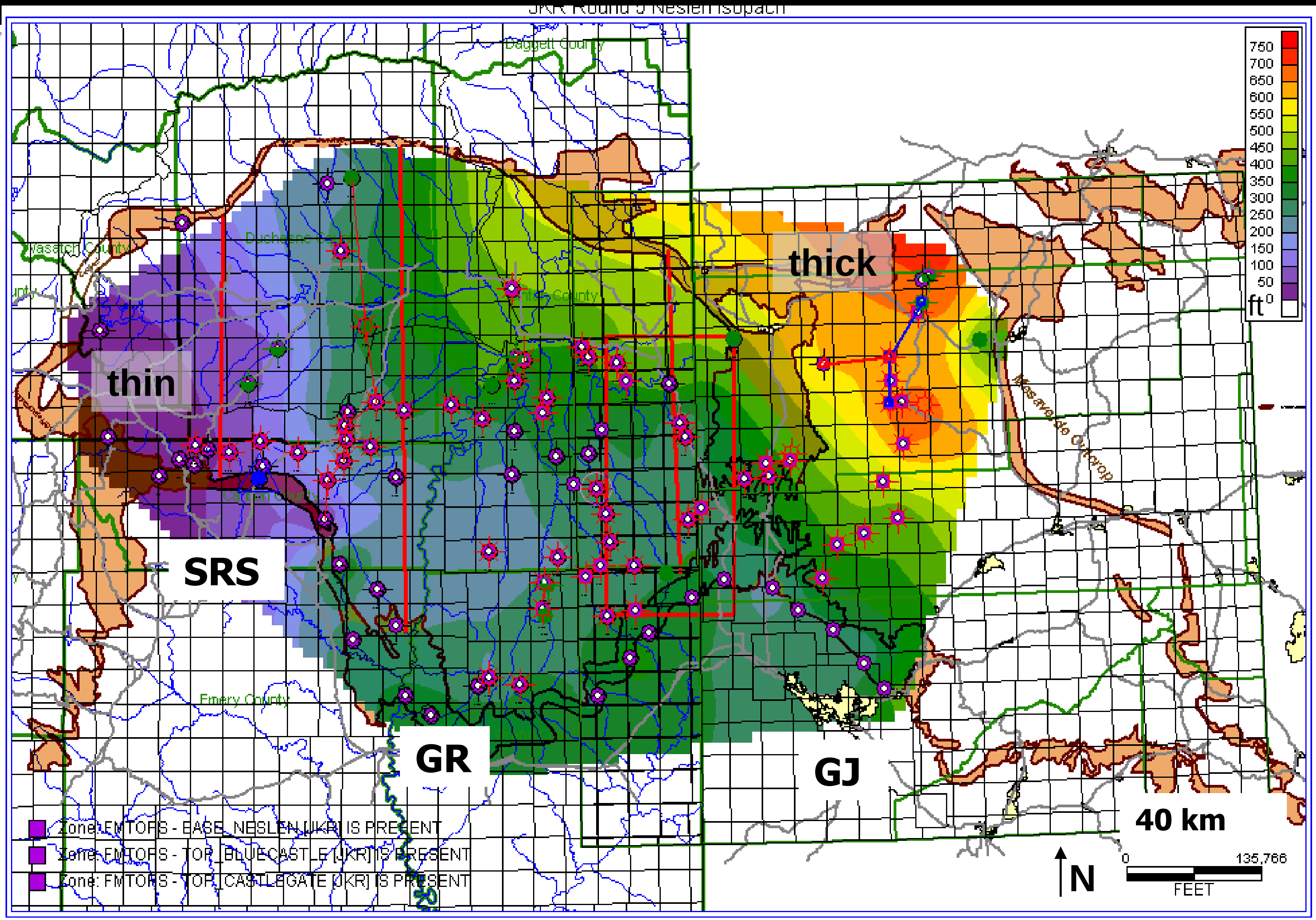




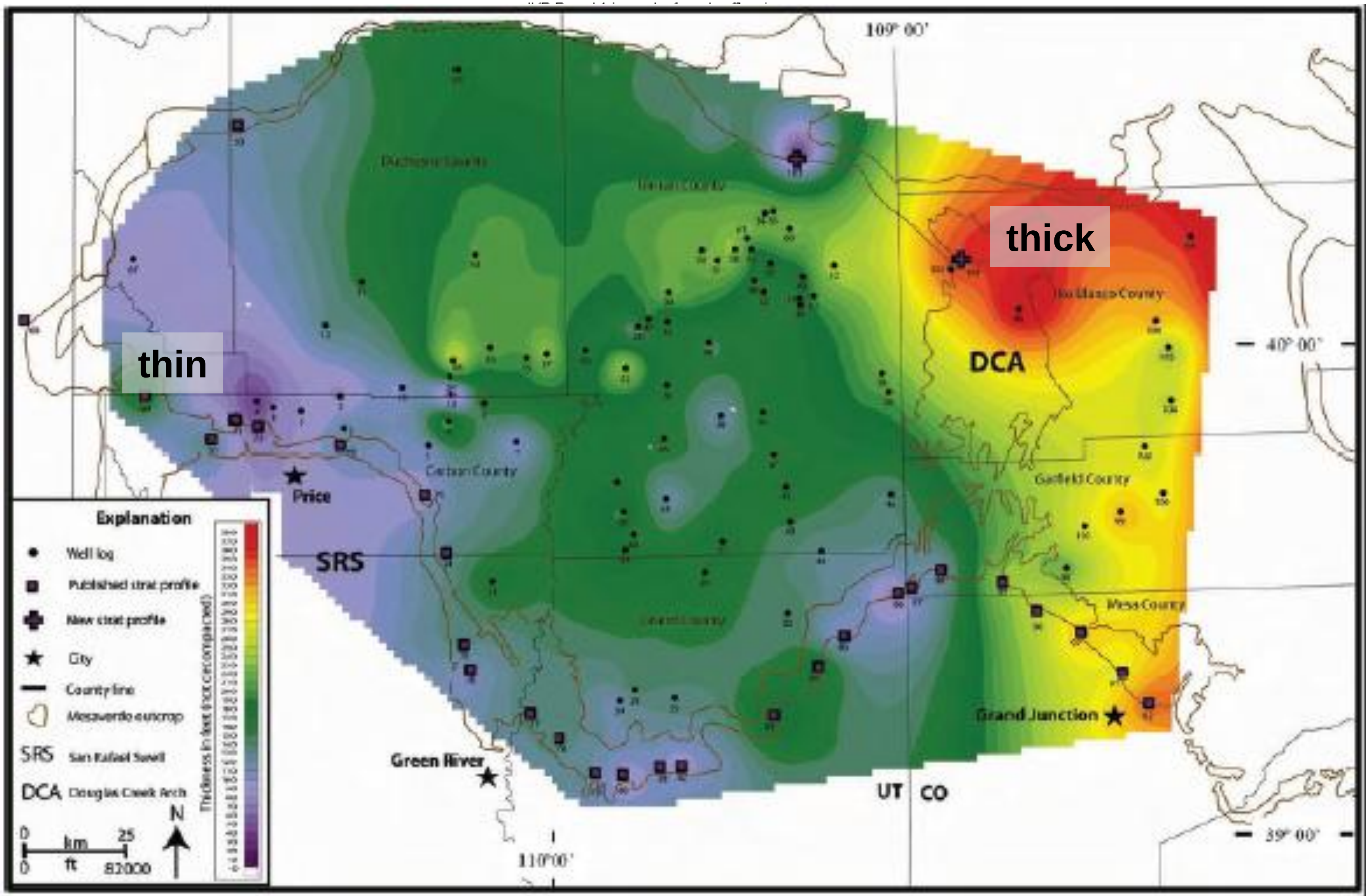
(Aschoff and Steel, 2011)



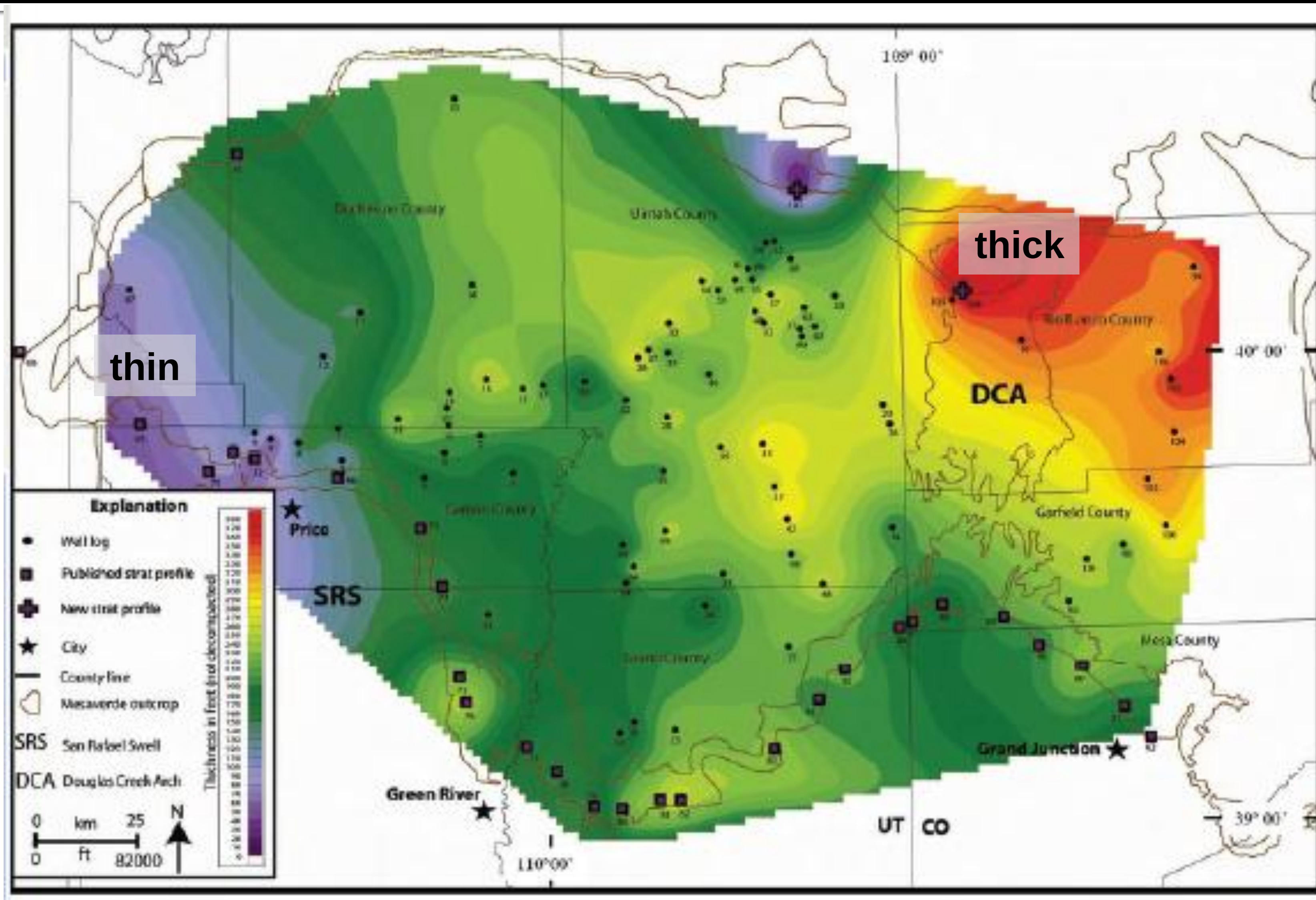
Isopach Map (ft)
Composite- Onlapping+Offlapping Sequence Sets
75.2-74.9 Ma



Isopach Map (ft)
LAR Wedge- OFFLAPPING SEQUENCE SET
75.1-75.2 Ma



Isopach Map (ft)
LAR Wedge- ONLAPPING SEQUENCE SET
75.1-75 Ma



Volume and Sediment Flux Calculations

A. Not Decompacted

Sequence (Age Ma)	Stratal Volume (km^3)	Duration (My)	Stratal Flux (km^3/My)	Partial or complete system calculated
S4-3 (75.2-75.1)	1,987.1	0.1	19,871.5	Complete
S4-4 (75.1-75.0)	2,055.1	0.1	20,551.1	Complete

B. Decompacted

Sequence (Age Ma)	Sediment Volume (km^3)	Duration (My)	Sediment supply (km^3/My)	Partial or complete system calculated
S4-3 (75.2-75.1)	6,304	0.1	63,049	Complete
S-4 (75.1-75.0)	6,585	0.1	65,859	Complete

Forward Stratigraphic Modeling
Dionisos (Diffusion-based)

Model Input Parameters

(1) Bathymetry

-assumed to be very gently, broad slope 0.1°

(2) Subsidence

-calculated using ispoach maps that show location of subsidence

(3) Sea level

-calculated using stratigraphic profile and superimposing sinusoidal fluctuation on top of that

(4) Location of Sediment Input

-sediment input was controlled by structural transverse zones in the thrust-belt

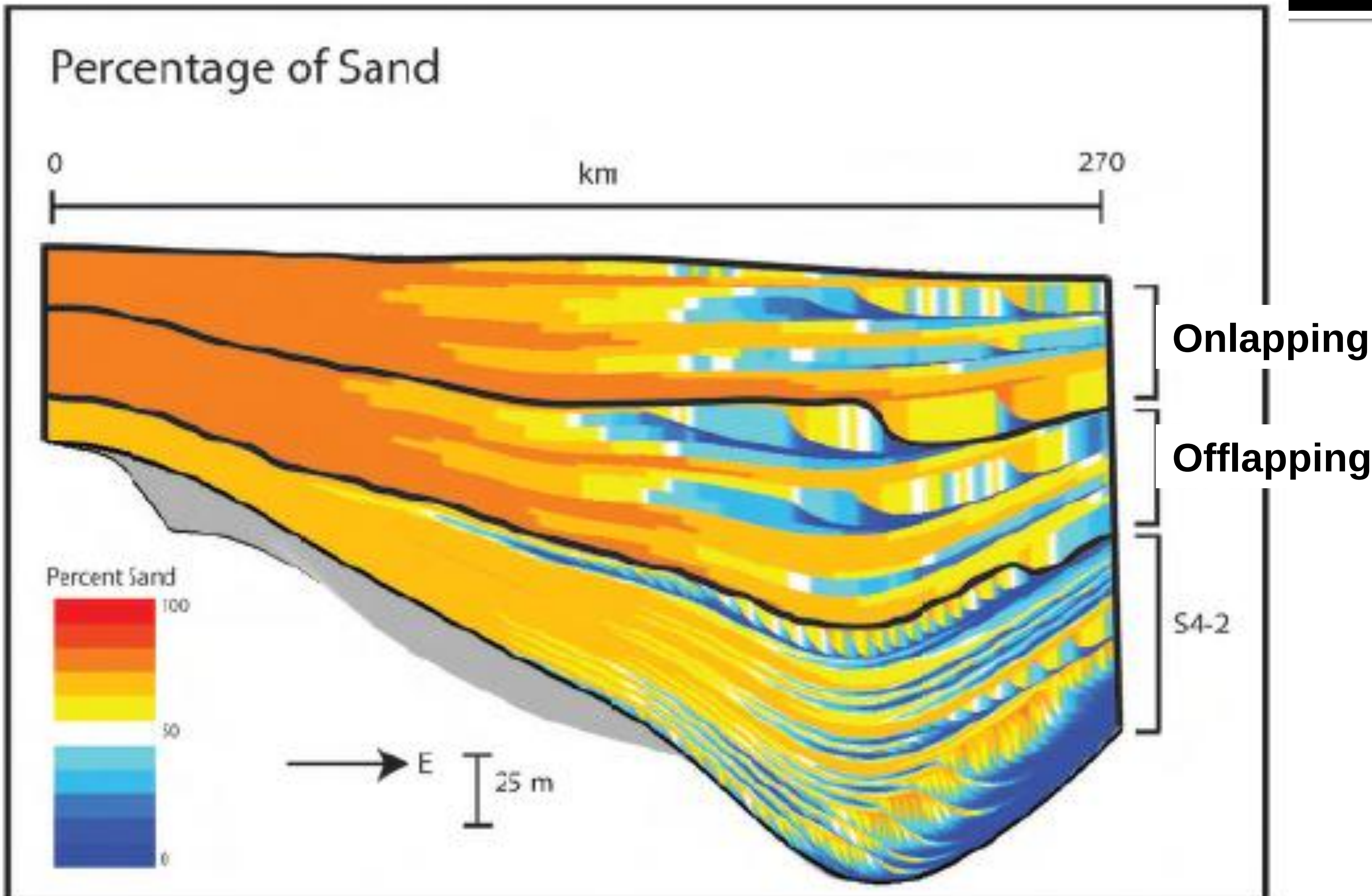
(5) Direction of Sediment Transport

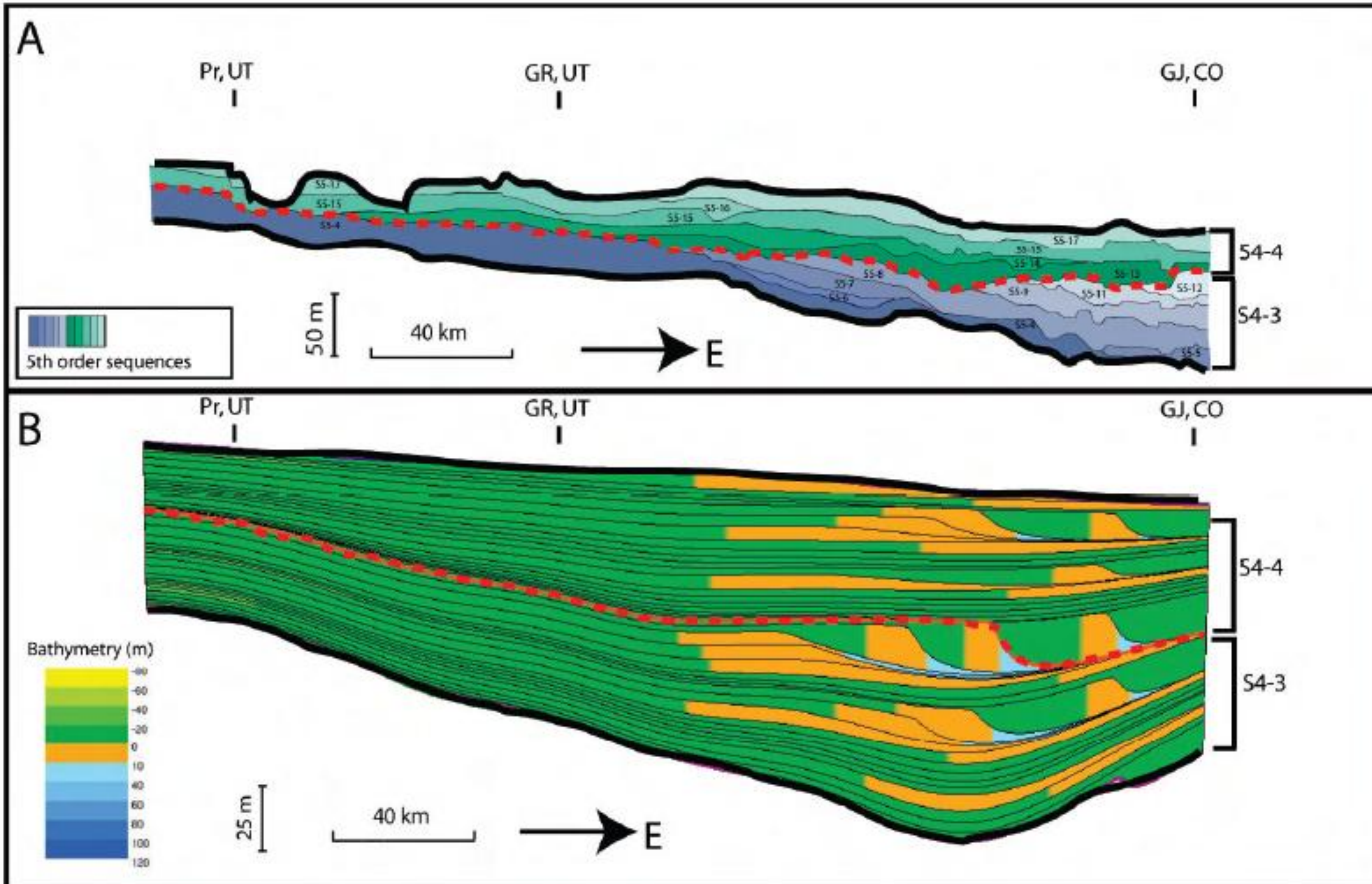
- to the east

(6) Sediment Transport efficiency

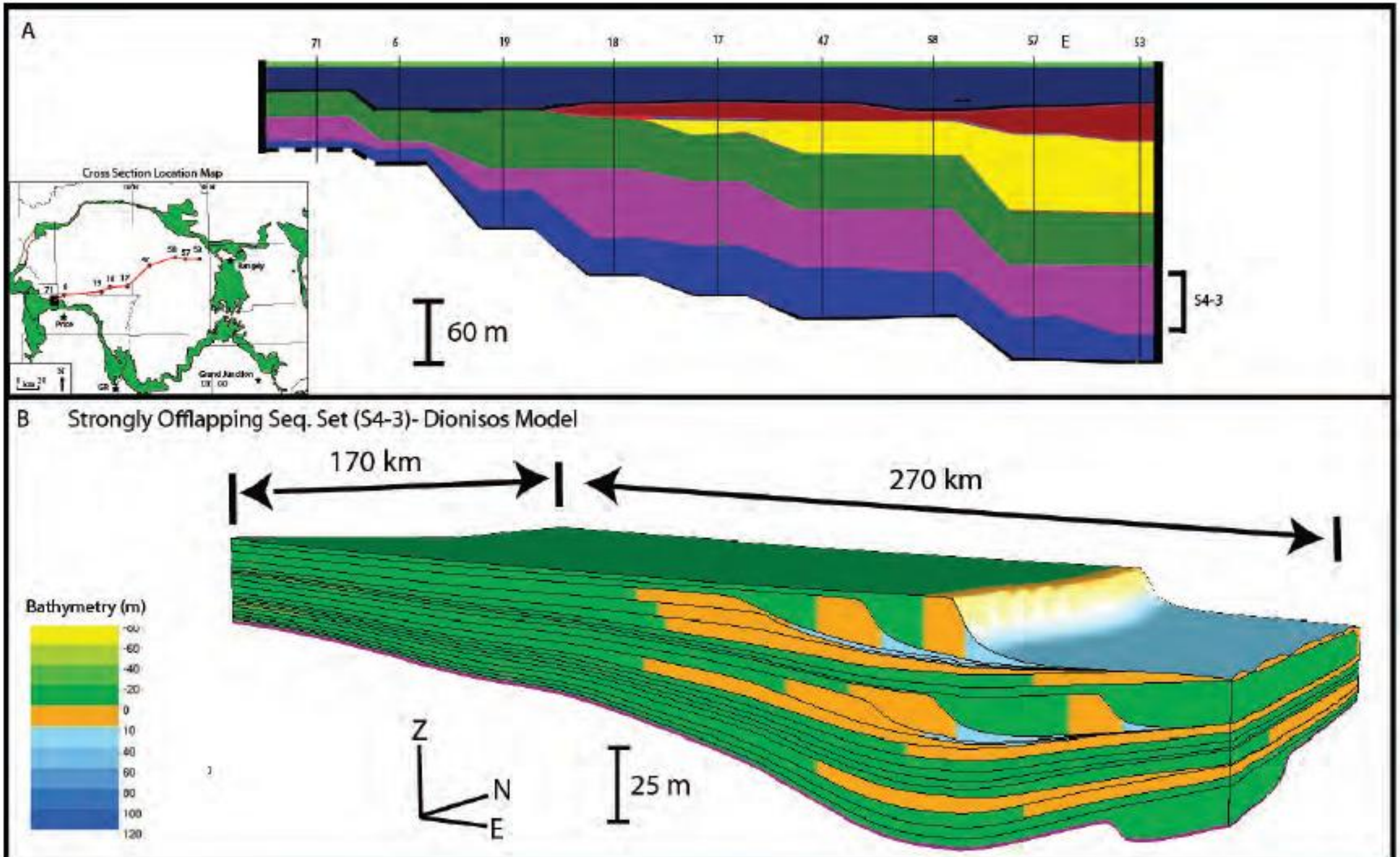
- **Continental- Sand** 668 km^2/kyr **Shale** 1490 km^2/kyr
- **Marine- Sand** 2.23 km^2/kyr **Shale** 11.1 km^2/kyr

77-75 Ma (entire wedge)

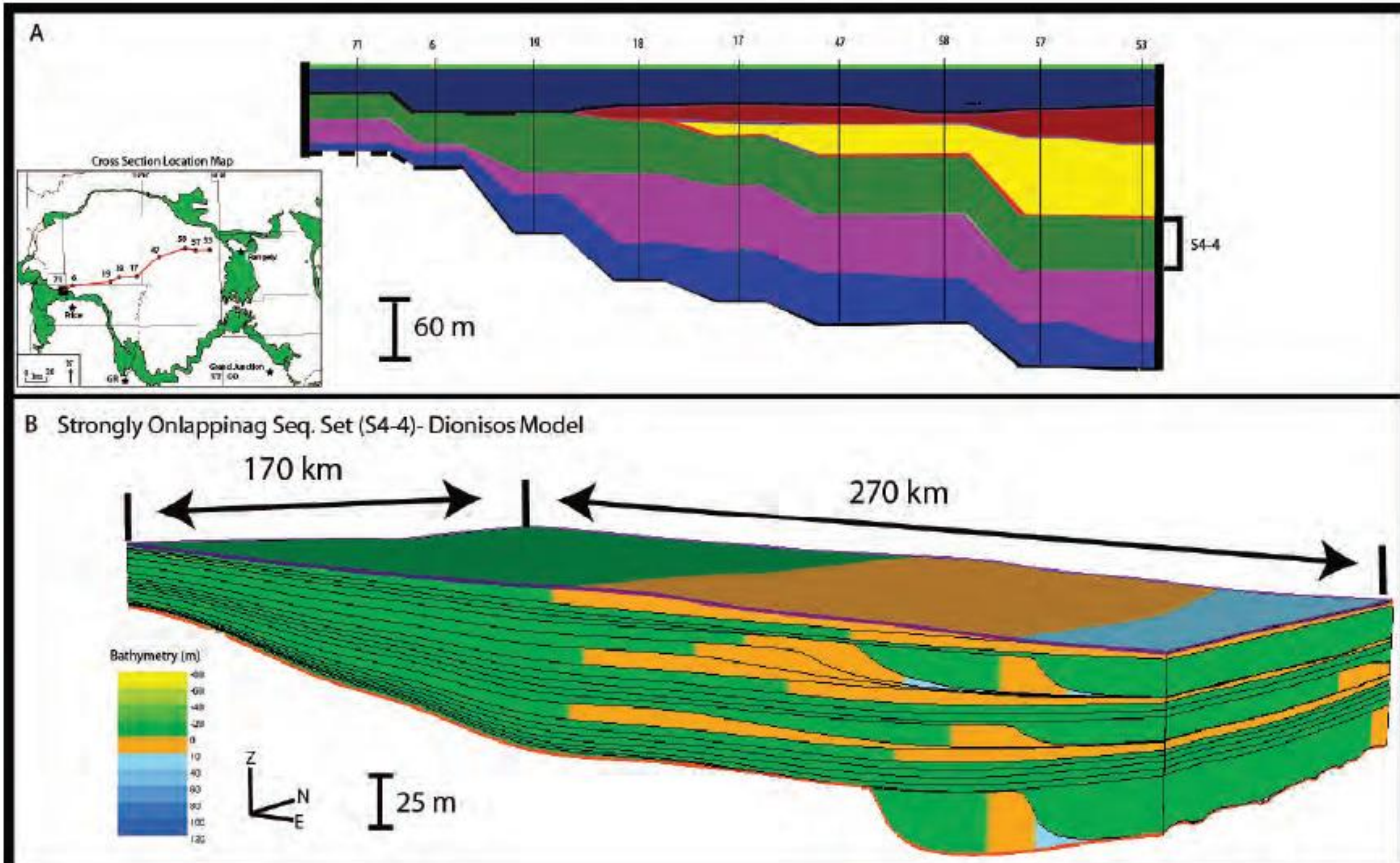



A
Pr, UT
GR, UT
GJ, CO
S4-4
S4-3
50 m
40 km
E
5th order sequences
B
Pr, UT
GR, UT
GJ, CO
S4-4
S4-3
Bathymetry (m)
25 m
40 km
E

Dionisos Model
LAR Wedge- OFFLAPPING SEQUENCE SET
75.1-75.2 Ma



Dionisos Model
LAR Wedge- ONLAPPING SEQUENCE SET
75.1-75 Ma



Sequence stratigraphy									Ages	
Sequence Architecture	Isopach Volume(km³) (undecompacted)	Isopach Flux (km³/My) (undecompacted)	Isopach Volume(km³) (decompacted)	Isopach Flux (km³/My) (decompacted)	Dionisos Volume(km³) (undecompacted)	Dionisos Flux (km³/My) (undecompacted)	4th order	5th order	Ma	Ammonites
									74.6	*D. cheyennense*
									74.8	*E. jenneyi*
							S4-5	S 5-18 to S 5-20	75 ★	
Strongly Onlapping	2,055	20,551	6,585	65,589	2,730	27,308	S4-4	S 5-13 to S 5-17	+/-0.11	*D. stevensoni*
Strongly Offlapping	1,987	19,871	6,304	63,049	2,217	27,217	S4-3	S 5-4 to S 5-12	75.2 ★ +/-0.28	*D. nebrascense*
							S4-2	Seq 5-3	75.4 +/-0.11 ★ 75.6	*B. scotti*
								Seq 5-2	75.8 76 76.2	*B. Perplexus*
								Seq 5-1	76.4 76.6 76.8 77 ★	
									+/-0.26	*B. asperiformis*

Conclusions

- Thrust-belt and Laramide tectonics active throughout the development of the LAR Wedge. Both on- and offlap were affected by both structural styles.
- Sediment flux does not vary greatly between the onlap and offlapping sequence sets. *However*, the onlap has a slightly <u>higher</u> supply.
- Highest frequency changes in architecture likely due to sea-level change, but the off- and onlapping sequence architecture within the LAR wedge is likely due to increased dynamic subsidence, which affected a broad area
- Dionisos models sediment fluxes very close to measured but tended to underestimate the flux
- Are we tracking cycles of dynamic subsidence??

Thank you

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