Controls on Deposition within Arid Continental Basin Margin Systems: Implications for Basin-Scale Fluid Migration*

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Abstract

Continental basin margins are commonly dominated by alluvial fan environments, which are long-lived throughout basin development. Fan deposition is influenced by: 1) varied transport and depositional mechanisms; 2) interactions between the fan and contemporaneous environments in the basin centre; 3) long-term allocyclic climatic variations; and, 4) localised autocyclic variations. Towards the distal extent of the basin, the alluvial fan interdigitates through a zone of interaction with contemporaneous environments in the basin centre. The sedimentology of the zone of interaction can have a significant impact upon basin-scale fluid flow by generating or restricting fluid migration pathways between the fan and permissible reservoir or seal lithologies in the basin centre. This work considers a well-exposed analogue for continental basin margin systems through the examination of the Cutler Group sediments of the Paradox Basin, western U.S.A. The work presents generalised spatial facies models across the Cutler Group alluvial fans and the zone of interaction. Temporal facies models have been constructed to highlight how long-term allocyclic climatic variations and short-term and localised autocyclic variations control deposition in the Cutler Group. The identified cyclicity highlights clear horizons, which can be used to cyclostratigraphically correlate through the deposits, allowing for the further examination of basin-scale fluid migration pathways. The generic facies models derived from this work are applied to the basin margin sediments of the Permian Brockram Facies, of the East Irish Sea Basin, U.K. The application of the Cuter Group models provides significant insight into the sedimentology, geometry, and flow pathway connectivity of the Brockram Facies. This work highlights the impact of the deposits of both the alluvial fan and the

zone of interaction on basin-scale fluid migration pathways and prospectivity in continental basins. The facies models show that basin margin sedimentation controls: 1) the connectivity of otherwise isolated potential reservoirs in the distal extent of the basin; 2) the development of 'thief zones' away from distal reservoirs; 3) the creation of bypass routes to charge distal reservoirs; and, 4) the introduction of baffles into an otherwise productive system. The net effect on fluid flow can be examined through the generation of a climate-based cyclostratigraphical framework.

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Nuccio, V.F., and S.M. Condon, 1996, Burial and Thermal History of the Paradox Basin, Utah and Colorado, and Petroleum Potential of the Middle Pennsylvanian Paradox Formation: U.S. Geological Survey Bulletin 2000–O, 47 p.

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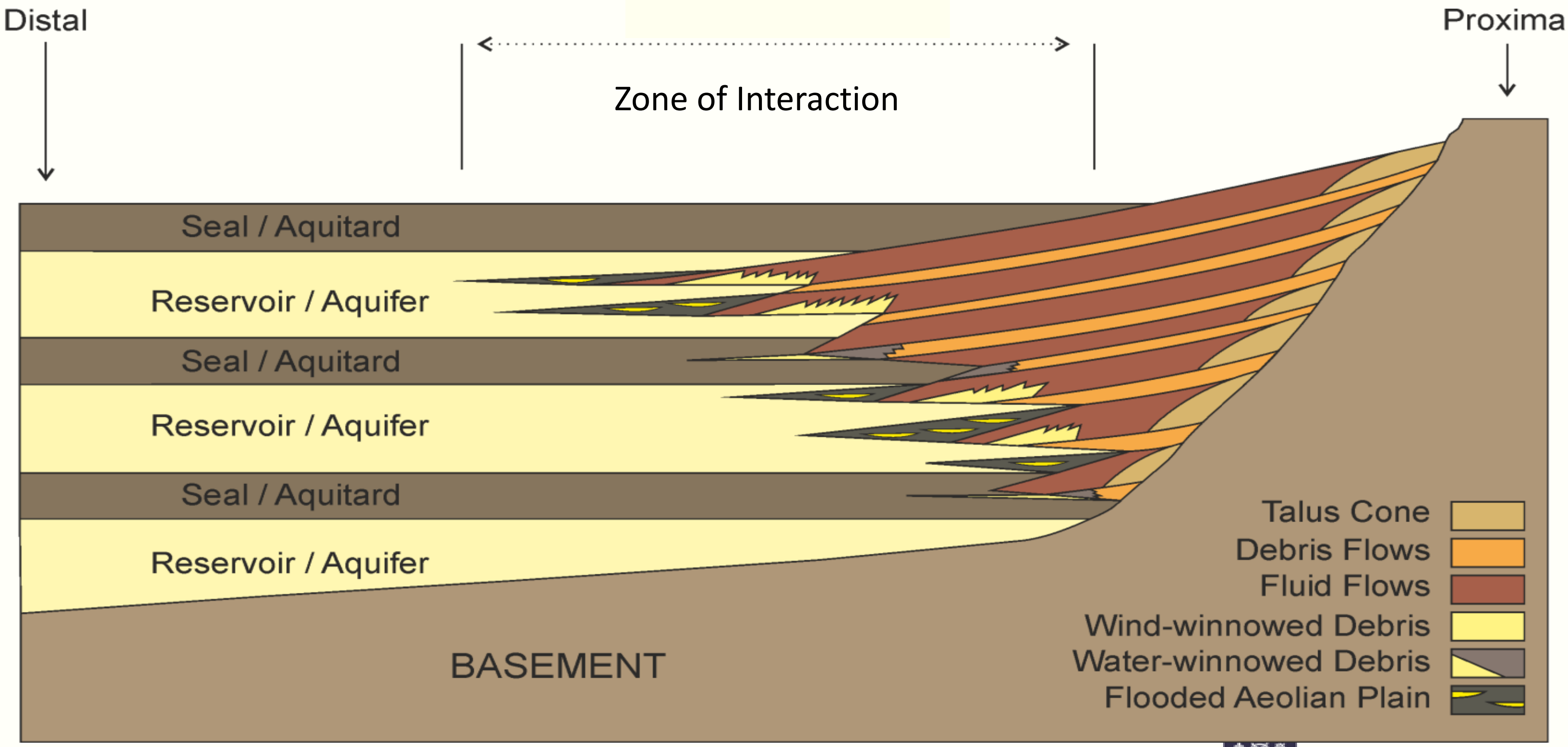
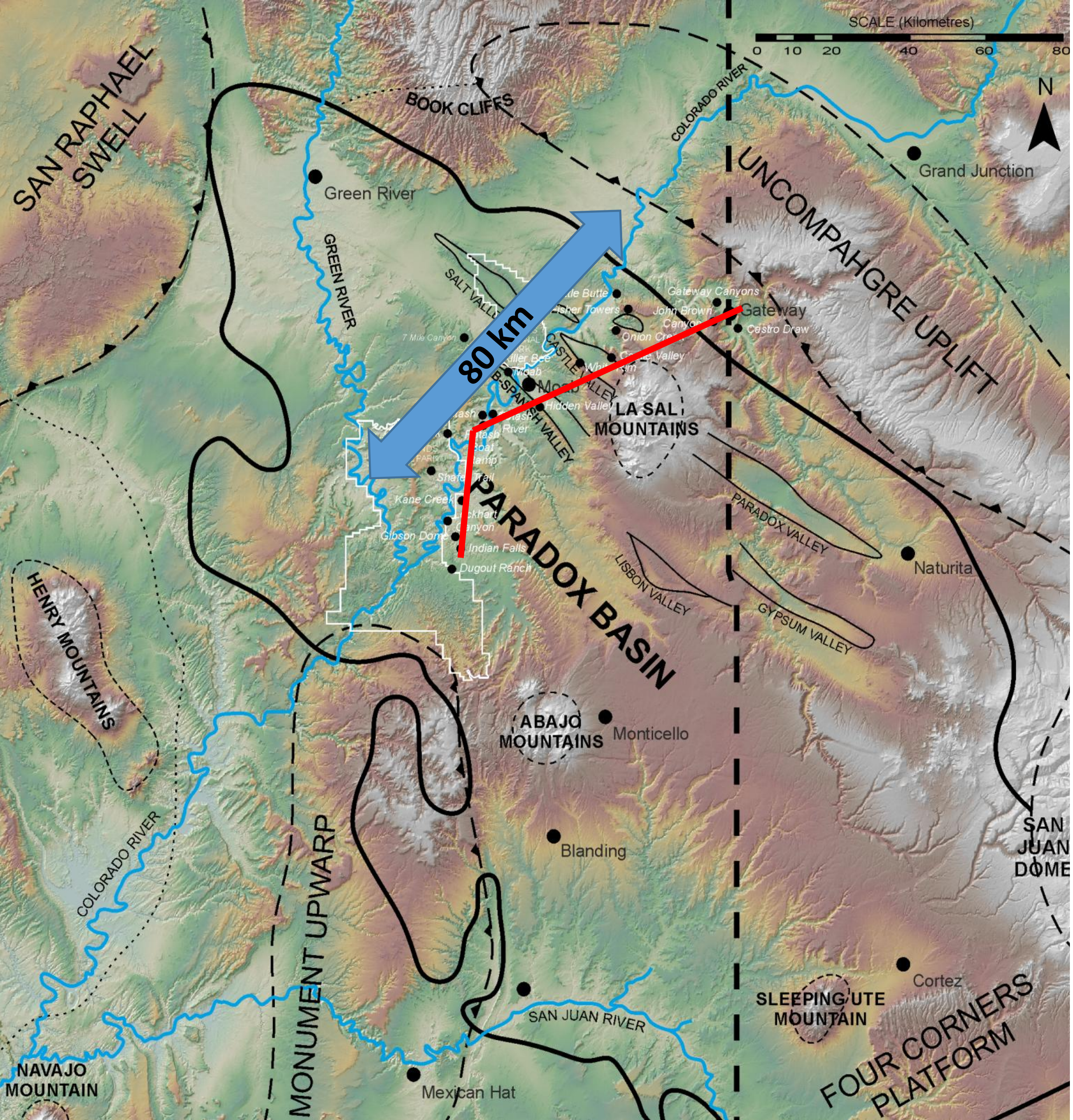
Project Rationale

- Understand the sedimentology of alluvial fan systems
- Understand interaction of fan with basin centre deposits
- Generates a climatic framework applicable to other fan deposits
- Assesses implications on basin-scale hydrocarbon migration and charge –
    - Do interactions create flow zones or flow barriers



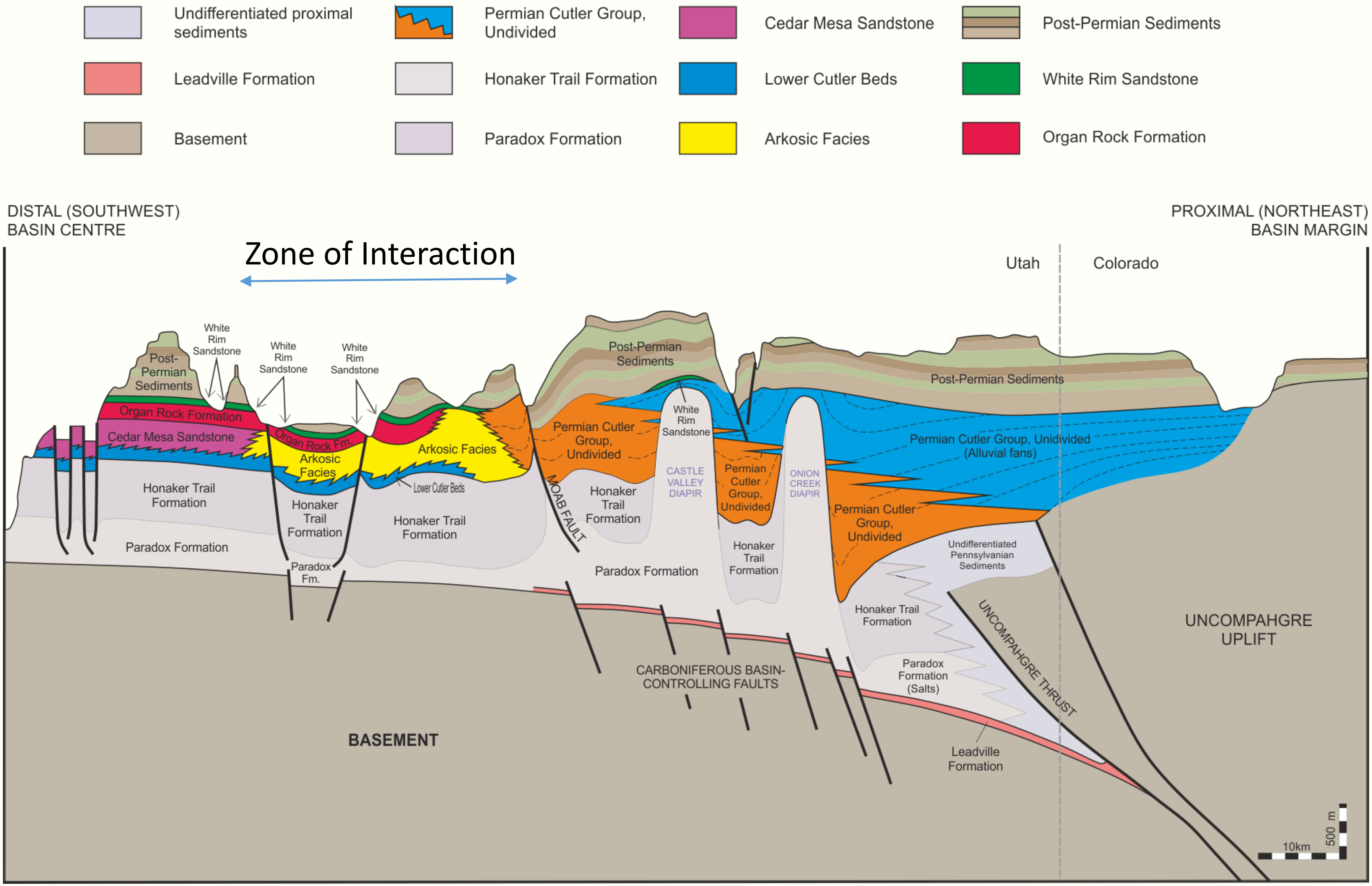


Paradox Basin in relation to the U.S.A.

The stratigraphy of the Paradox Basin

Pg	Green River Formation	
	Wasatch Formation	
K	Mesa Verde Group	
	Mancos Shale	
	Dakota Sandstone	
	Cedar Mountain Formation	
J	Morrison Formation	
	San Rafael Group	
	Glen Canyon Group	
T	Chinle Formation	
	Moenkopi Formation	
P	Cutler Group, Undivided	White Rim
		Organ Rock
		Cedar Mesa
		Lower Cutler beds
C	Hermosa Group	

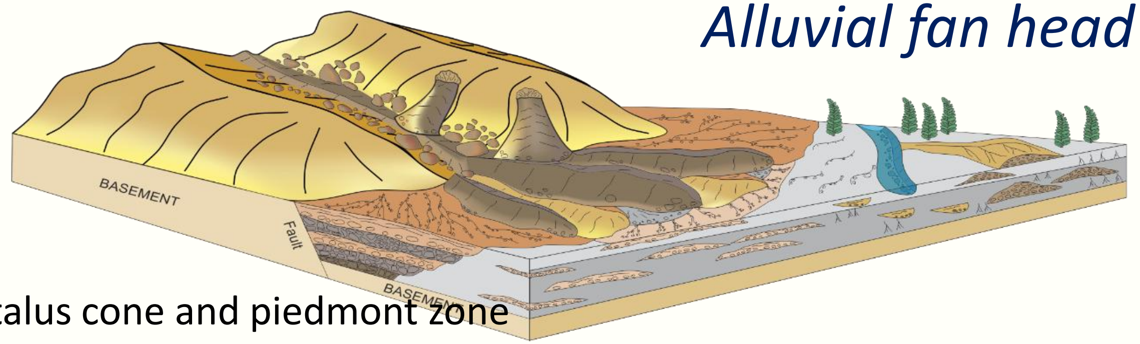
After Nuccio & Condon 1996



Undifferentiated proximal sediments
Permian Cutler Group, Undivided
Cedar Mesa Sandstone
Post-Permian Sediments
Leadville Formation
Honaker Trail Formation
Lower Cutler Beds
White Rim Sandstone
Basement
Paradox Formation
Arkosic Facies
Organ Rock Formation
DISTAL (SOUTHWEST)
BASIN CENTRE
PROXIMAL (NORTHEAST)
BASIN MARGIN
Zone of Interaction
Utah
Colorado
Post-Permian Sediments
White Rim Sandstone
Organ Rock Formation
Cedar Mesa Sandstone
Honaker Trail Formation
Paradox Formation
Organ Rock Fm.
Arkosic Facies
Lower Cutler Beds
Paradox Fm.
Permian Cutler Group, Undivided
MOAB FAULT
CASTLE VALLEY DIAPIR
ONION CREEK DIAPIR
Permian Cutler Group, Undivided (Alluvial fans)
Undifferentiated Pennsylvanian Sediments
Paradox Formation (Salts)
UNCOMPAHGRE THRUST
UNCOMPAHGRE UPLIFT
CARBONIFEROUS BASIN-CONTROLLING FAULTS
BASEMENT
Leadville Formation
500 m
10km

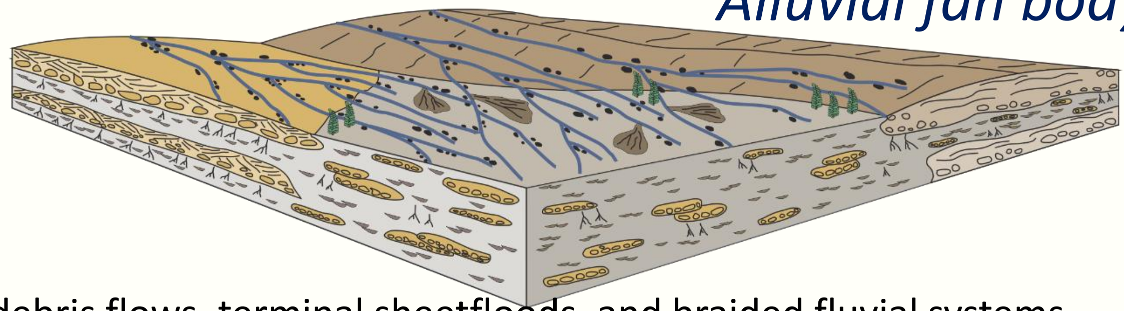
Evolution of the basin margin alluvial fans

Alluvial fan head



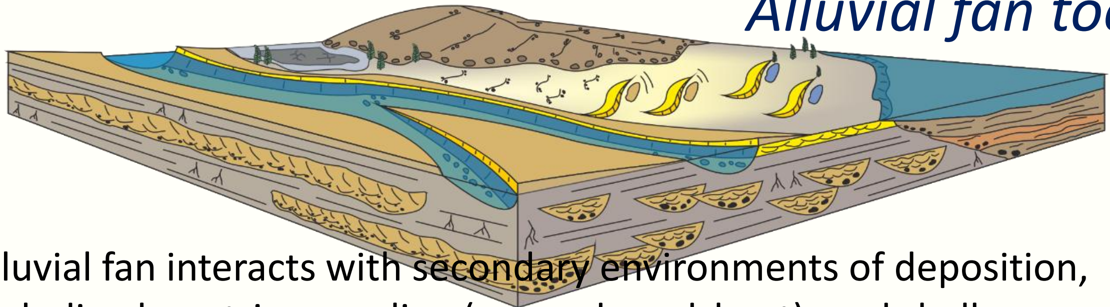
talus cone and piedmont zone

Alluvial fan body



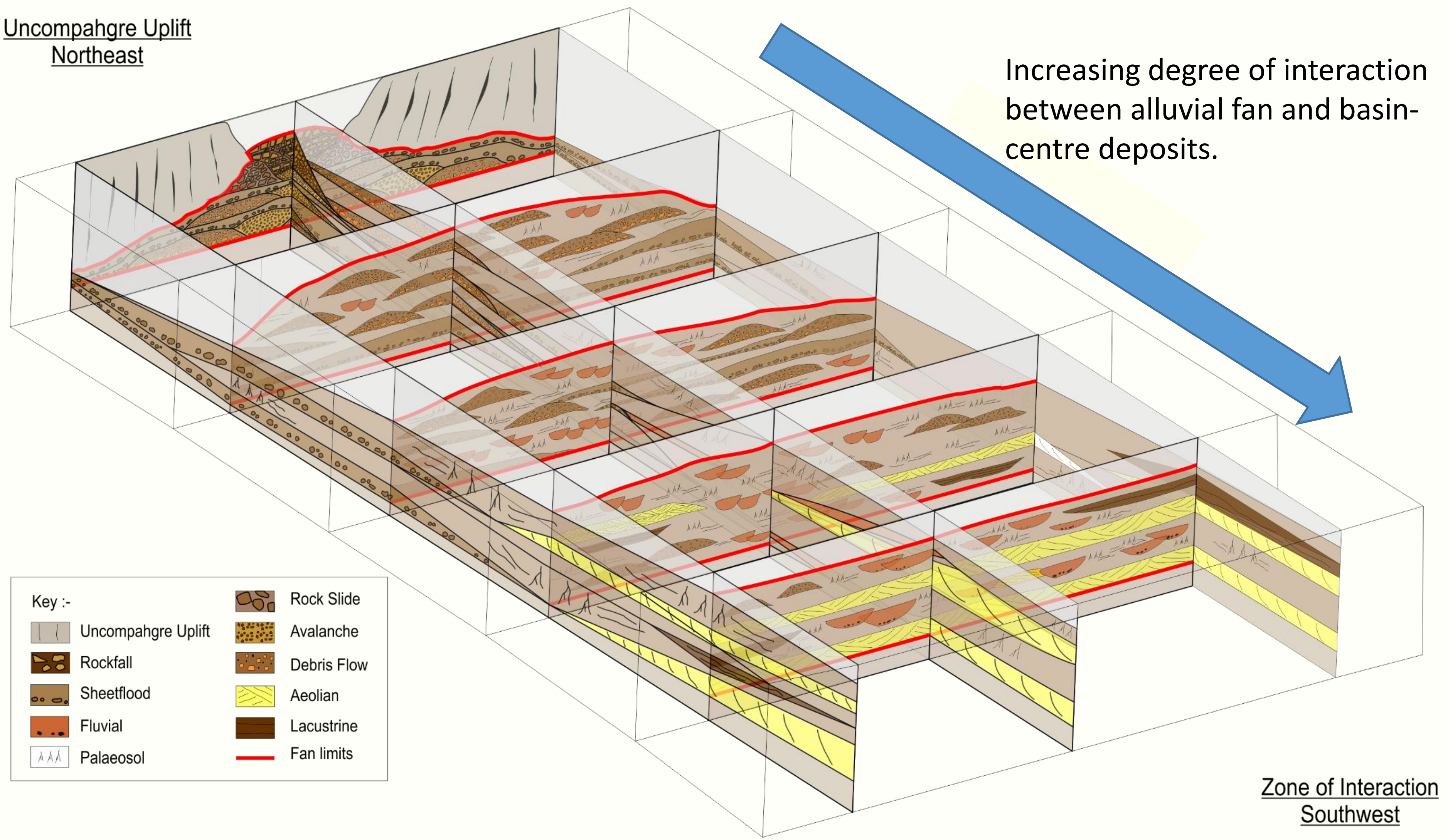
debris flows, terminal sheetfloods, and braided fluvial systems

Alluvial fan toe

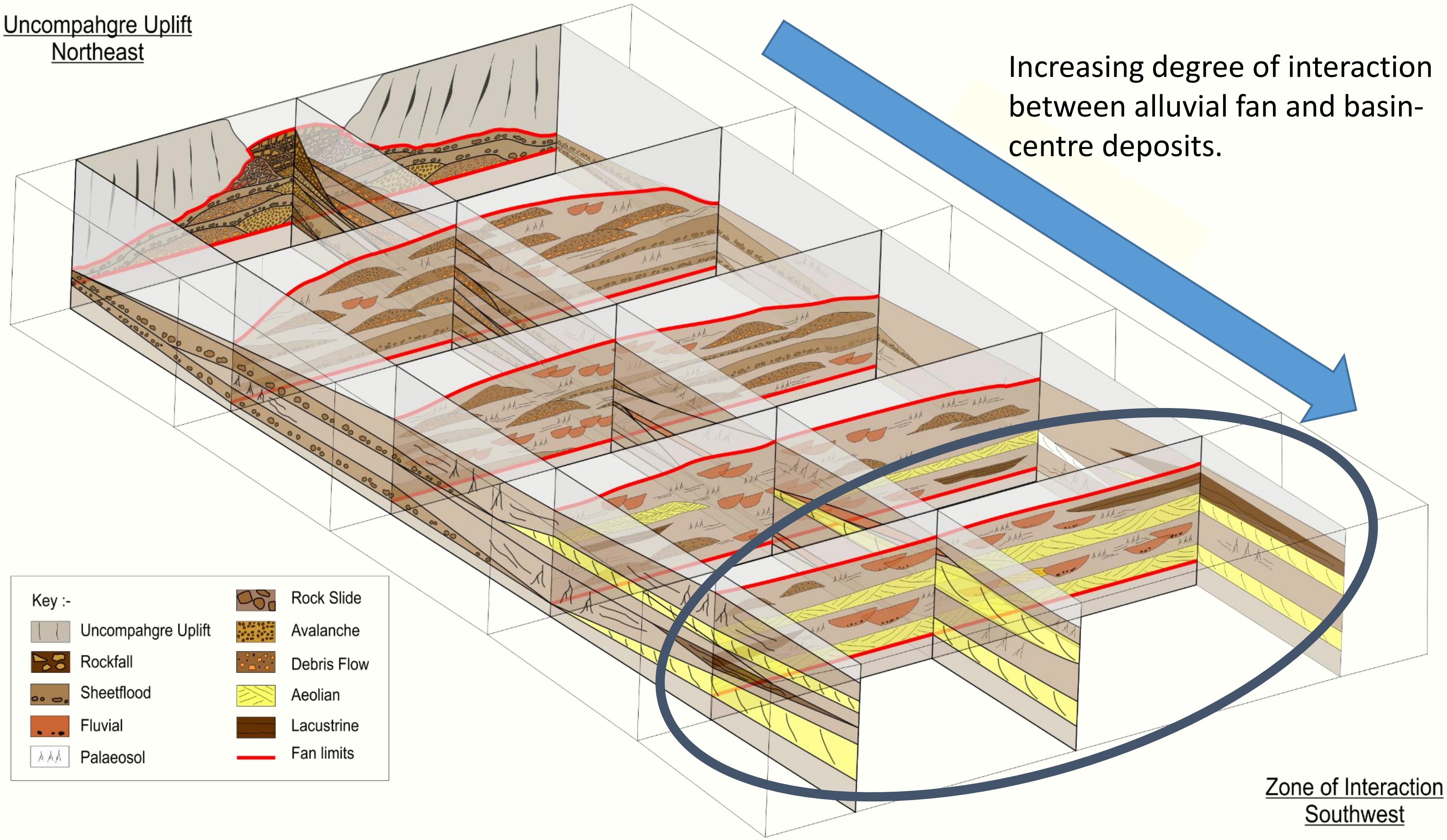


alluvial fan interacts with secondary environments of deposition, including lacustrine, aeolian (erg and sandsheet), and shallow marine

Fence diagram across the Paradox Basin

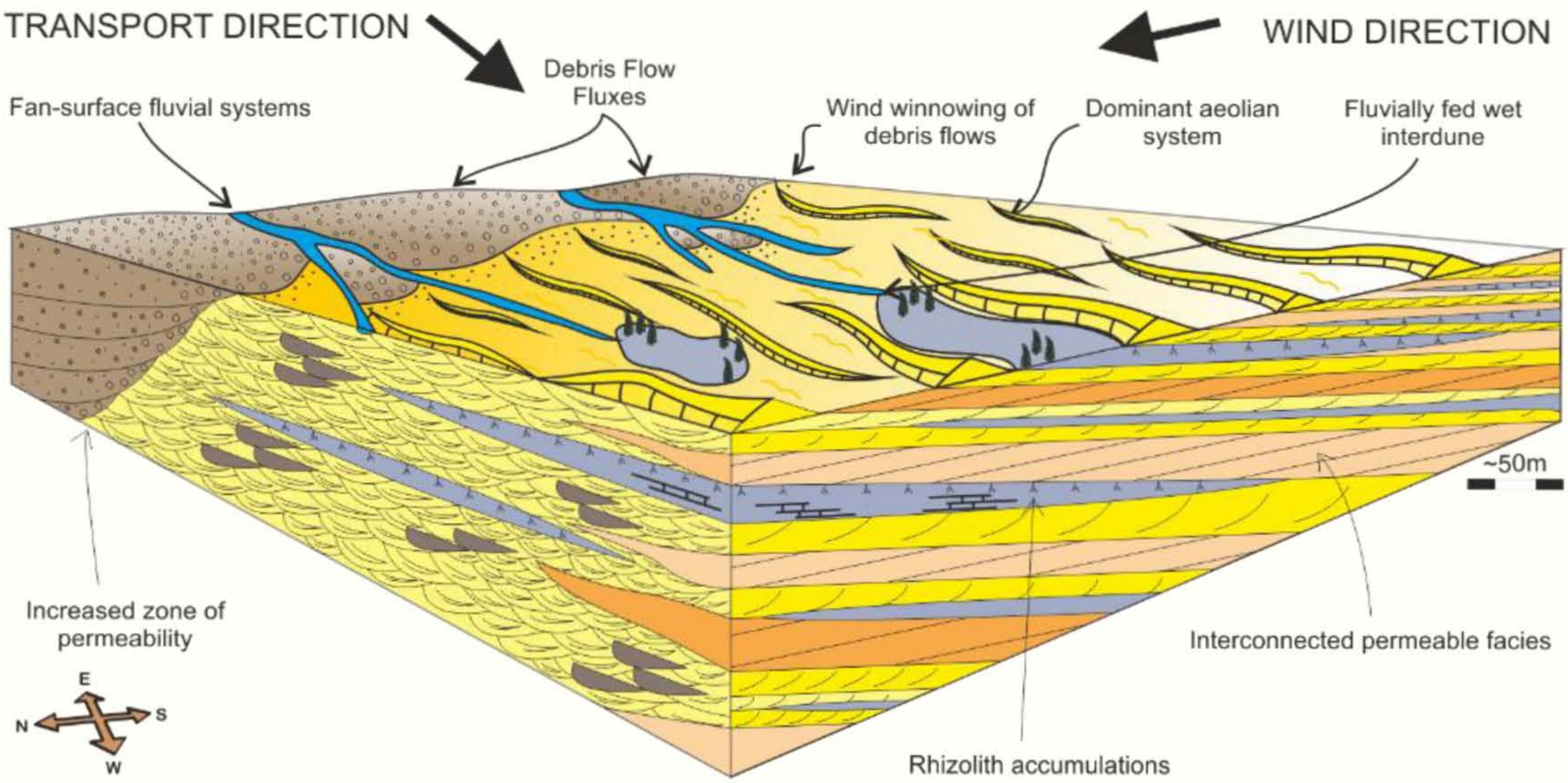


Fence diagram across the Paradox Basin



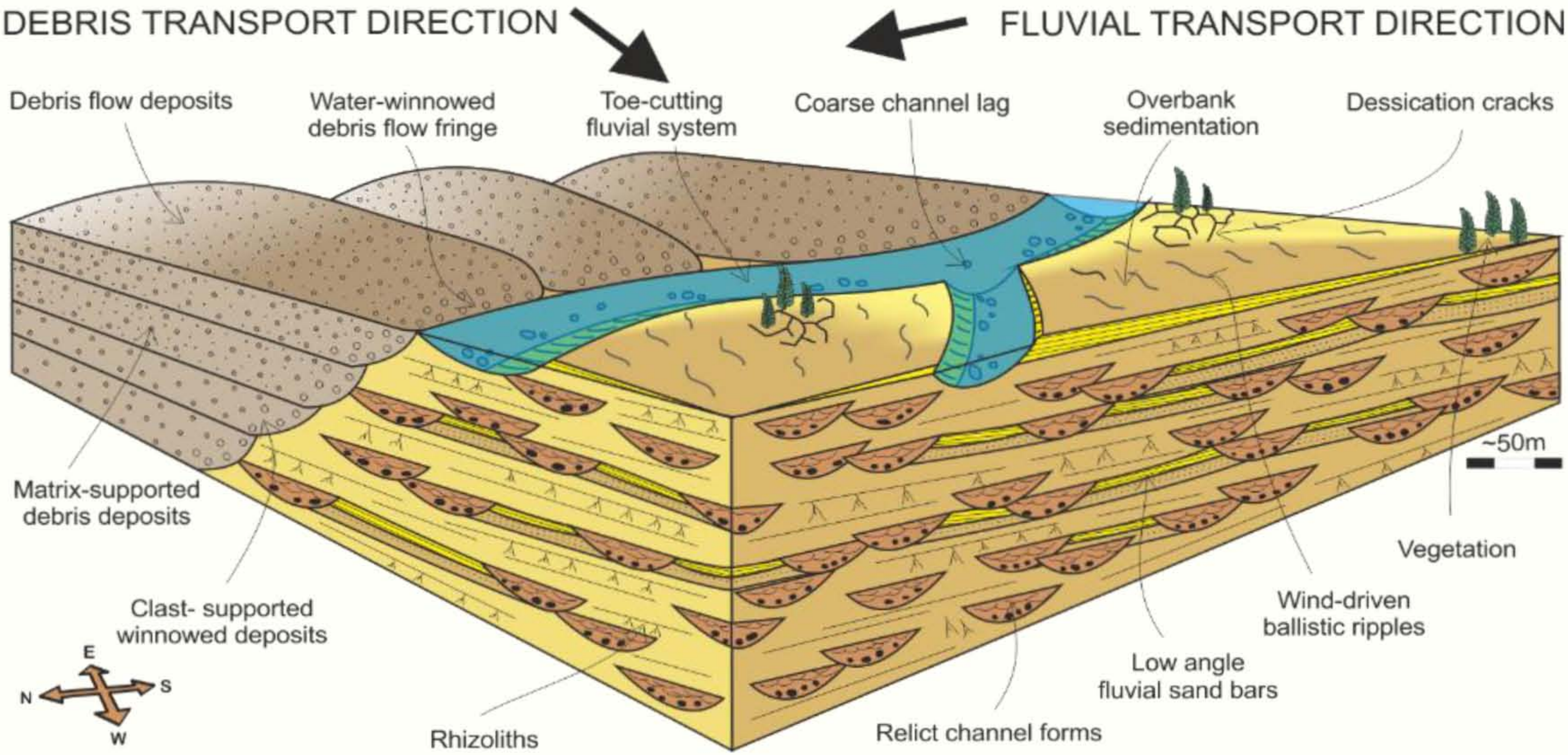
Clear fluvially-driven, Aeolian and lacustrine deposits in distal basin

Debris flow to aeolian interaction



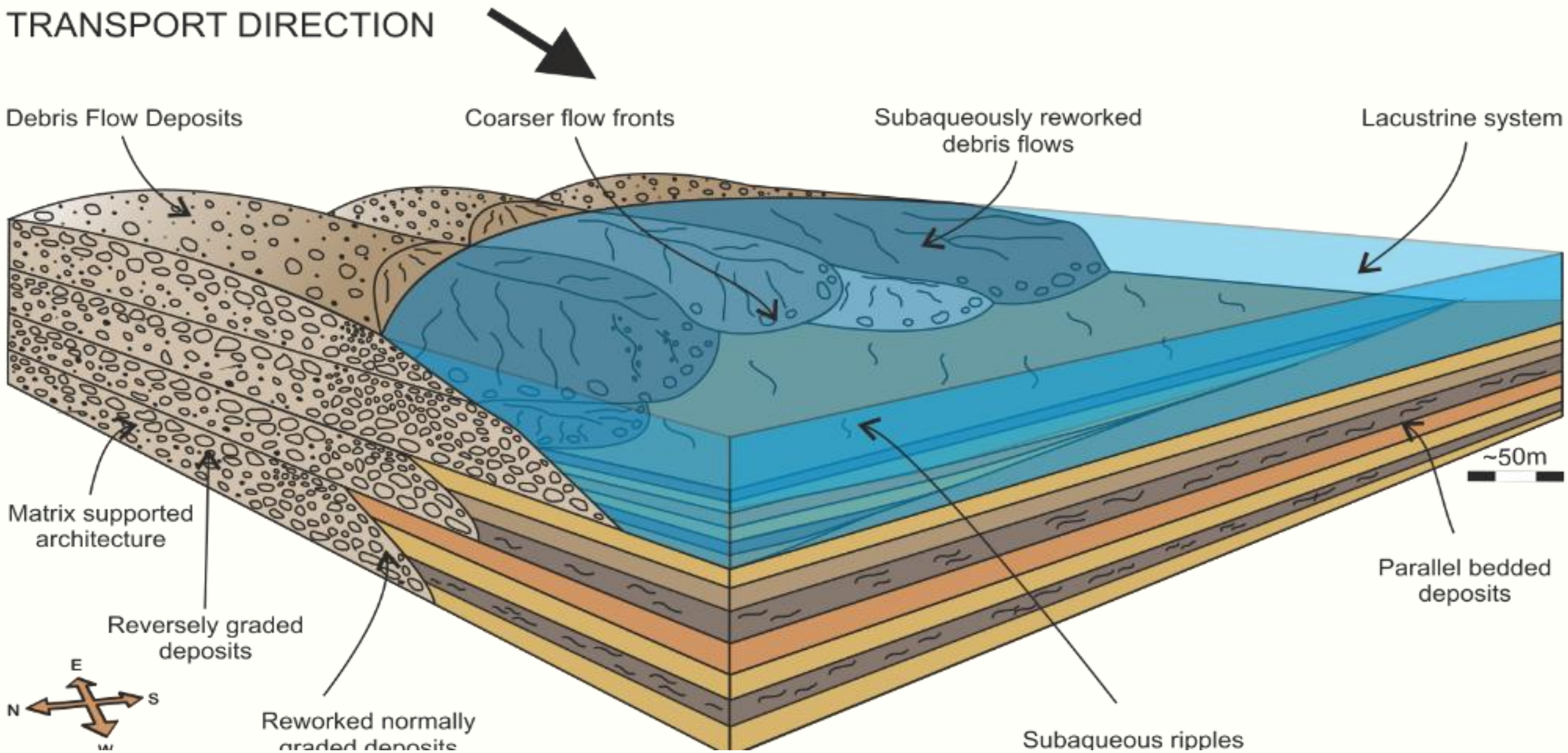
- The wind-blown distal aeolian environment led to wind-driven winnowing of the front of the debris flow, and the subsequent removal of the finer-grained matrix, increasing permeability.

Debris flow to fluvial interaction



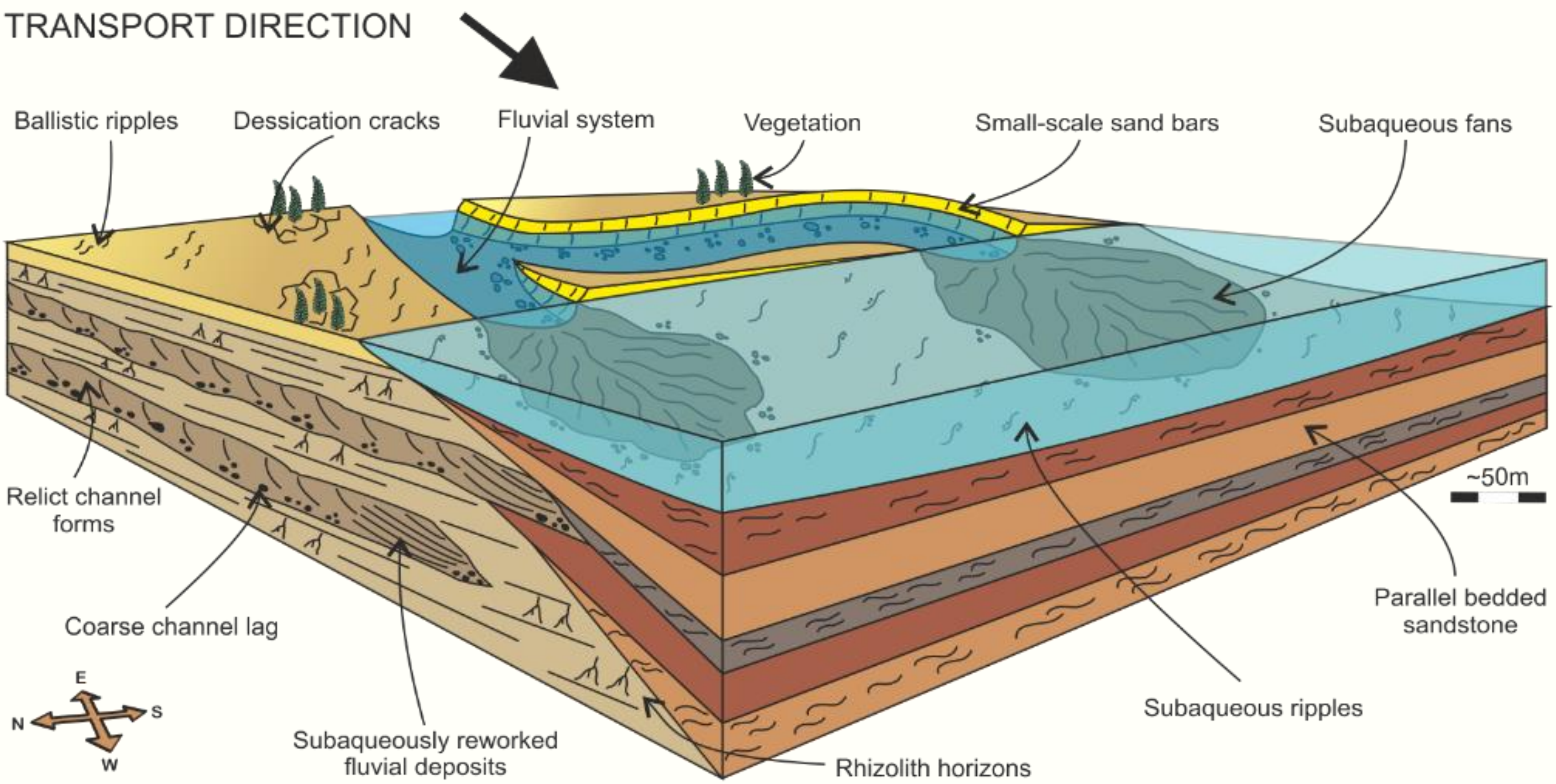
- fluvial water infiltrated the front of the debris flow deposits, and partially removed a component of the matrix, increasing permeability

Debris flow to lacustrine interaction



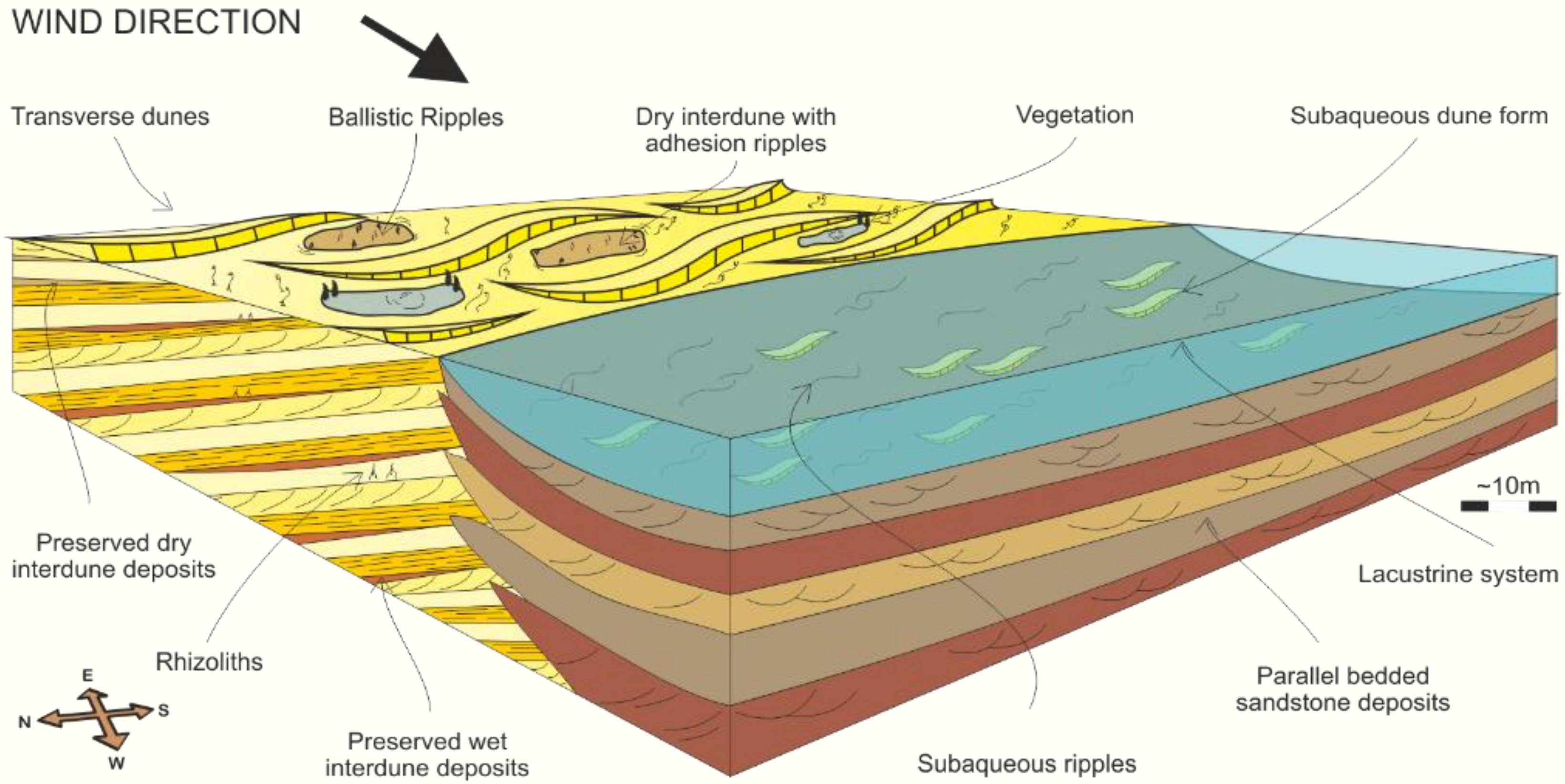
- The debris flow deposits became reworked in basin centre lacustrine environment - led to the initial deposition of the coarse-grained component of the debris flow deposits and gravitational settling of the finer-grained component of the flow, which entered suspension within the water column.

Fluvial to lacustrine interaction



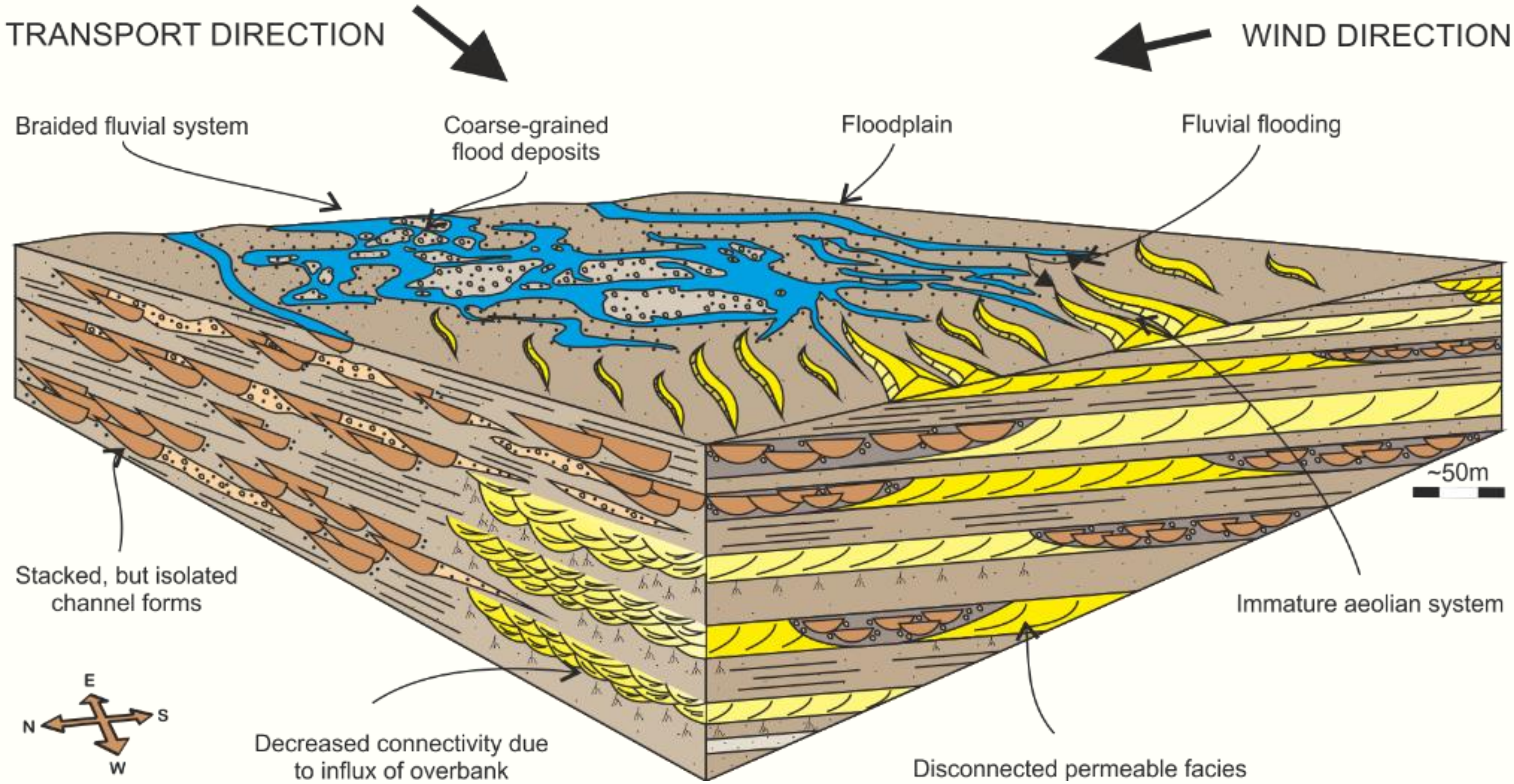
- deposition of fine-grained subaqueous fans at river mouths. Initial deposition of the coarser-grained component of the flow – followed by the gradational settling of the finer-grained portion. The fluvial systems tend to be ephemeral, therefore these subaqueous fans built through time.

Aeolian to lacustrine interaction

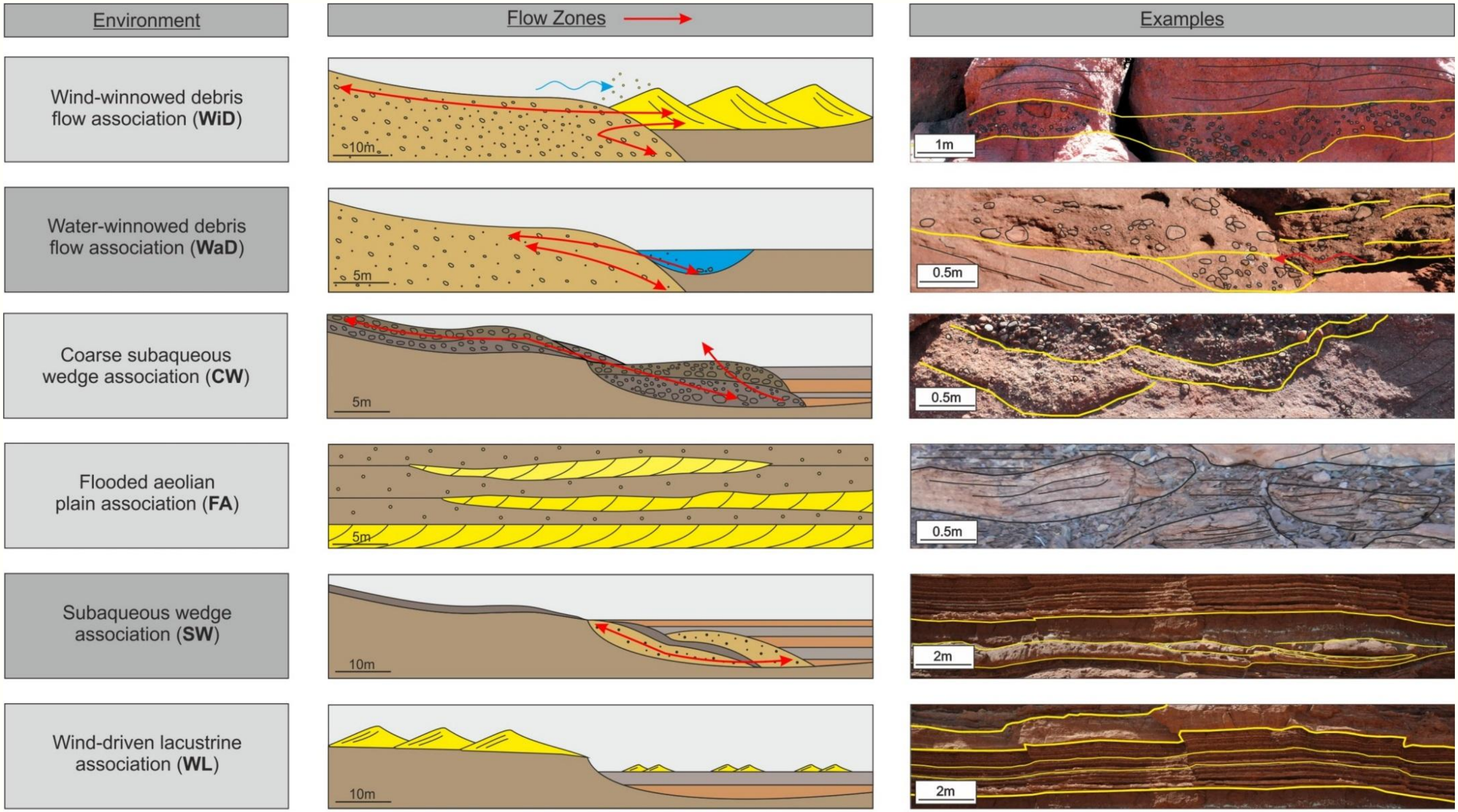


- Very little change in the overall architecture of the deposits. The aeolian wind-blown sands provided sediment to the lacustrine system, which superimposes a finer-grained, better-sorted, well-rounded nature on the sediment.

Fluvial to aeolian interaction



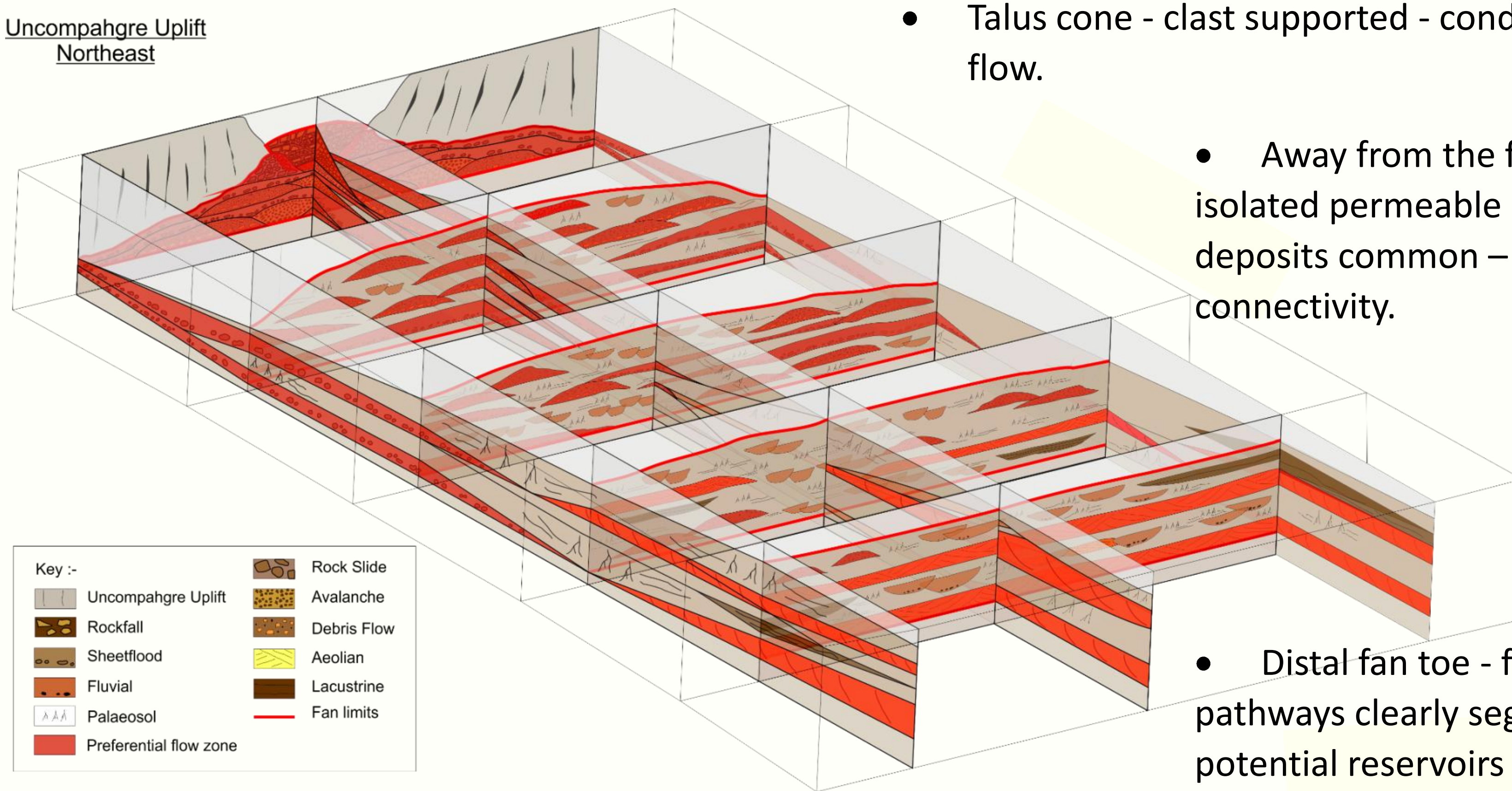
- The ephemeral fluvial systems from the fan occasionally flooded the distal aeolian erg in the basin centre - leading to isolation of dune forms between fine-grained flood plain deposits. The orthogonal palaeocurrent of the fluvial system and the palaeowind direction lead to the creation of flow pathways between the dune forms, which heightens the flooding potential.



Interaction Zone deposits impact on basin-scale fluid flow:

- Winnowed distal fan associations create flow pathways, bypass zones, thief zones from distal basin.
- Flooded zones isolates reservoir lithologies, creating baffles and decreasing flow.
- Wind-altered sediments have little effect on fluid flow characteristics.

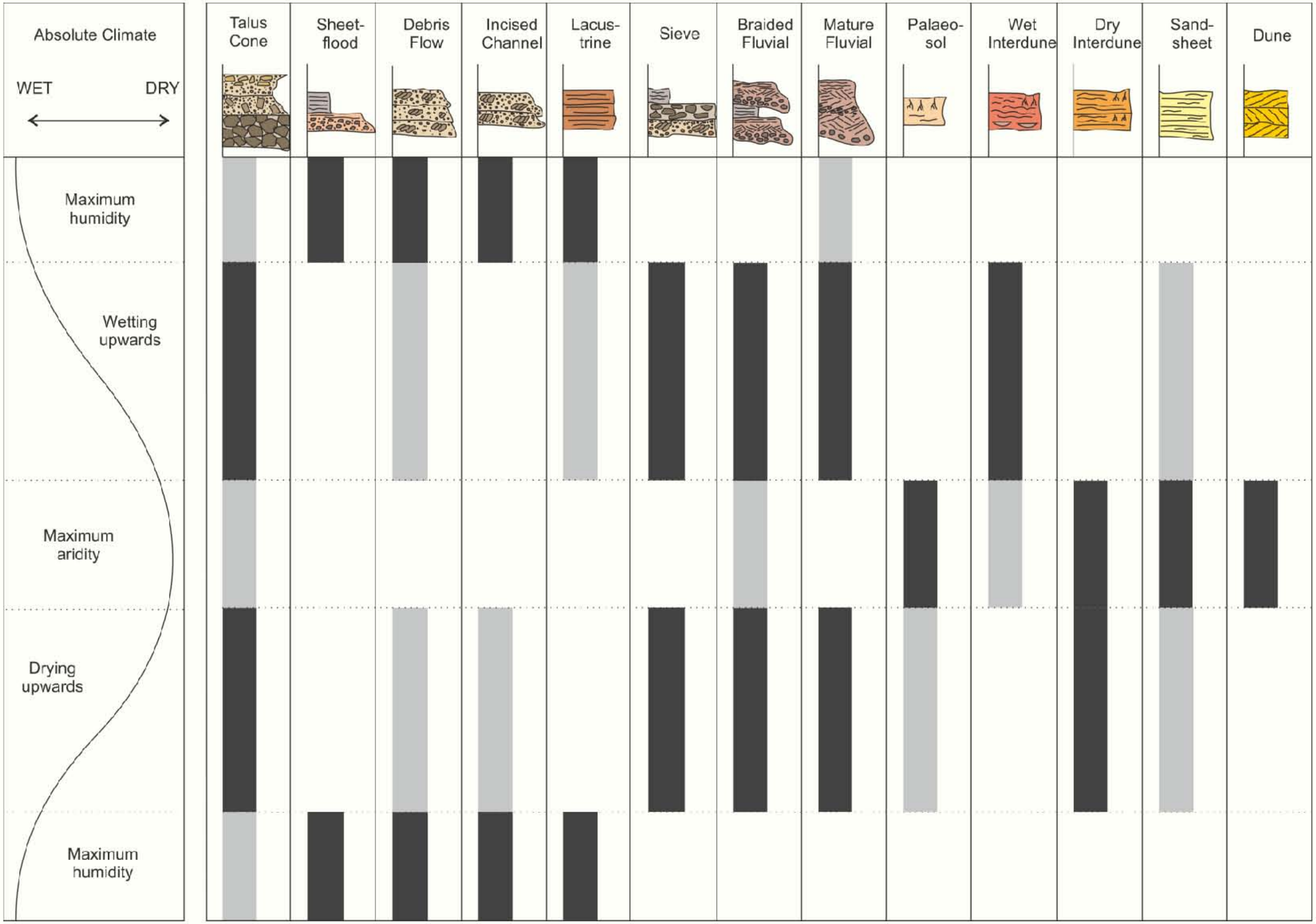
Flow zones across the Paradox Basin



- Talus cone - clast supported - conducive to fluid flow.
- Away from the fan head – isolated permeable debris flow deposits common – provide connectivity.
- Distal fan toe - flow pathways clearly segregated – potential reservoirs in distal basin.

- Diagram highlights how the distal basin is connected to the alluvial fan through flow pathways in the ZOI, and how the fan itself is then full of longitudinal preferential flow zones.
- Can lead to the complete outwards migration of fluid away from the basin centre reservoirs.

Climate cyclicity as a prediction technique on the fan



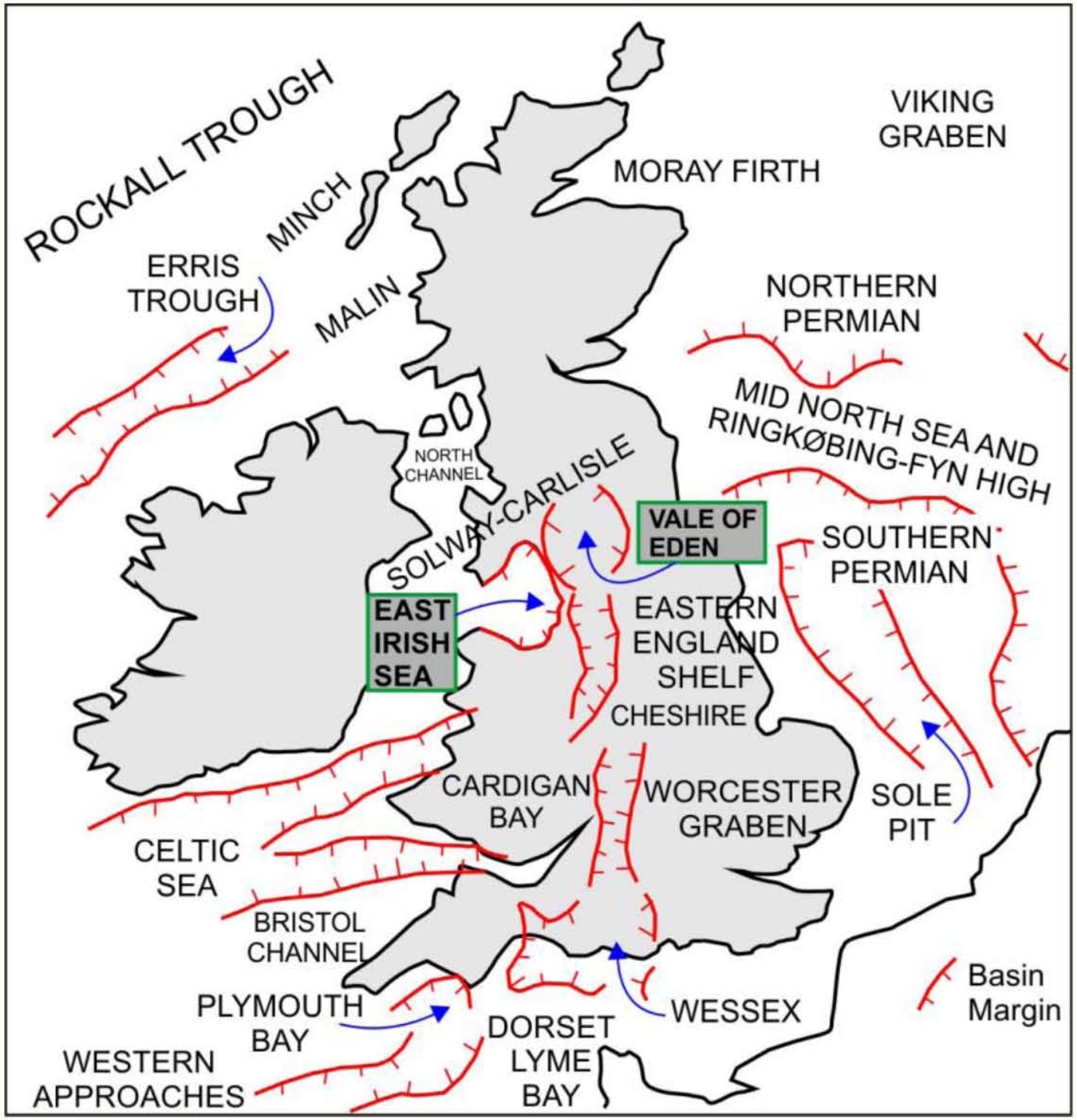
Max humidity = Debris flow & sheetfloods

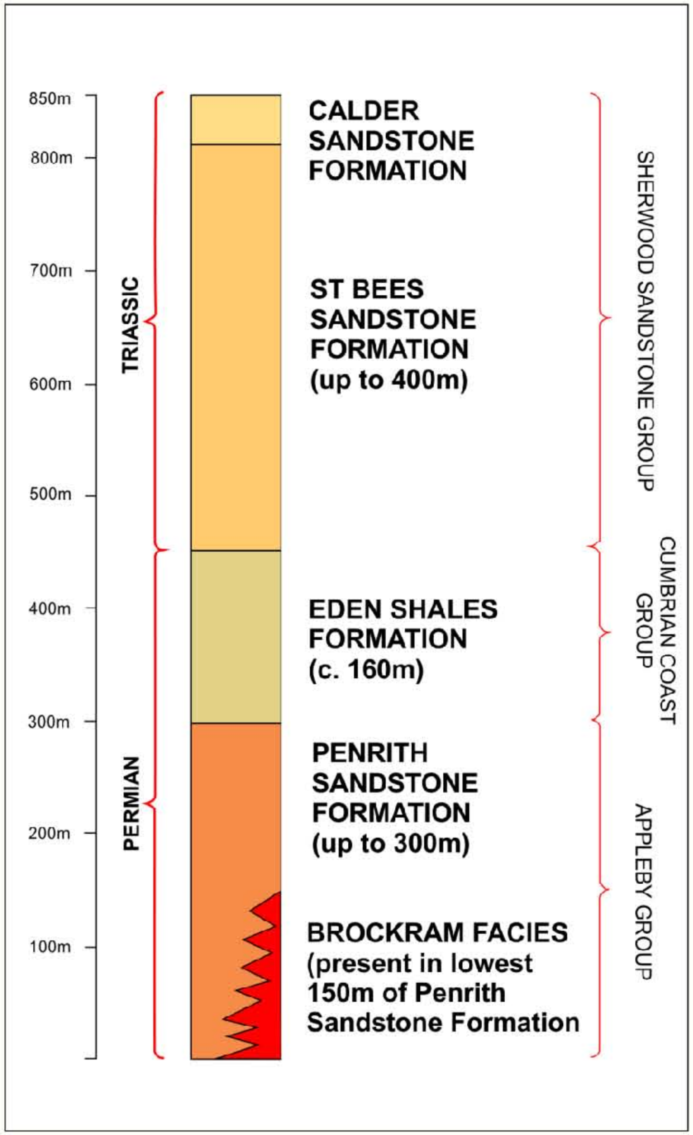
Wetting up = Sieve & channel deposits

Max aridity = soils& dunes

Drying up = Dry inter-dunes

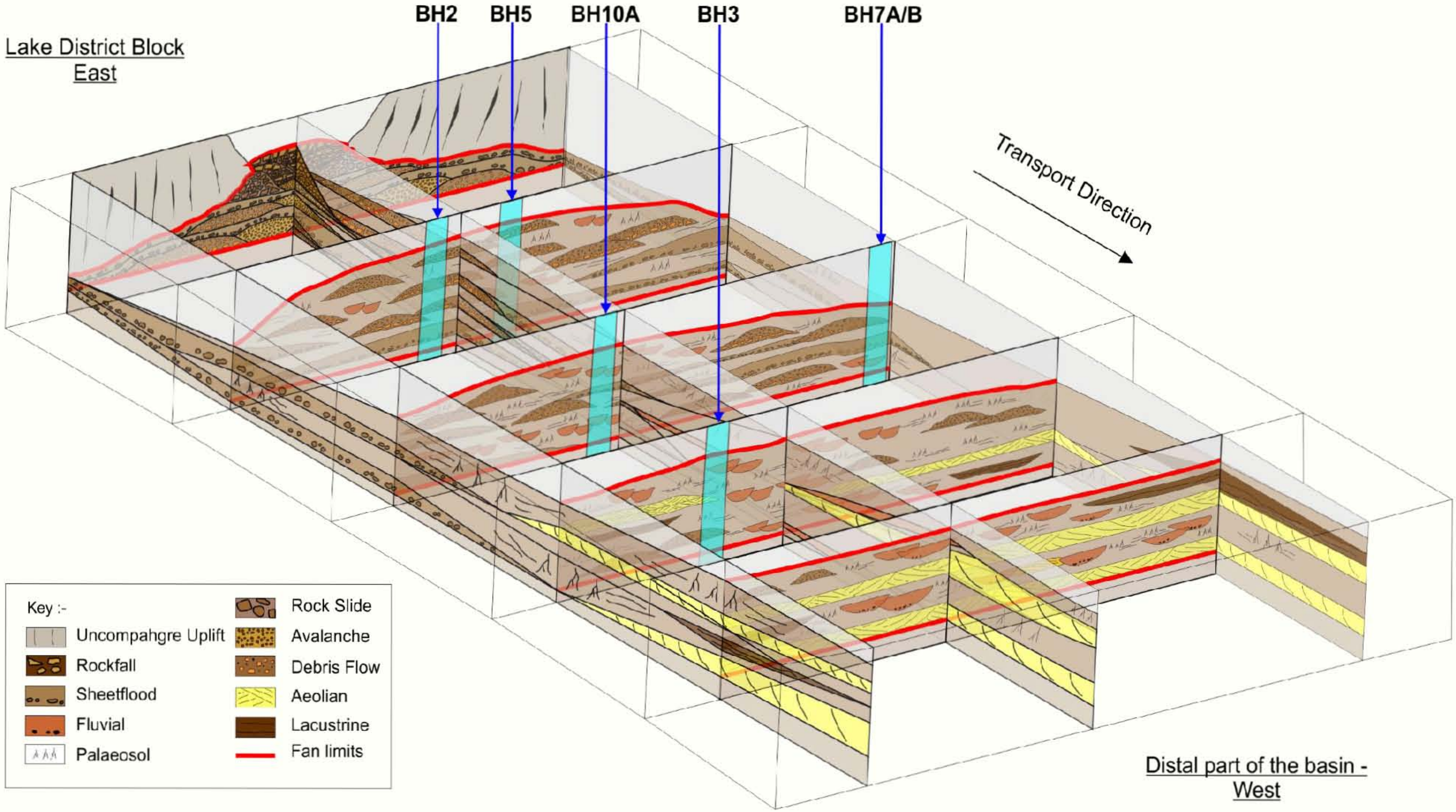
The Brockram Facies



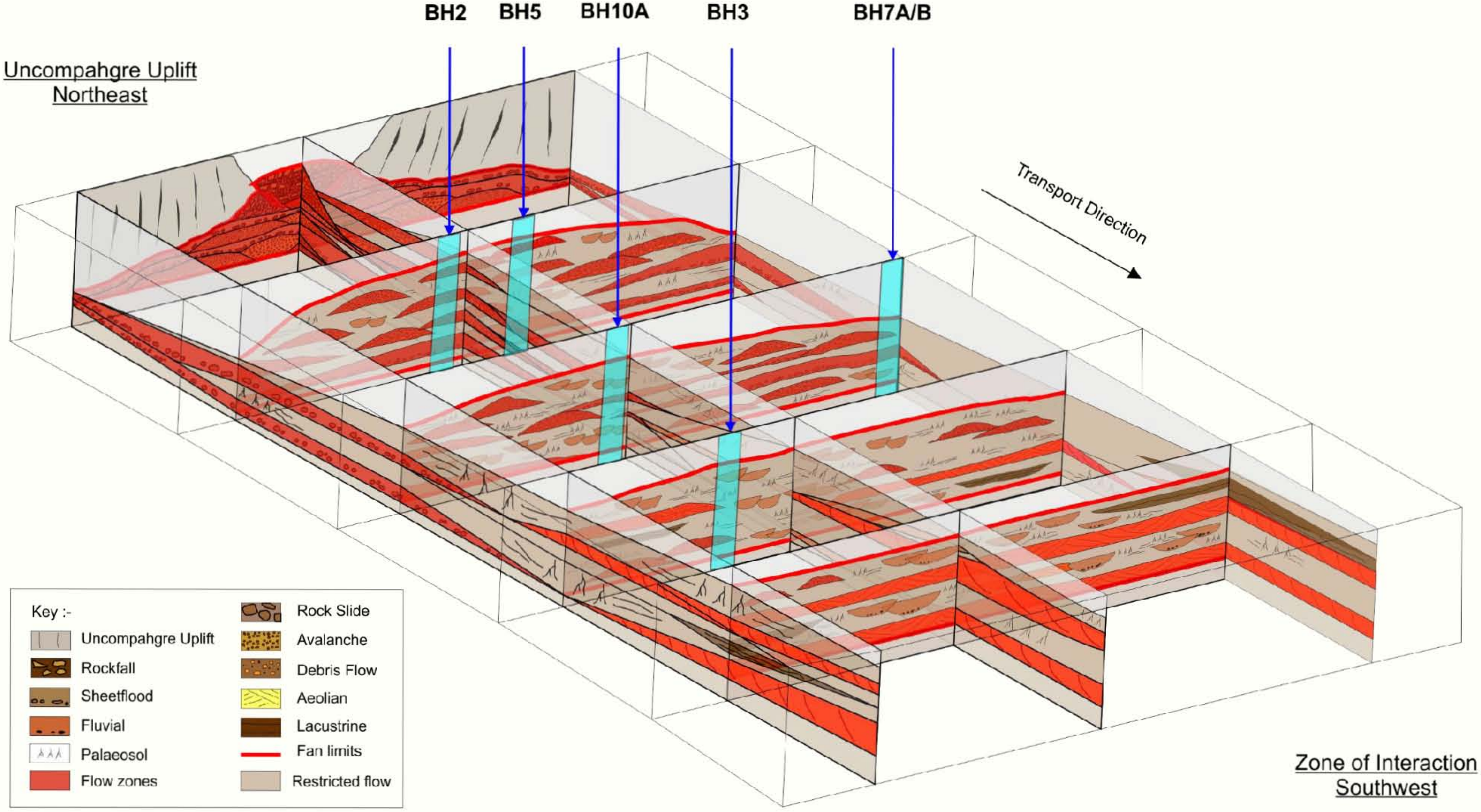


After Ackhurst et al. 1997

Borehole Positions – Relation to the Cutler Group



Borehole Positions – Relation to observed flow zones



Conclusions

- Long-lived alluvial fan settings interact with contemporaneous sediments in the distal basin
- The deposits of the distal basin respond to longer-term climate changes
- The deposits of the alluvial fan are affected by shorter-term climatic variations
- The response of the fan environments to wetting and drying cycles can be identified in the deposits
- This response can be used to better understand similar systems in the subsurface, e.g. the Brockram Facies