

PS Recognition of Fluvial Megafans: Comparison of Early Eocene Green River Formation in the Uinta Basin and Late Cretaceous Williams Fork Formation in the Piceance Basin*

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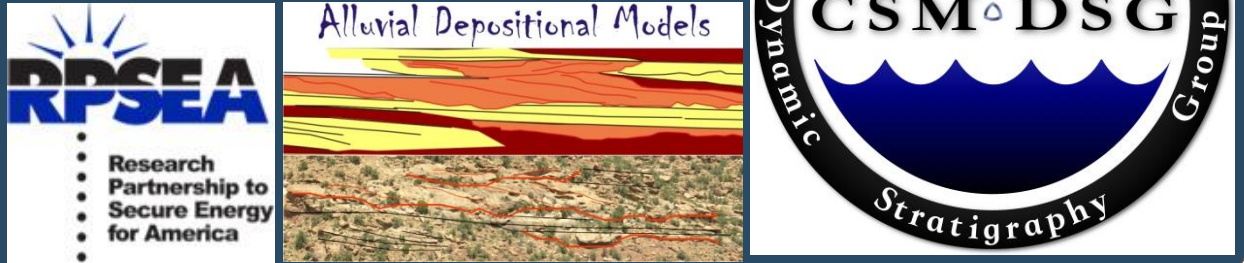
Abstract

Various large fluvial fan systems have been recognized in the geological record. Yet their sedimentologic and stratigraphic differences are unclear. This study recognizes the Early Eocene Green River Formation in the Uinta Basin and the Cretaceous Williams Fork Formation in the Piceance Basin as fluvial megafans, as seen by their lateral extent, internal architecture, and lateral and vertical facies transitions. Outcrop measured sections and photomosaics with GPS survey were integrated with areal mapping of channel dimensions, channel to floodplain ratio, and sedimentary facies variability. Core and well log were also used to quantify facies proportions and distributions. Sandying upward successions exist in both basins, seen as an increase in channel to floodplain ratio, channel size, and degree of amalgamation. Similar trends are also observed laterally that channel fill facies become more heterolithic away from the proximal fan zone. There are multiple scales of upward sandying packages, the largest being the whole fan system, and the smallest the individual avulsion packages. High avulsion rates and channel return frequency are interpreted to control the high degree of amalgamation on the proximal fans. The amalgamation degree is especially high in the Uinta Basin, where the channel fills indicate dominant upper flow regime and high deposition rates, representing flashy or highly seasonal deposition. The Williams Fork channel fills have a smaller proportion of upper flow regime and especially high deposition rate structures. The seasonality in places is indicated by repeated upward fining flood deposits. The red floodplain mudstones in the Green River Fm signify sustainably dry conditions, whereas the gray floodplain mudstones in the Williams Fork Fm indicate higher annual precipitation. The progradational fan units are interbedded by lakebeds in the Uinta Basin and tidal deposits in the Piceance Basin. The Green River Fm shows more frequent vertical and lateral alternations of fluvial deposits with lakebeds than tidal deposits in the Williams Fork Fm. Facies architectural variability in fluvial megafan systems was evaluated and a 3-D stratigraphic model was developed. The results showed that lateral and vertical facies associations vary with channel avulsion style and position within a fan. These systems were proved to be sediment supply driven rather than accommodation driven in both basins, regardless of sea level or lake level control.



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ABSTRACT

Various large fluvial fan systems have been recognized in the geological record. Yet their sedimentologic and stratigraphic differences are unclear. This study recognizes the Early Eocene Green River Formation in the Uinta Basin and the Cretaceous Williams Fork Formation in the Piceance Basin as fluvial megafans, as seen by their lateral extent, internal architecture, and lateral and vertical facies transitions. Outcrop measured sections and photomosaics with GPS surveys were integrated with areal mapping of channel dimensions, channel to floodplain ratio, and sedimentary facies variability. Core and well logs were also used to quantify facies proportions and distributions.

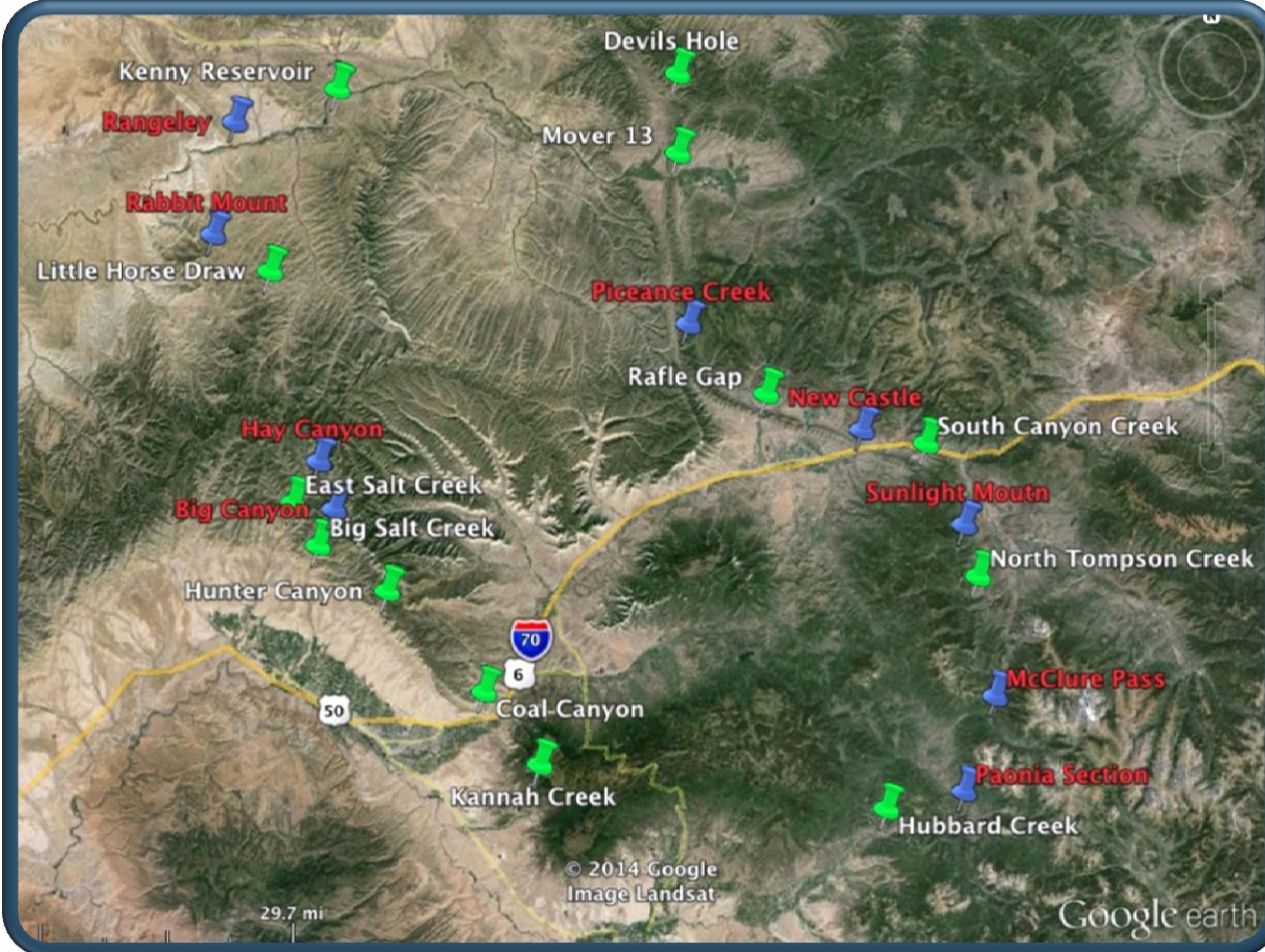
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STUDY AREA

The Wasatch and Green River Formation in the Uinta Basin, and the Williams Fork Formation in the Piceance Basin have been chosen due to the high quality of exposures, and availability of subsurface data. They are also complementary in that the Uinta Basin fluvial fan system indicates considerably dryer climatic conditions, and built into a lake, whereas the Williams Fork Formation fed into the Western Interior Seaway. Both systems indicate seasonal climate with seasonally and yearly variable discharge and precipitation. Field locations include: Nine Mile Canyon, 191 Road Cut, Hay Canyon In The Uinta Basin; Paonia Reservoir, Hubbard Creek, Hannah Creek, Coal Canyon, Big Salt Creek, Raffle Gap, New Castle, etc. in the Piceance Canyon.

Piceance Basin outcrop locations



Uinta Basin outcrop locations



Nine mile canyon outcrop locations



BACKGROUND

The Uinta Basin is asymmetrical with over 3000m thick alluvial-fluvial-lacustrine deposits that accumulated from the latest Cretaceous through middle Eocene time (Ryder et al., 1976). The climax of Laramide intraforeland uplift was recorded by the Paleocene North Horn Fm basal and internal unconformities, and coarse synorogenic conglomerates in the Uinta Basin (ca 71.3-55Ma) (Dickinson et al., 1988; DeCelles, 2004). The Eocene Green River Fm consists of alluvial-fluvial sediments derived from a large river system (California Paleoriver) with headwaters in the Mojave block and intertonguing lacustrine deposits (Ryder, 1976; Dickinson et al., 2012).

The Piceance Basin is an asymmetrical basin in the North American Cordilleran Basin receiving sediments transported from the Sevier fold and thrust belt (DeCelles, 2004). The Mesaverde Group is composed of the Iles Fm and Williams Fork Fm, and conformably overlying on the marine Mancos Shale from the Western Interior Seaway. The late Cretaceous Williams Fork Fm was deposited as a thick fluvial interval with great thickness variation from approximately 1200 feet to 5000 feet eastward (Collins, 1976). Beds dip steeply (>60°) to overturned near the Grand Hogback in the eastern part of the basin, and dip relatively gently (1-20°) in the west (Cole and Cumella, 2003). This change is caused by later basin margin uplift and erosion defined by the Ohio creek conglomerate below the Wasatch Fm (Collins, 1976; Cole and Cumella, 2003; Johnson and Roberts, 2003).

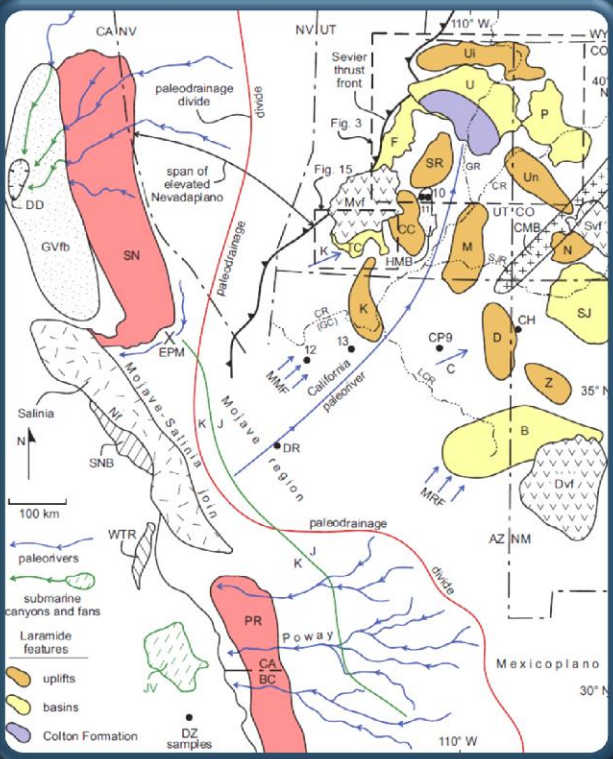


Figure 1. Left figure shows tectonic background illustration of Laramide basins and uplifts from Dickinson et al., (2012). California paleoriver is the major sediment provider of the Uinta Basin from south. Right figure shows geographic location of Piceance Basin in Late Cretaceous.



FLUVIAL MEGAFAN

The fluvial megafan model was developed by Singh et al., (1993), based on the Kosi megafan, and further developed by Shukla et al. (2001) based on the Ganga Megafan (North India). These systems had previously been described as inland deltas (Gole and Chitale, 1966), wet alluvial fans (Schumm, 1977), or braided stream fans (Blatt et al., 1980). Fluvial megafans are unusually large fan-shaped bodies (areas of 103-105 km²) of sediment that created by rivers draining mountain ranges (usually thrust belt in foreland basin). Leier et al. (2005) linked fluvial megafans to moderate to large drainage basins with moderate to high relief, and proposed the formation of fluvial megafan requires rivers that undergo seasonal fluctuation in discharge.

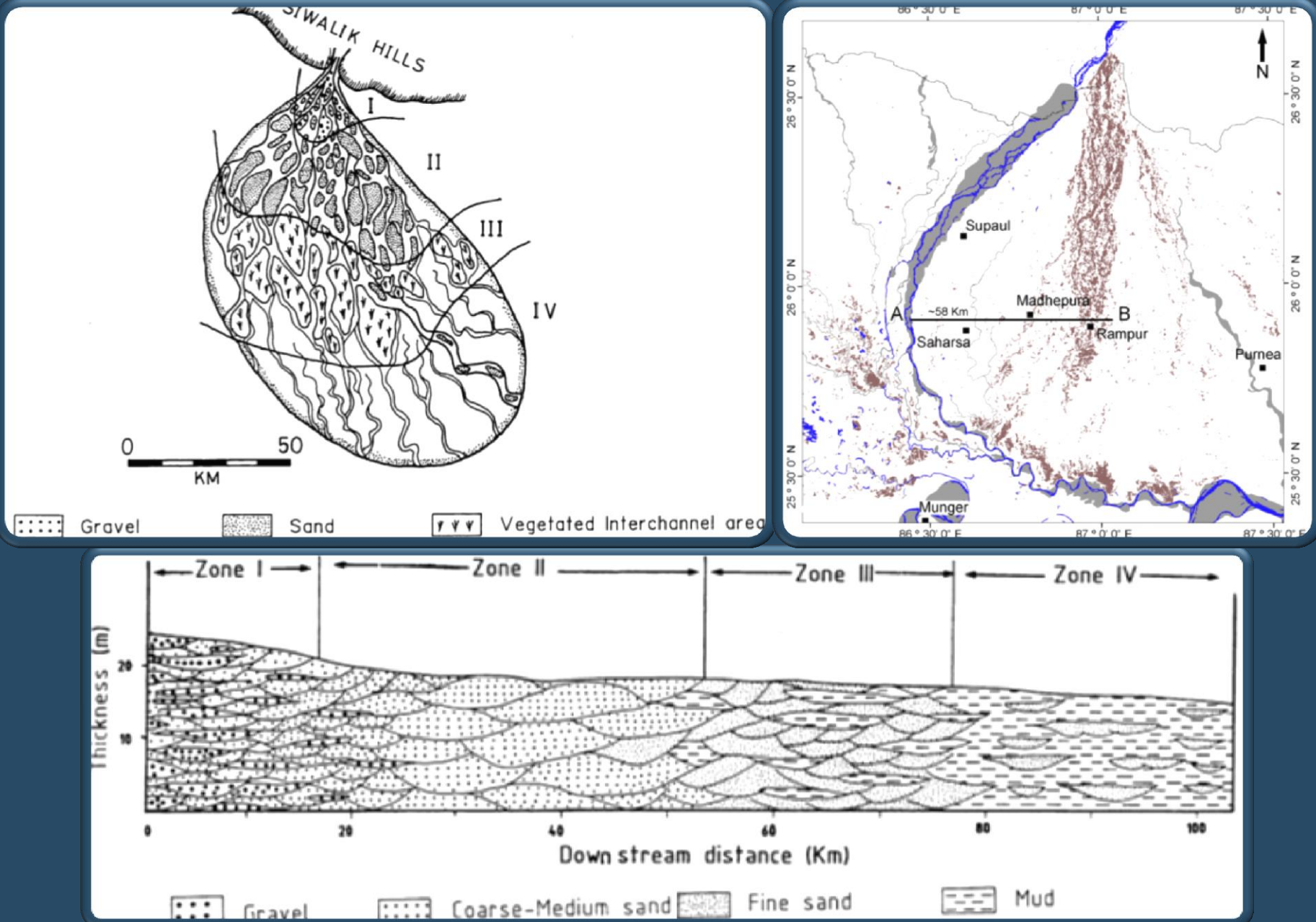


Figure 2. Megafan example from Shukla et al., (2001)

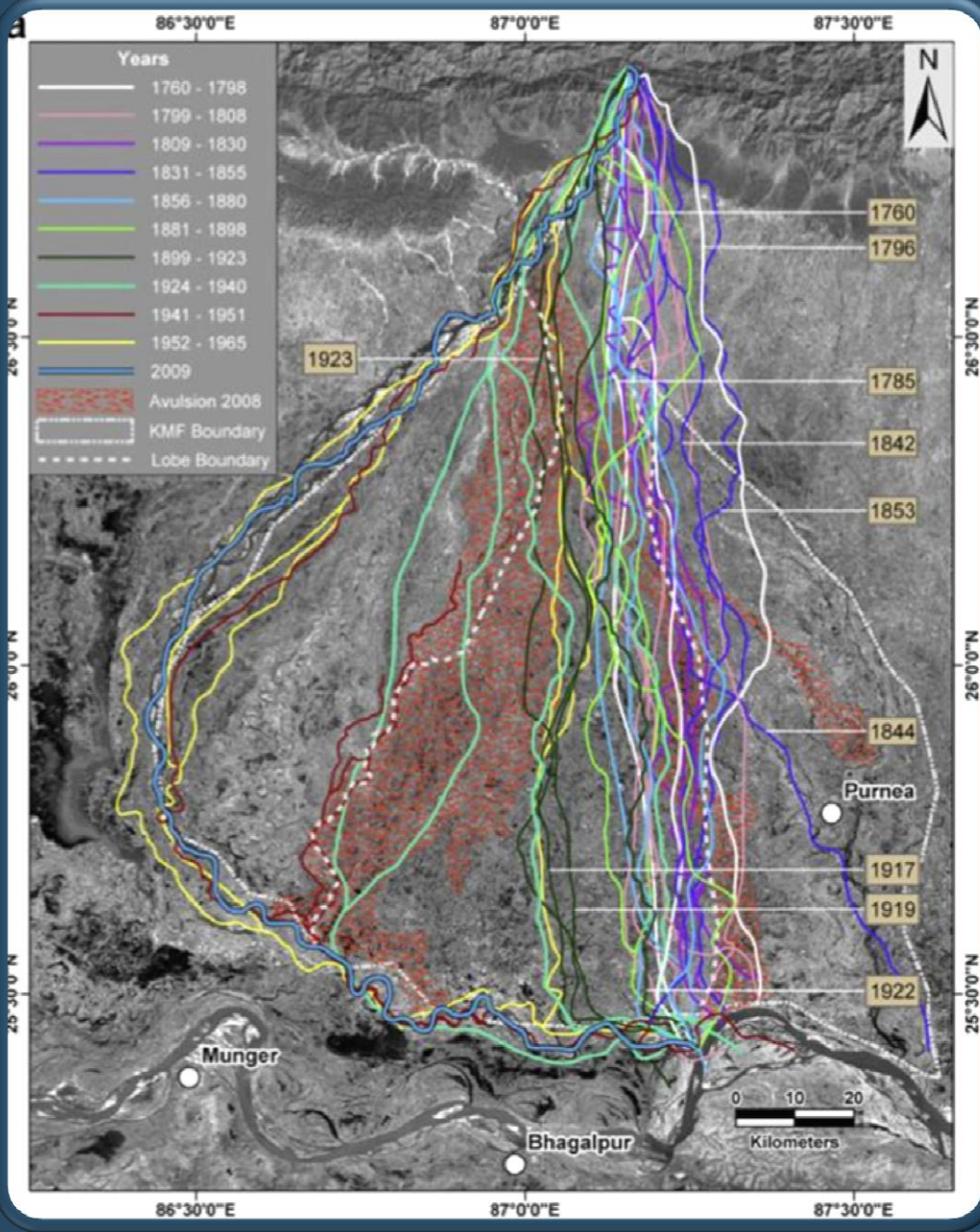


Figure 3. Megafan example from Chakraborty et al., (2010)

METHODOLOGY

The work in the Uinta Basin and the Piceance Basin builds on the preliminary results of the stratigraphic framework that has been accomplished by the ADMC and Green River Consortia and on the recent RPSEA project work respectively. Subsurface data will be added in both basins, and published papers and theses are to be reassessed according to the new hypothesis.

Field work examined sedimentary features of fluvial fans, extent of the fluvial system, vertical and lateral trends in channel dimensions, degree of amalgamation, channel fill lithofacies, and proportion of sand vs. mud.

The vertical facies heterogeneity is documented using lateral mapping, detailed measured sections and high-resolution outcrop photomosaics. Measured sections are obtained along the western, southern, and eastern margins in the Uinta Basin and along the margin of the Piceance Basin. Stratigraphic cross sections will be generated to show general facies types, stratal bounding surfaces, and major erosional surfaces. Outcrop Gamma Ray will be taken for correlation with well logs.

Subsurface data (well logs and cores) will be incorporated to make comparisons between the two data sets. This subsurface data will complement the outcrop correlations.

Satellite images and modern fluvial megafans will be checked as a comparison of specific features, such as lobe switching, dynamic discharge data, and avulsion rate.

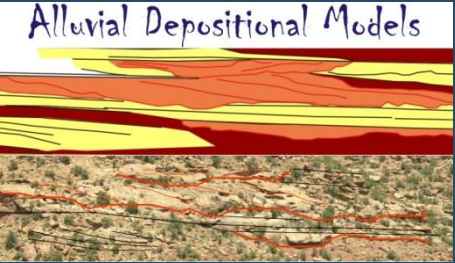
SIGNIFICANCE

- Visualize basin-scale stratigraphic relationships of fluvial successions with contemporaneous lacustrine and marine deposits.
- Update fluvial reservoir models.
- Contribute to the advancement and development of the fluvial fan concept.
- Demonstrate that fluvial megafans, unconfined fluvial systems, can be of great economic interest.
- Improve predictability, reserves estimation, and forecasting in fluvial plays, which are not traditional confined fluvial systems.
- Test the assumptions on accommodation controls
- Improve understanding on fluvial stratigraphy
- Improve facies models for seasonal rivers



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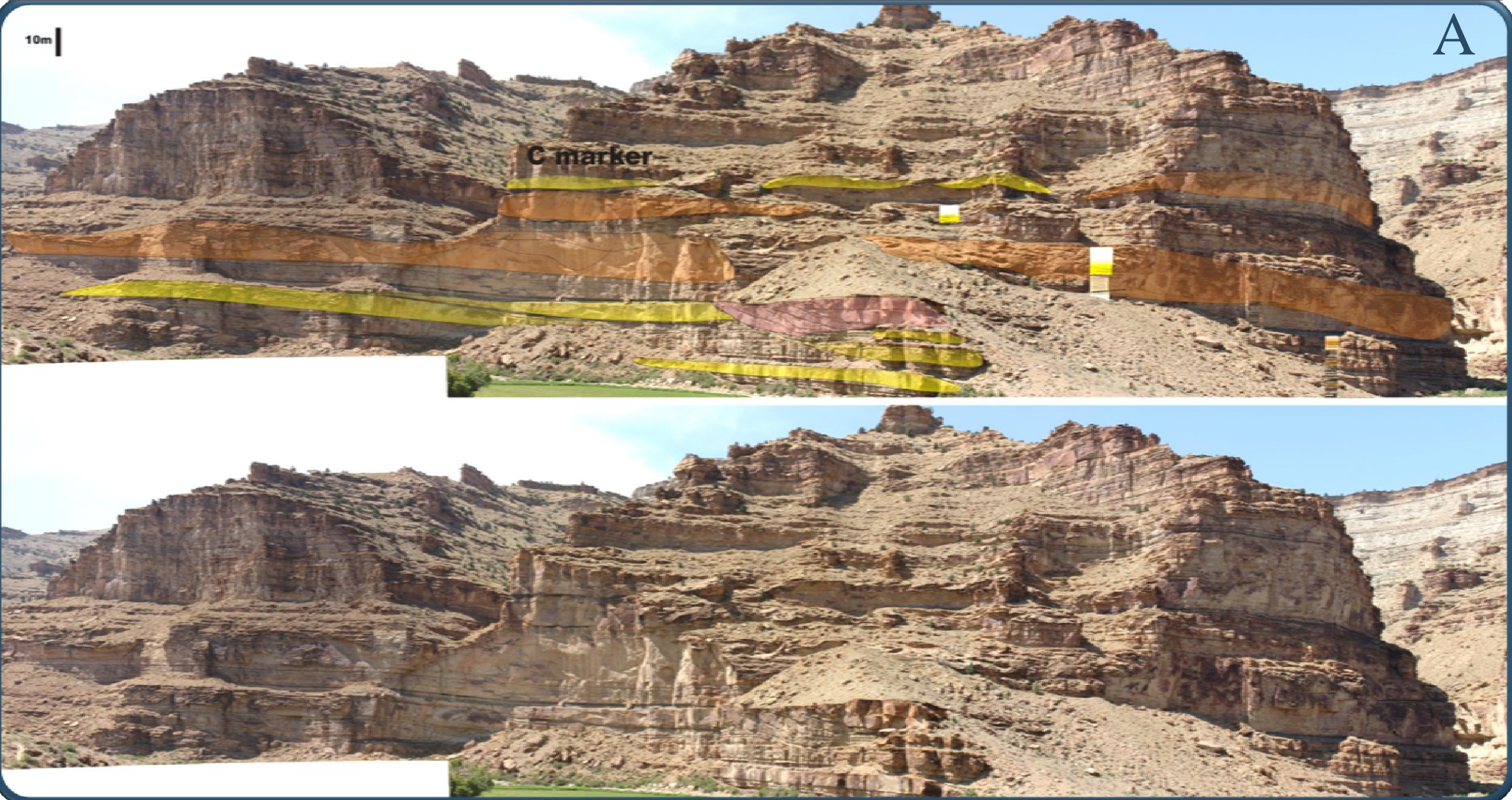
Jianqiao Wang¹, Piret Plink-Bjorklund¹, Chayawan Jaikla¹ ¹ Department of Geology & Geological Engineering, Colorado School of Mines



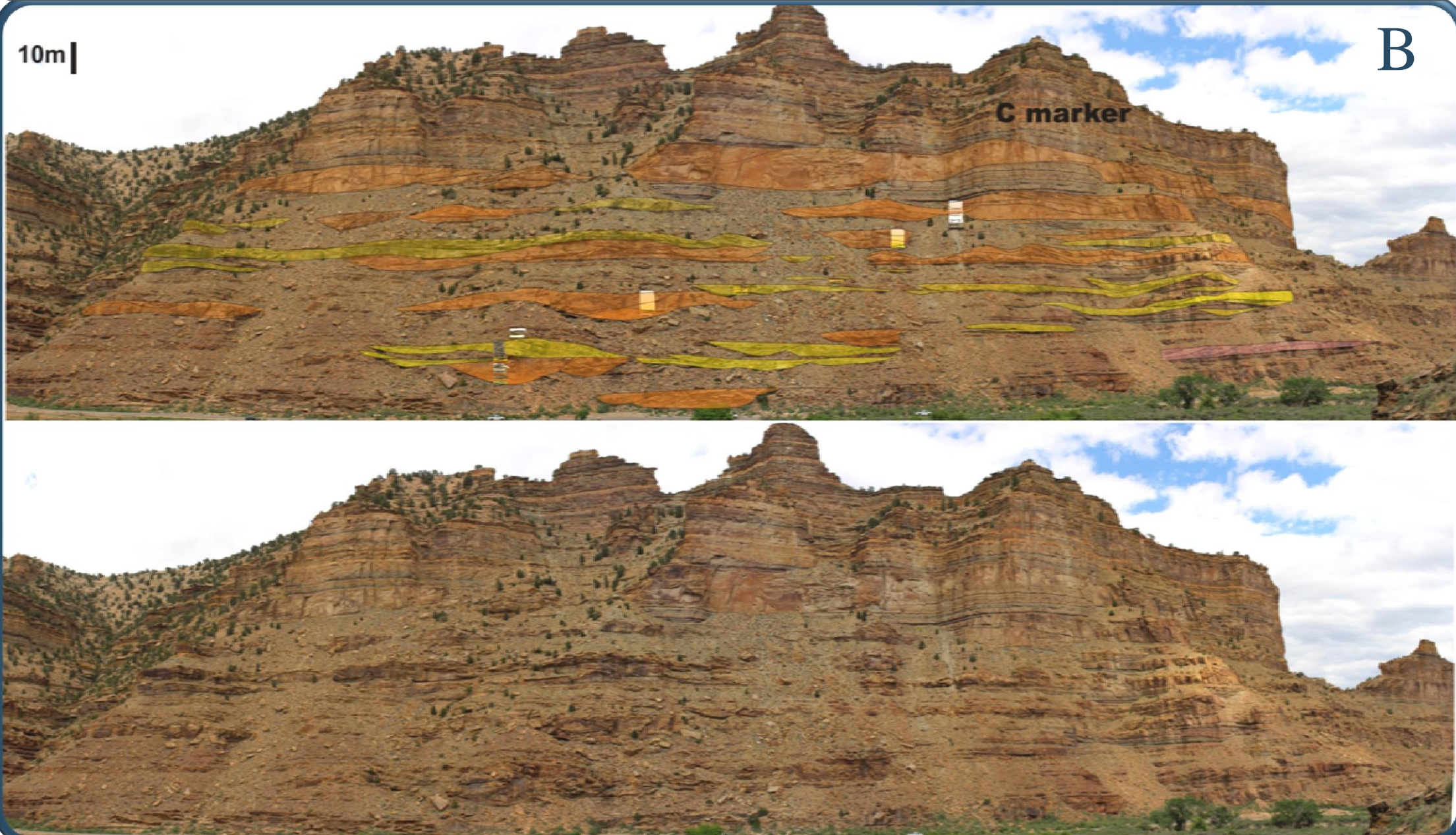
CRITERIA FOR RECOGNITION

To distinguish from DFS, it is a radiating set of channels produced by successive nodal avulsions, in which generally only one channel is active at one time (North and Warwick, 2007). Specifically, fluvial megafans are recognized for the mound like fan shape, large lateral extent, predictable lateral and vertical changes in net/gross ratio, channel amalgamation degree, and channel size/type. Fluvial megafan deposits have been recognized in the ancient stratigraphic record in the Paleogene Pyrenees (Alberto et al., 2007), Luna System in the Ebro Basin (Arenas et al., 2001), Cretaceous to Paleocene Cordilleran foreland basin (Lindsey, 1972; Lawton et al., 1994; DeCelles and Cavazza, 1999), western margin of Cretaceous foreland basin (Foreman et al., 2012), and Pennsylvanian deposits in the Paradox Basin (Barbeau, 2003), as well as in modern examples, occurring in Gangetic Plain in front of Himalaya (Geddes, 1960; Wells and Dorr, 1987a, 1987b; Willis, 1993; Sinha and Friend, 1994; DeCelles et al., 1998), Chaco Plains across South America (Latrubesse et al., 2012), southern European Alps (Fontana et al., 2014), and in the central Andes (Damanti, 1993; Horton and DeCelles, 2001).

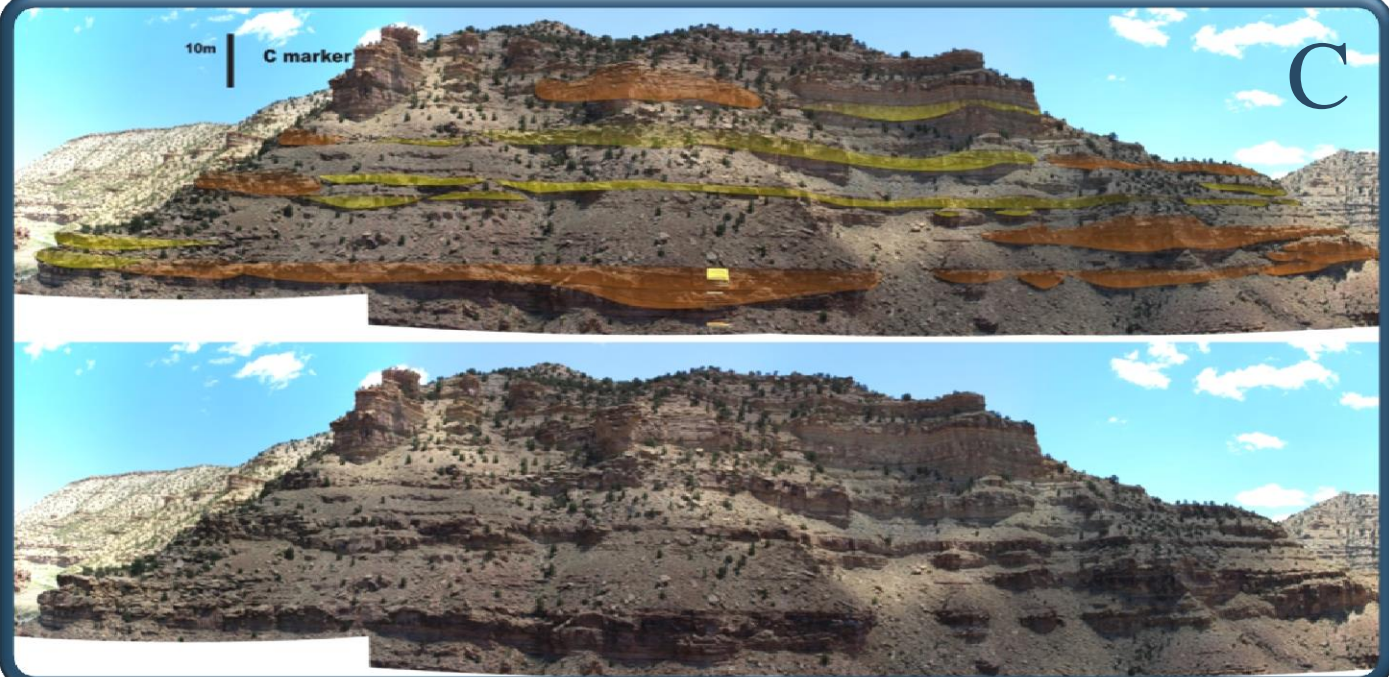
45 mile marker in Nine Mile Canyon



41 mile marker in Nine Mile Canyon



38 mile marker in Nine Mile Canyon



LATERAL TREND

	191 Road Cut (Distal)	9 Mile Canyon (Proximal)	Hay Canyon (Distal)
CHANNEL ARCHITECTURE	<ul style="list-style-type: none">Inclined heterolithic accretion units	<ul style="list-style-type: none">TabularIncisedAccretion unitsLenticular	<ul style="list-style-type: none">TabularIncisedAccretion unitsSharp based
FLOODPLAIN	<ul style="list-style-type: none">Wood piecesPurple/red, greenClaystone-siltstone	<ul style="list-style-type: none">Mud cracksPurple/red, greenRoots, wood piecesClaystone-siltstone	<ul style="list-style-type: none">GreenishClaystone-siltstoneCoal
LAKE BEDS	<ul style="list-style-type: none">Fissile carbonaceous mudGreenish grey	<ul style="list-style-type: none">Ooid GrainstoneMolluscan ClaystoneOstracod bearing sandstoneBlocky carbonaceous mudOrange skeletal rudstone	<ul style="list-style-type: none">Organic Carbonate 'oil shale'Blocky carbonaceous mudGreenish greyFissile carbonaceous mud
SEDIMENTARY STRUCTURE	LFR and UFR	UFR, HDR dominant	UFR, HDR dominant

191 Road Cut



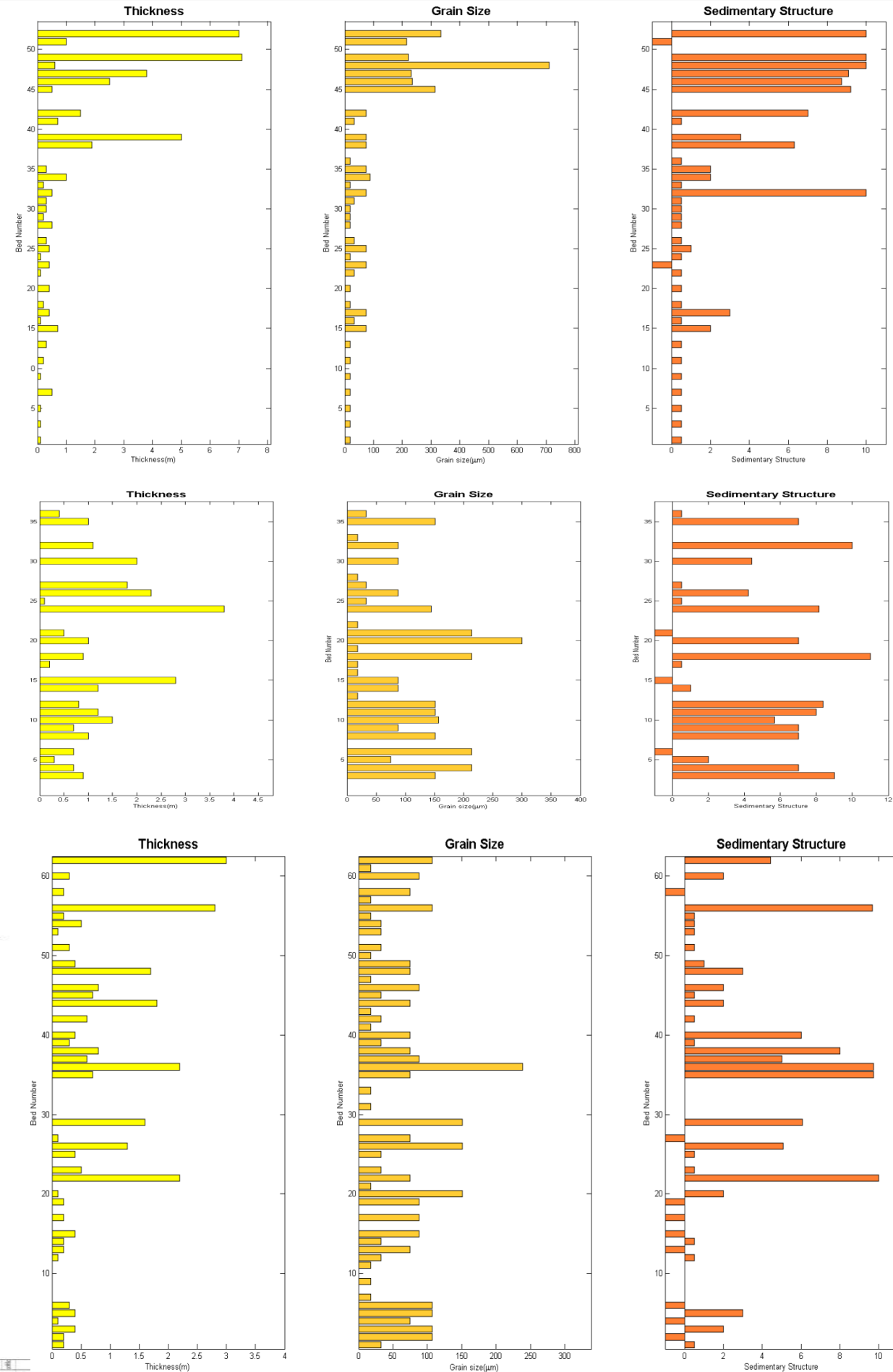
Heterolithic channel

Hay Canyon



Small channel incision

VERTICAL TREND



Nine Mile Canyon



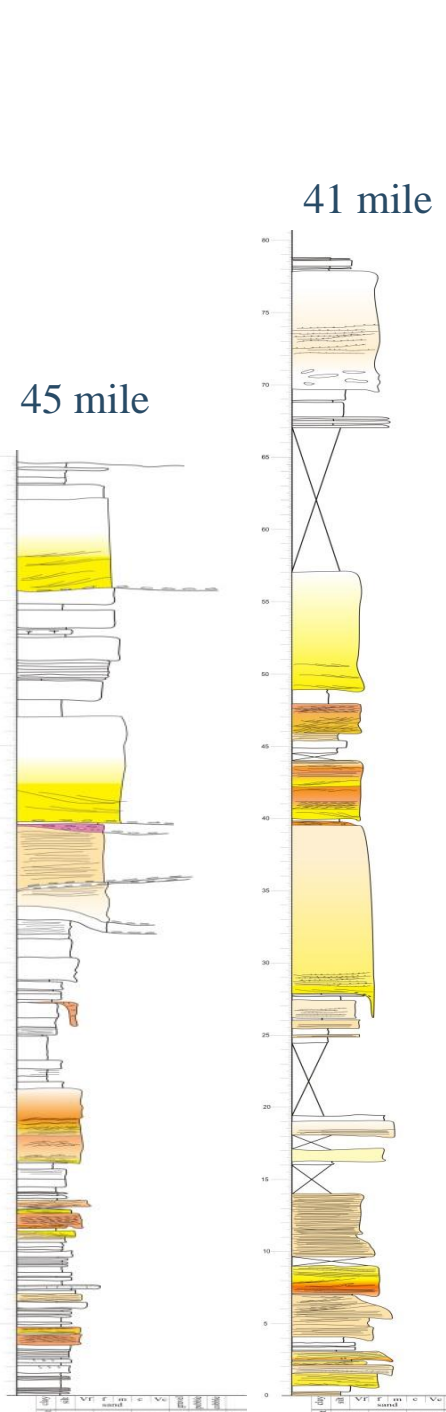
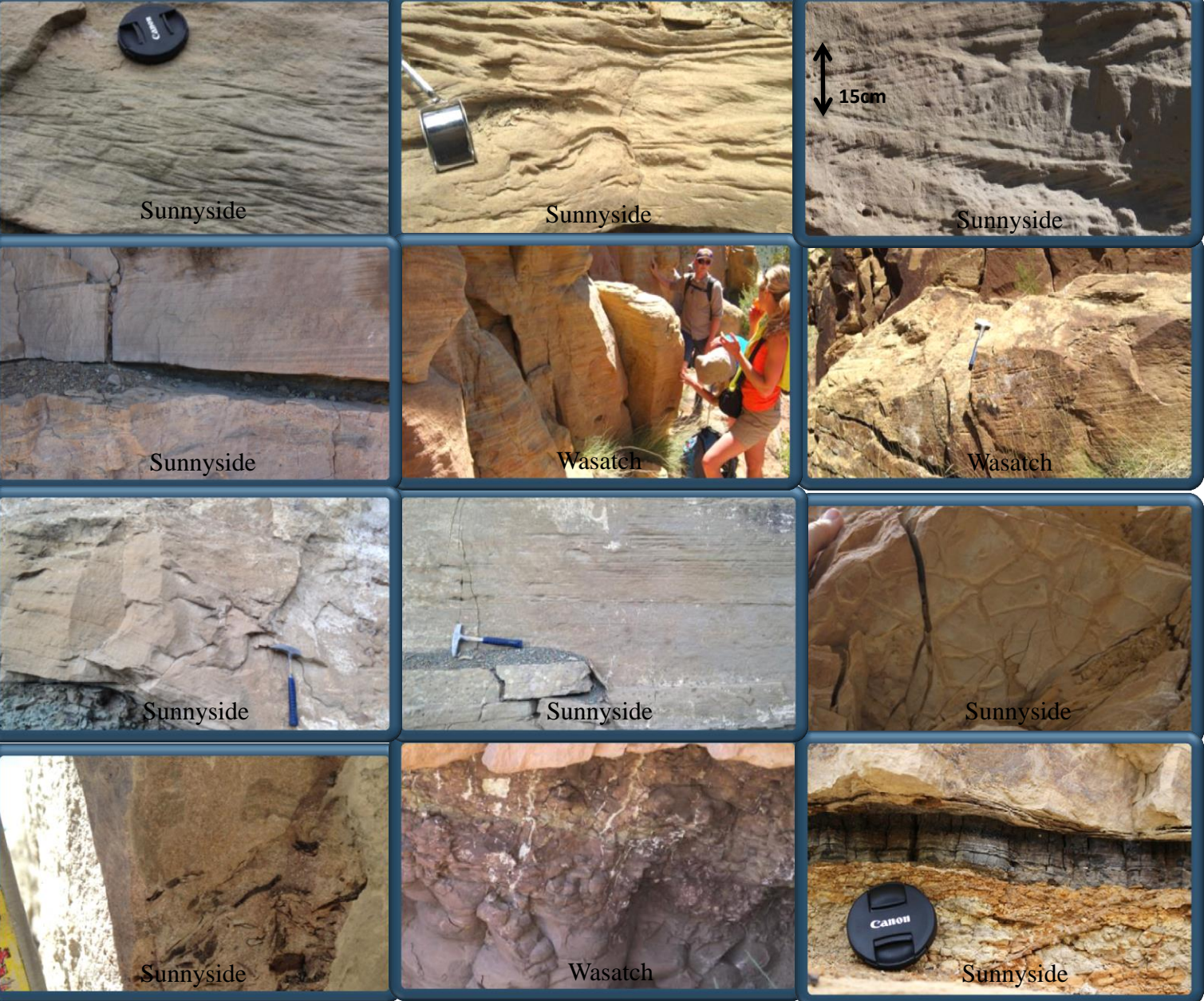
Large channel incision

Coal Canyon, Piceance Basin



Figure above: coarsening upward packages shown in the Williams Fork Formation. Figure to the right: Pictures showing different facies (from upper left to lower right) climbing ripples, climbing ripples with soft sediment deformation, climbing dunes, convex-up low-angle bedforms, gradational planar laminations, scour and fills, scour and fills, gradational planar laminations, mud cracks, terrestrial organic matters, bioturbated mudstone, cm scale coal layer

FACIES

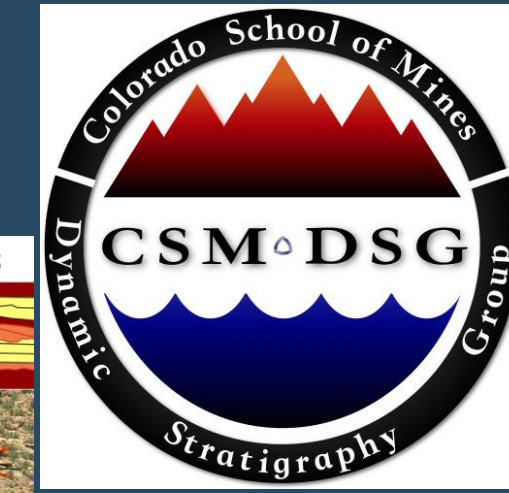
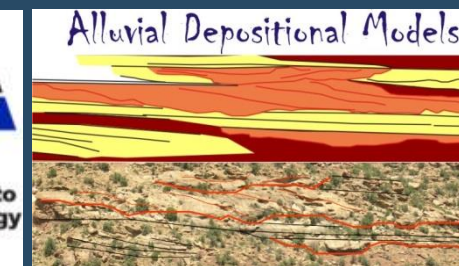


Internal erosive surfaces in channel



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SEASONAL INDICATORS

Seasonal precipitation provides extreme high water discharge as well as sediment supply. These pronounced seasonal fluctuations in fluvial discharge, erosion, and sediment transport are reflected in many fluvial megafans. Specifically, modern fluvial megafans in actively aggrading basins are produced by seasonal rivers resulting from highly seasonal precipitation patterns (Leier et al., 2005). Figure 5 below implies megafans do not form if the rivers are not seasonal. It also shows many seasonal rivers do not form megafans. Note that discharge peakedness equals the ratio of average discharge during the month with the greatest discharge over the average annual discharge. All ancient examples of fluvial megafans have been linked to seasonal discharge (e.g. Lawton et al., 1994; DeCelles and Cavazza, 1999). Increased seasonality increases monsoon strength, consequently promotes formation of fluvial megafan (Goodbred, 2003; Leier, et al., 2005).



Figure 4. Outcrop examples showing seasonal indicators: layered conglomerate, in channel mud, soft sediment deformation, aggradational ripples/soft sediment deformation, in-channel bioturbation

Characteristic facies (Plink-Bjorklund, 2015):

- Froude transcritical and supercritical flow (upper flow regime) sedimentary structures: parallel or planar laminations, convex-up low-angle bedforms, scour and fill structures, humpback or sigmoidal cross strata. These are attributed to high flow velocities, and the characteristically rapid rise, sharp peak and rapid decline of the flood hydrograph.
- High deposition rate sedimentary structures: aggradational UFR sedimentary structures, climbing dune stratification, climbing ripple lamination, and gradational planar lamination.
- In-channel mud layers
- Thick soft-sediment clast conglomerates
- Soft-sediment deformation structures
- In-channel vegetation and vegetation-induced sedimentary structures.
- In-channel trace fossils

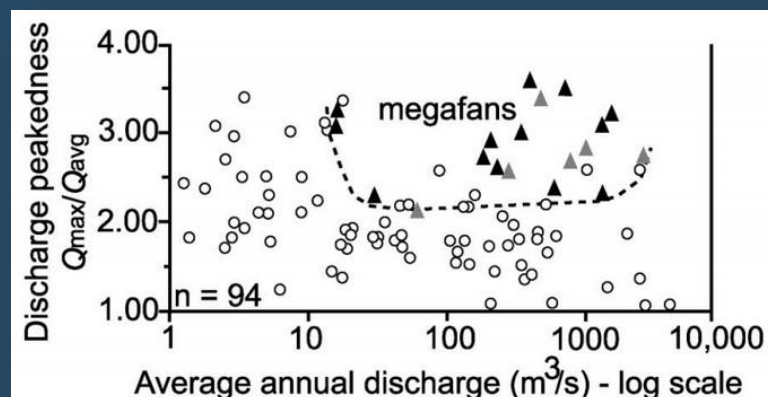


Figure 5. Modern fluvial megafans' discharge compare to the rest fluvial fans (Leier et al., 2005)

DOMINANT PROCESSES

Many channel avulsions have occurred during the last decade show significant channel location changes.

Kosi River:

- Time: August 2008
- Reason: triggered by a breach at a location 12km upstream
- Results: it forced the Kosi River shift by ~120km eastward (Sinha, 2009) with 80%-85% of the Kosi water discharge shifted (Sinha, 2009).

Indus River:

- Time: 2010
- Results: It caused two major river avulsions. One of them made the river flow 50-100km west of its pre-location (Syvitski and Brakenridge, 2013).



Figure 6. Kosi Fan satellite image (Shukla et al., 2004)

What is avulsion?

- Avulsion is a natural consequence of crevasses in the natural levees (Assine, 2005). Gradual avulsions occur through the process of crevassing and a gradual shift of river discharge to the new channel. Abrupt avulsions are shifts of majority of the discharge during single flooding events. Avulsions happened in Kosi River and Indus River may result in permanent channel location shift over many years of time.

Are avulsions related to seasonal precipitation ?

- As long as sediment accumulation in the main channel elevates high enough, ongoing flood may then breach in banks and levees allow shift of channel. The temperate crevasse may evolve into a complete avulsion with repeating floods. Seasonal precipitation certainly promotes avulsion as deposition rate is high enough to fill up the channel and UFR flow scouring deeply enough to create a persisting new channel. Meanwhile, numerous sediments accelerate speed of the filling process. In this case, the new channel may be immediately occupied rather than taking decades.

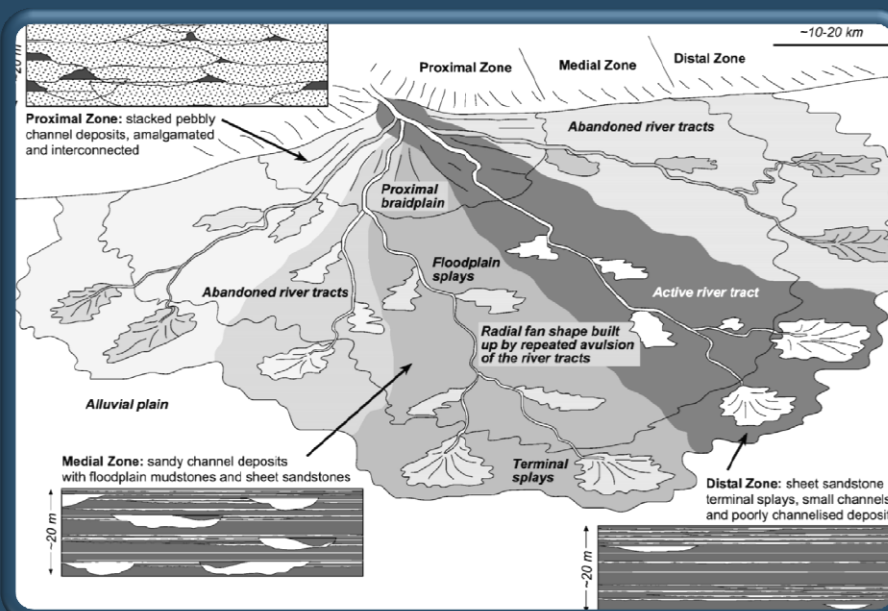


Figure 7. Fluvial distributary system (Nichols and Fisher, 2007)

Avulsion vs. bifurcation

- By dropping sediments as flow velocity decreases entering a water body, the flow is forced to bifurcate. e.g. mouth bar development
- River changes its main path as old path being filled up by sediments
- Hard to distinguish from satellite image

FLUVIAL STRATIGRAPHY

Question 1. Accommodation control vs. autogenic control

- Fan aggrades as lobes switch
- Channel avulsion controlled
- Ultimately controlled by sediment flux and river discharge
- Fluvial megafans export sediment and water and may feed large delta and submarine fan systems, (Ganges-Brahmaputra delta and fan)
- Large channel size and high amalgamation degree in proximal fluvial megafans allows predictable downstream and vertical changes, as seen in each avulsion cycles, which is hard to predict in confined river system.

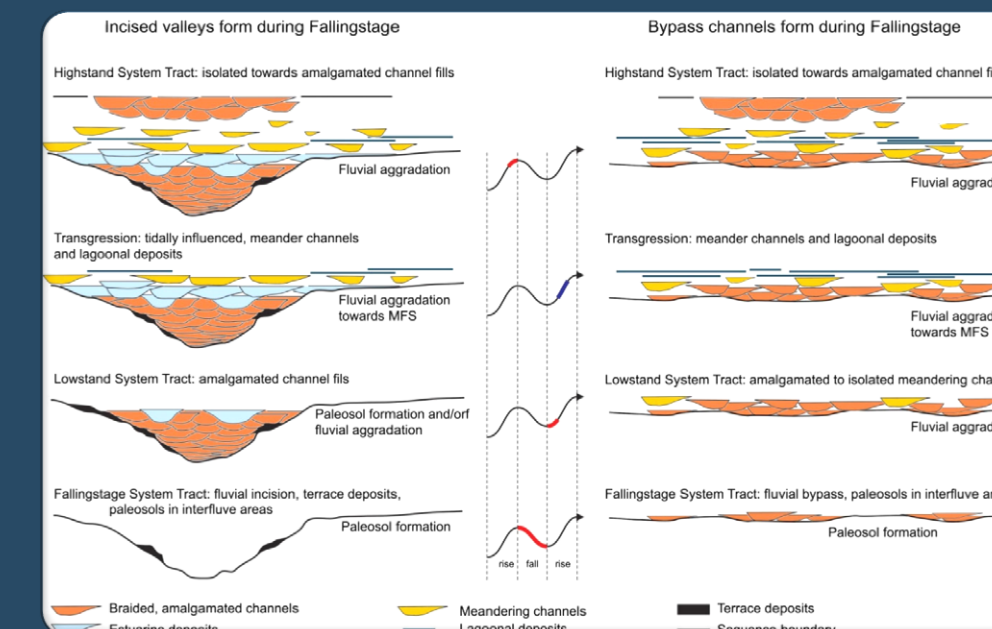


Figure 8. Fluvial stratigraphy diagram illustration (Van Strien, modified from Shanley and McCabe, 1993)

Question 2. complicated system

- Lake level vs. sea level (fluctuation cycle)
- Mixed carbonate and siliciclastic system
- Proportion of true deltaic deposits

Question 3. Architectural elements

From Plink-Bjorklund, 2015

- Flood unit
- Poorly developed macroforms
- Avulsion

Question 4. Signified topography

- Transverse profile: self-built mound shape topography

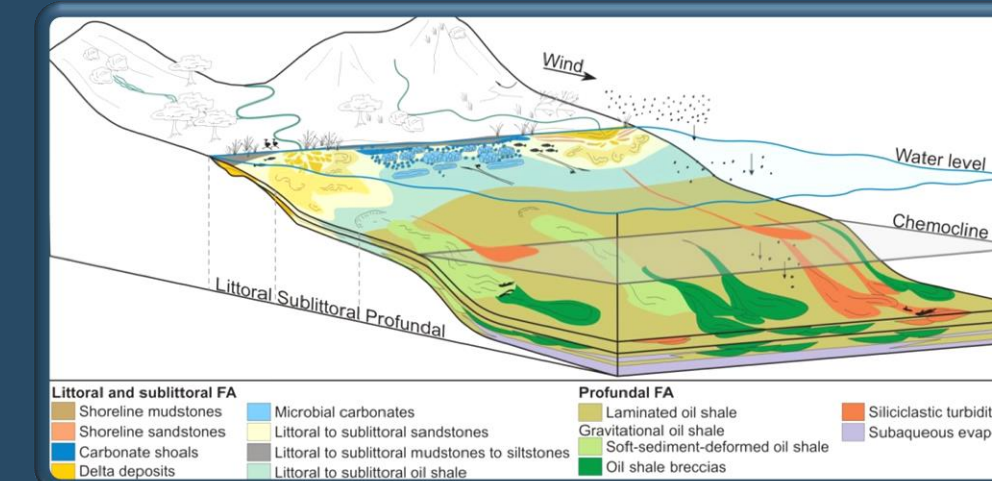


Figure 9. Lacustrine depositional environment with mixed siliciclastic and carbonate deposits (Tänavsüu-Milkeviciene and Sarg 2012).

PRELIMINARY RESULTS

- Channels are larger in axial part of fluvial megafan.
- Flood plain deposits become more extensive in fan margin.
- High deposition rate sedimentary structures are dominant.
- Amalgamation rate increases laterally and vertically towards the axial part of the fan system.

FUTURE WORK

- Subsurface data analysis (Well logs, cores, thin sections)
- Generate conceptual geologic model in Petrel
- Test geologic model production data
- Run flow simulation under geologic parameters control

ACKNOWLEDGEMENT

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