Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2021 - 2022

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

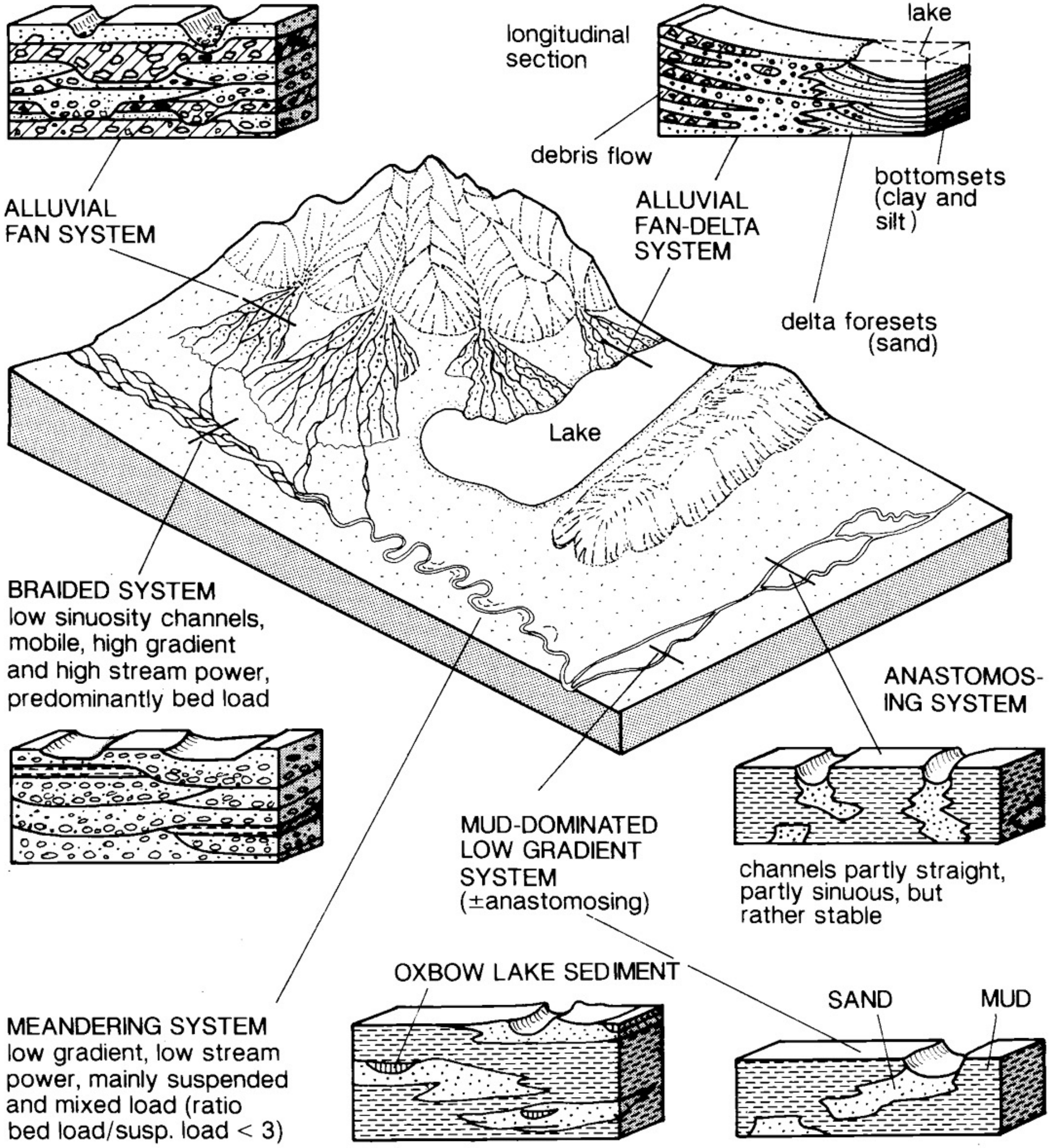
Docente: **Michele Rebesco**

Modulo 3.8
Fluvial deposits

Outline:

- Introduction to alluvial deposits
- Alluvial fans
- Braided rivers
- Meandering rivers
- Channel belt sandstone packages
- Seismic examples

Principal types of fluvial systems and generalized characteristics of their cross sections (vertical scale exaggerated)



Several types of fluvial systems, although there are no sharp boundaries between these depositional environments

Einsele. Sedimentary Basins, 1992

Glossary

alluvial deposit = Material deposited by rivers

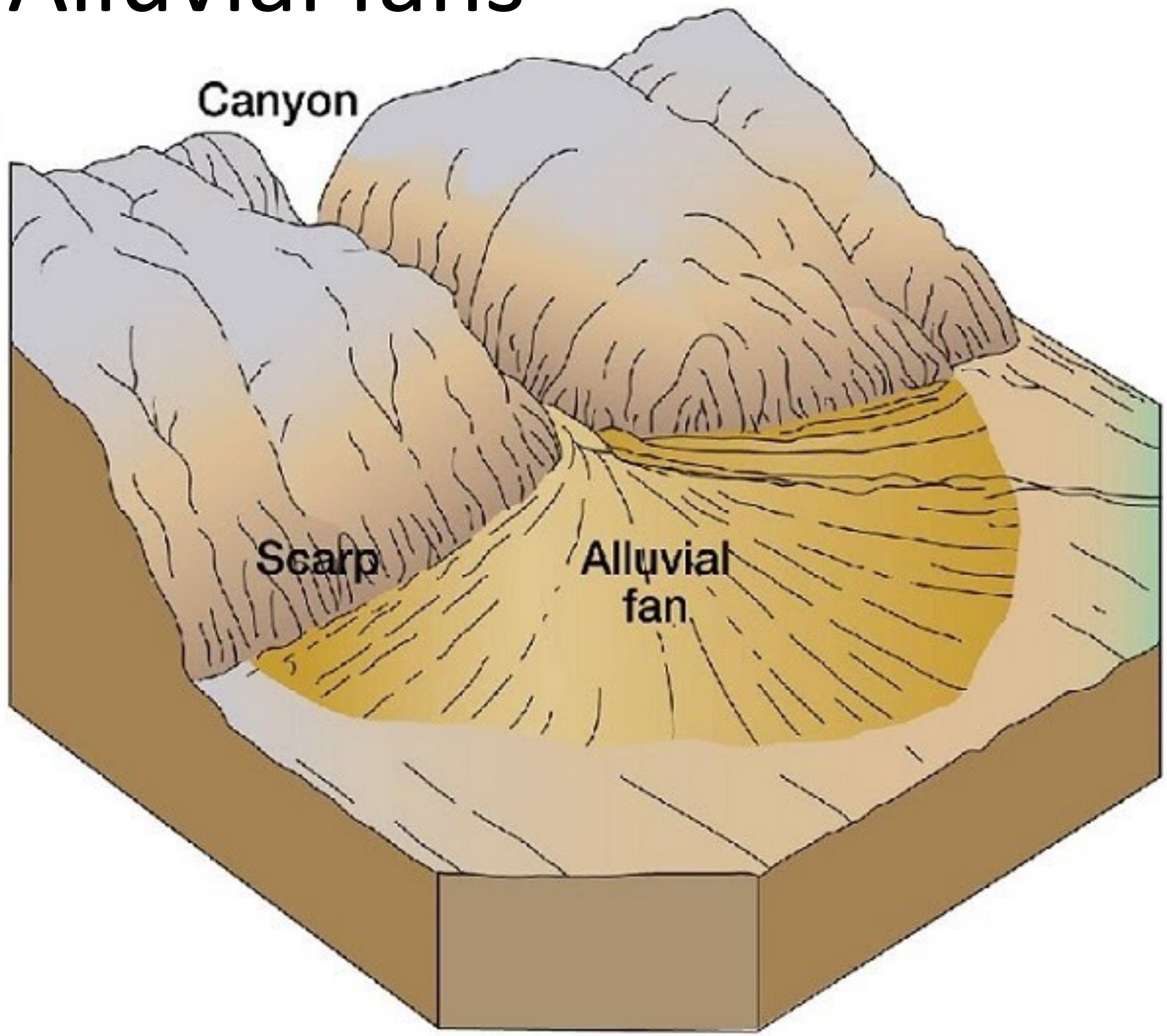
Alluvium= A general term for clay, silt, sand, gravel or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semi-sorted sediment

A point bar is a depositional feature made of alluvium that accumulates on the inside bend of streams and rivers.

A crevasse splay is a sedimentary fluvial deposit which forms when a stream breaks its natural or artificial levees and deposits sediment on a floodplain

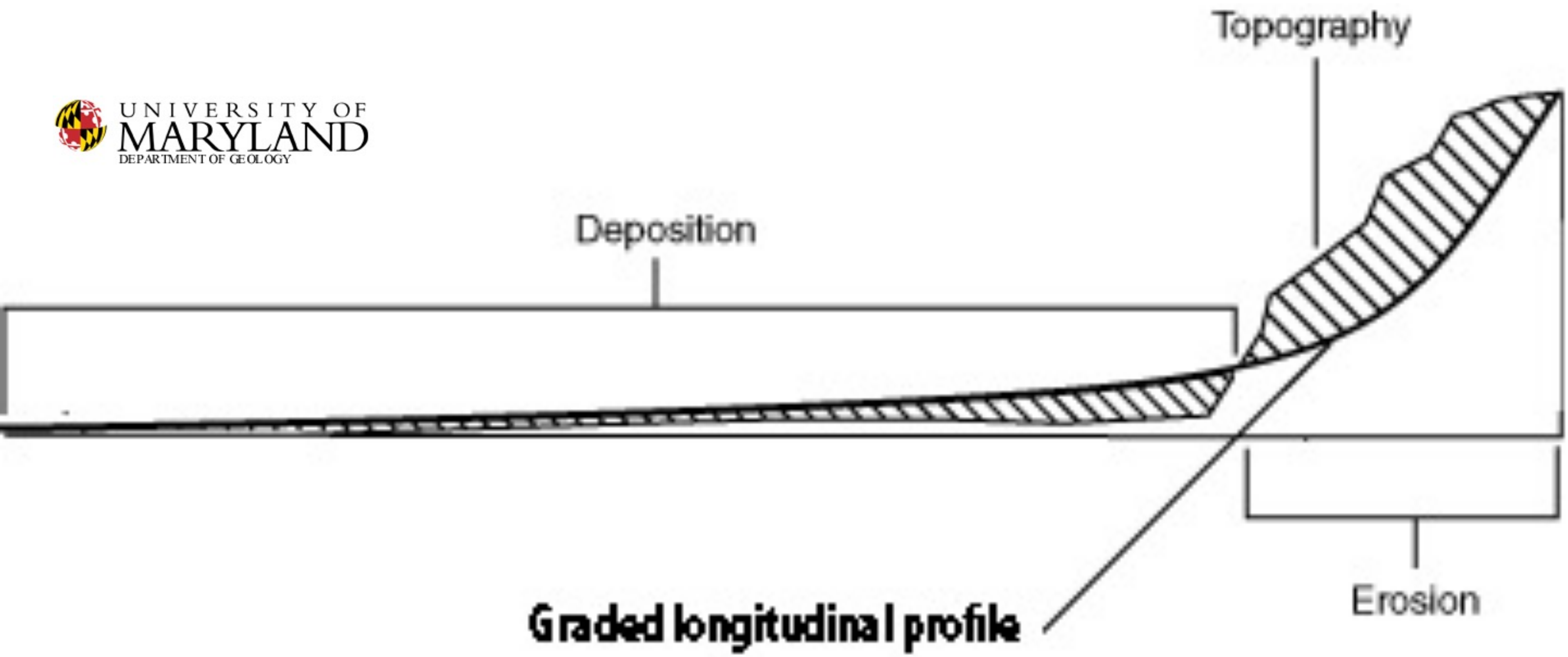
Alluvial fans

A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited at the base of mountains where fast-flowing streams from a narrow mountain valley meet relatively-flat surfaces of basin floors or broad valleys. At this juncture, the gradients of streams abruptly decrease and gravel, sand, and other sediments are deposited.



Graded profile

Non-marine environments are poorly preserved because they sit above the base level (usually sea level) of streams flowing across them and often above their graded longitudinal profile, the level on Earth's surface above which sediments must eventually erode, and below which they are deposited.



The alluvial fan is the most proximal (close to sediment source) and coarse grained of water-transported sedimentary environments. They typically form at the point where streams lose the competence to transport framework clasts. Consequently, the sediment alluvial fans contain is recently derived from local sources. Alluvial fans are generally restricted in area, typically being no more than 1-10 km from their sediment's source rock.

UNIVERSITY OF MARYLAND
DEPARTMENT OF GEOLOGY

Alluvial fans are the products of two main depositional processes:

Debris flows: channelized slurry flows consisting of sediment-water mixtures incorporating fine material (sand, silt and clay), coarse material (gravel and boulders) and a variable quantity of water.

Sheet-flow: Shallow water that is not confined to a stream bed, moving across a shallow incline.

Debris flow deposits

A debris flow deposit occurs when the masse of all sizes of sediment (ranging from boulders to clay) saturated with water is rapidly deposited on the proximal (upper) to middle fan as paraconglomerates with little to no stratification.

They form bodies that are:
lobate in map view (above)
tabular and of uniform thickness in cross section (left).
Debris flows deposits occasionally preserve reverse grading (coarsening upward), especially near their bases.

University of Maryland
Department of Geology

Sheet flows

Shallow water that is not confined to a stream bed, moving across a shallow incline.

Recall that in arid environments, rain tends to come as large intermittent cloudbursts. Thus, although braided stream channels may cross the fan surface, these are usually dry. When flow occurs during flash floods, it soon overtops the channels and floods the fan surface as sheet flow. Sheet flow deposits (right) are usual stratified and well sorted with sand ripples and cross beds, and basal conglomerates

Secondary processes include:

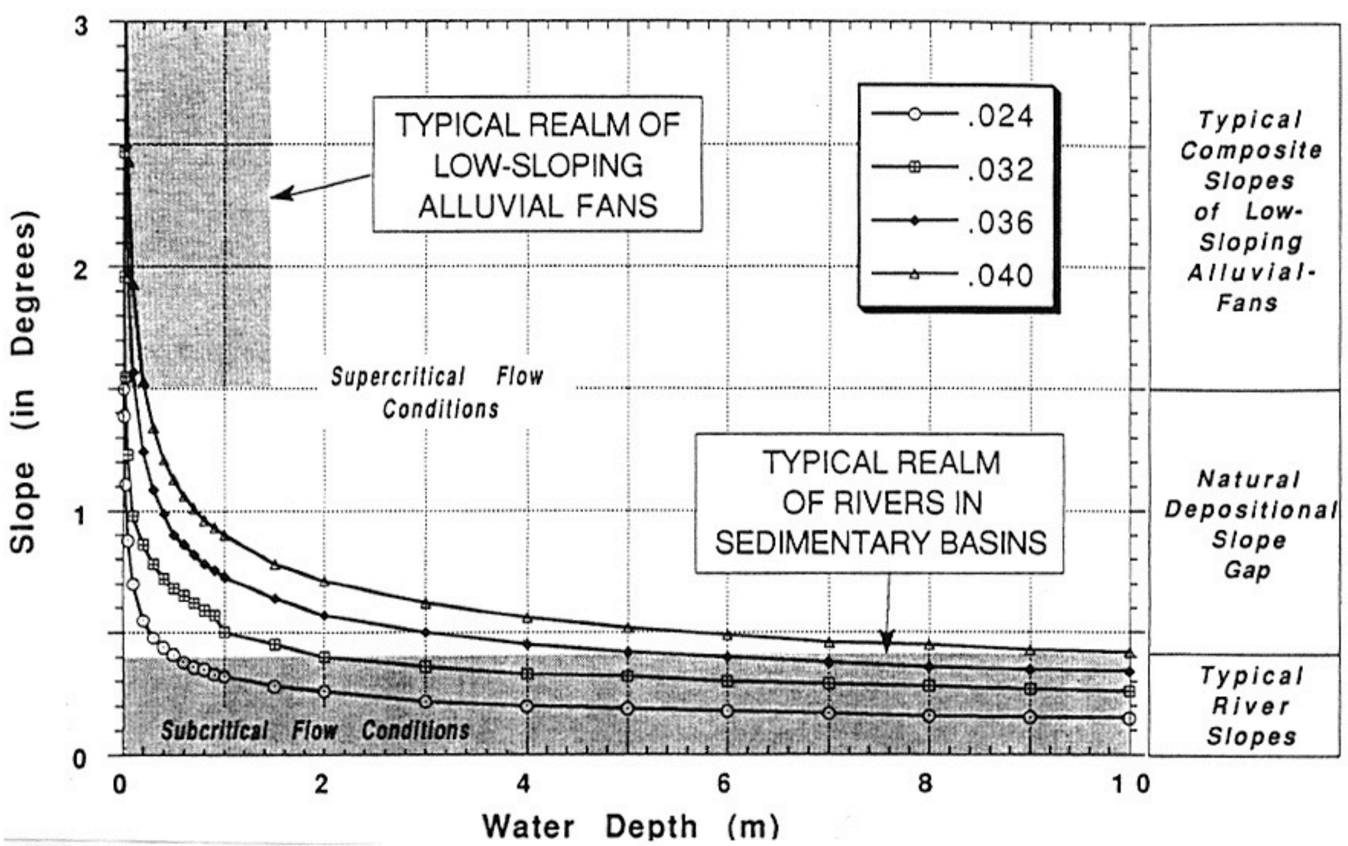
Mudflow: Dominated by matrix particles saturated with water that move en masse and rapidly deposited.

Stream flow: Across the surface, usually as braided streams.

Flow regime

Slope angle increases with sediment size. Thus, the slope magnitude depends on the fan's source material (with coarser clasts yielding steeper slopes) and tectonic setting.
Due to this steep slope, alluvial fans are always upper flow regime (i.e. turbulent - Re > 2000) and commonly supercritical (i.e. rapid - Fr > 1). In contrast, river (fluvial) environments have gradients of 0.5 - 0.01 degree.

In the modern world, alluvial fans are bodies of very course grained sediment. They have steep upper surfaces, ranging from 16 -1.5 degrees, with the slope decreasing towards the basin.



Sieve deposits

Sediment laden water flowing down the steep gradient of the fan surface doesn't deposit fine sediment. Indeed, this tends to wash through the pore space between large clasts. Instead only other large clasts are captured in orthoconglomerates termed sieve deposits.

UNIVERSITY OF MARYLAND
DEPARTMENT OF GEOLOGY

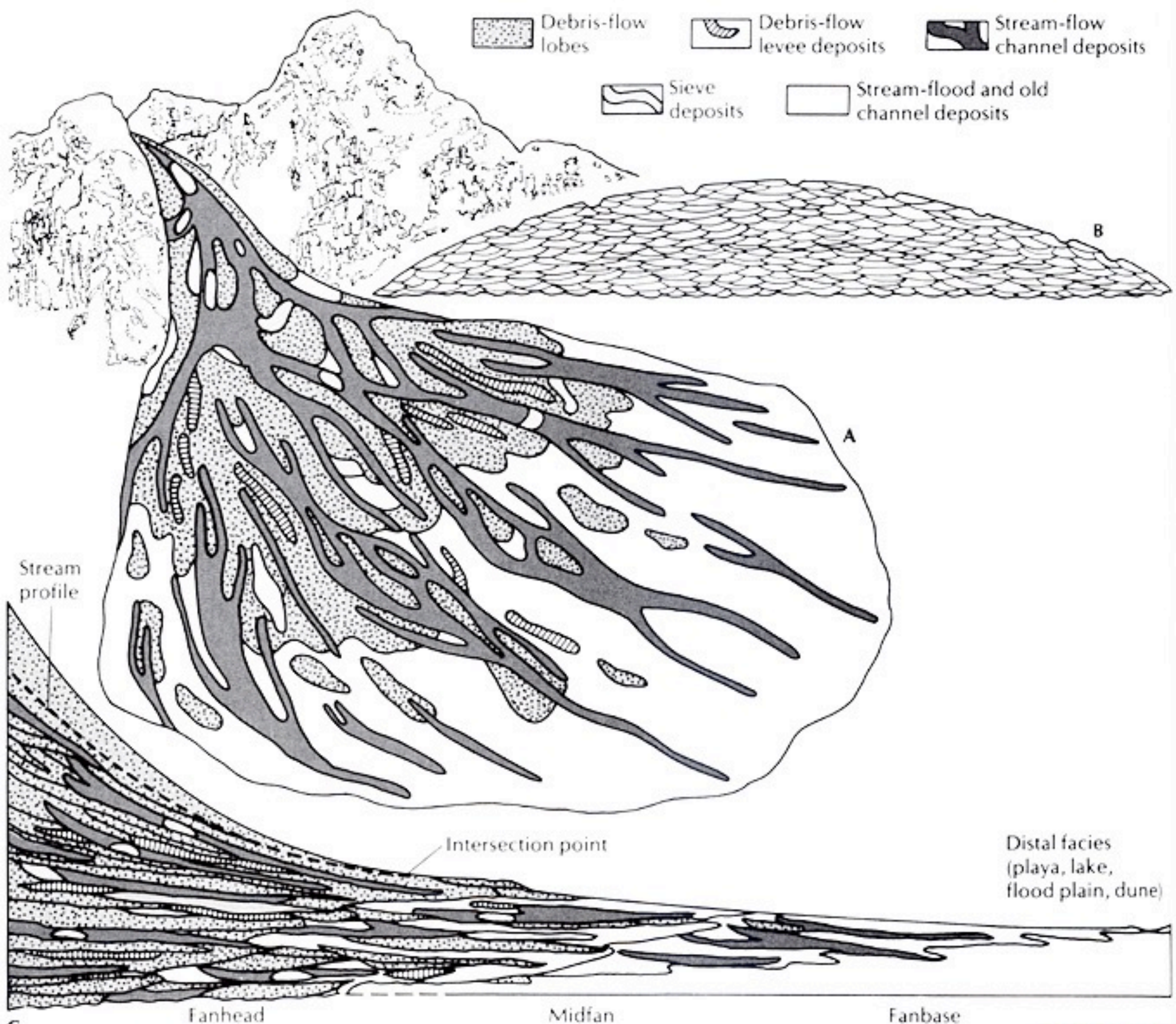
Braided stream deposits

The upper surface of an alluvial fan is dominated by braided streams, which typically have wide and shallow anastomosing channels that form in the upper reaches of streams where slope is greater and where flowing water is often choked with more sediment than the fluid can carry. During the highpoint in a flood water escapes the main channel and creates a sheet flood of well-sorted sand or fine gravel with little or no silt or clay (midfan sheets are typically well-sorted, well stratified, and cross-bedded). During low flow or the waning stages of flash floods when water is confined to stream channels, braided stream deposits are laid down.

UNIVERSITY OF MARYLAND
DEPARTMENT OF GEOLOGY

distribution of the four fan deposits

the fan tends to aggrade upward, becoming steeper as it does so and prograde outward into the basin.
As a result, at any given locality, there is a general coarsening upward trend.

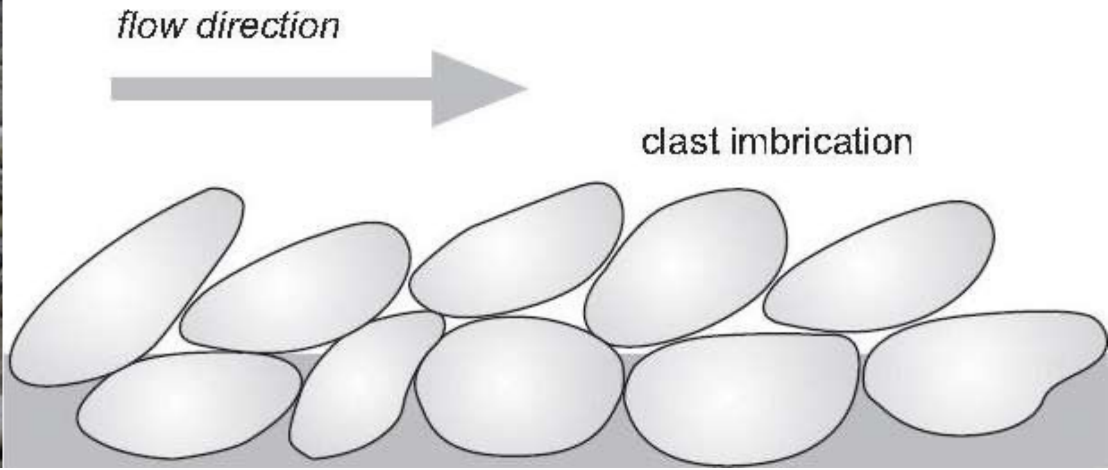


© Spearing 1974

The sequence of coarsening upward cross-bedded sandstones, conglomerates, and unsorted debris flow deposits occurs due to progradation of the fan out into the distal valley.
Fan deposits are generally limited in lateral extent, but their thickness can be considerable (up to 1000s of m in some basins if subsidence is persistent).
Sediments can be very immature and angular with abundant coarse rock fragments and feldspars.
Sheet flood deposits are typically oxidized, so redbeds are common.
Fossils are not generally preserved in the coarse-grained facies of an alluvial fan.
Regardless of grain size, current flow is indicated through sedimentary structures and/or imbrication, with sand being the smallest clast size.

Imbrication

In sedimentology, imbrication is a primary depositional fabric consisting of a preferred orientation (**in the direction of flow**) of clasts such that they overlap one another in a consistent fashion, rather like a run of toppled dominoes. Imbricated sediments are deposited in relatively high energy, unidirectional flow. Imbrication along the long-axes observed in conglomerates is formed through deposition of clasts carried in suspension in a rapidly waning flow (for example flash floods)



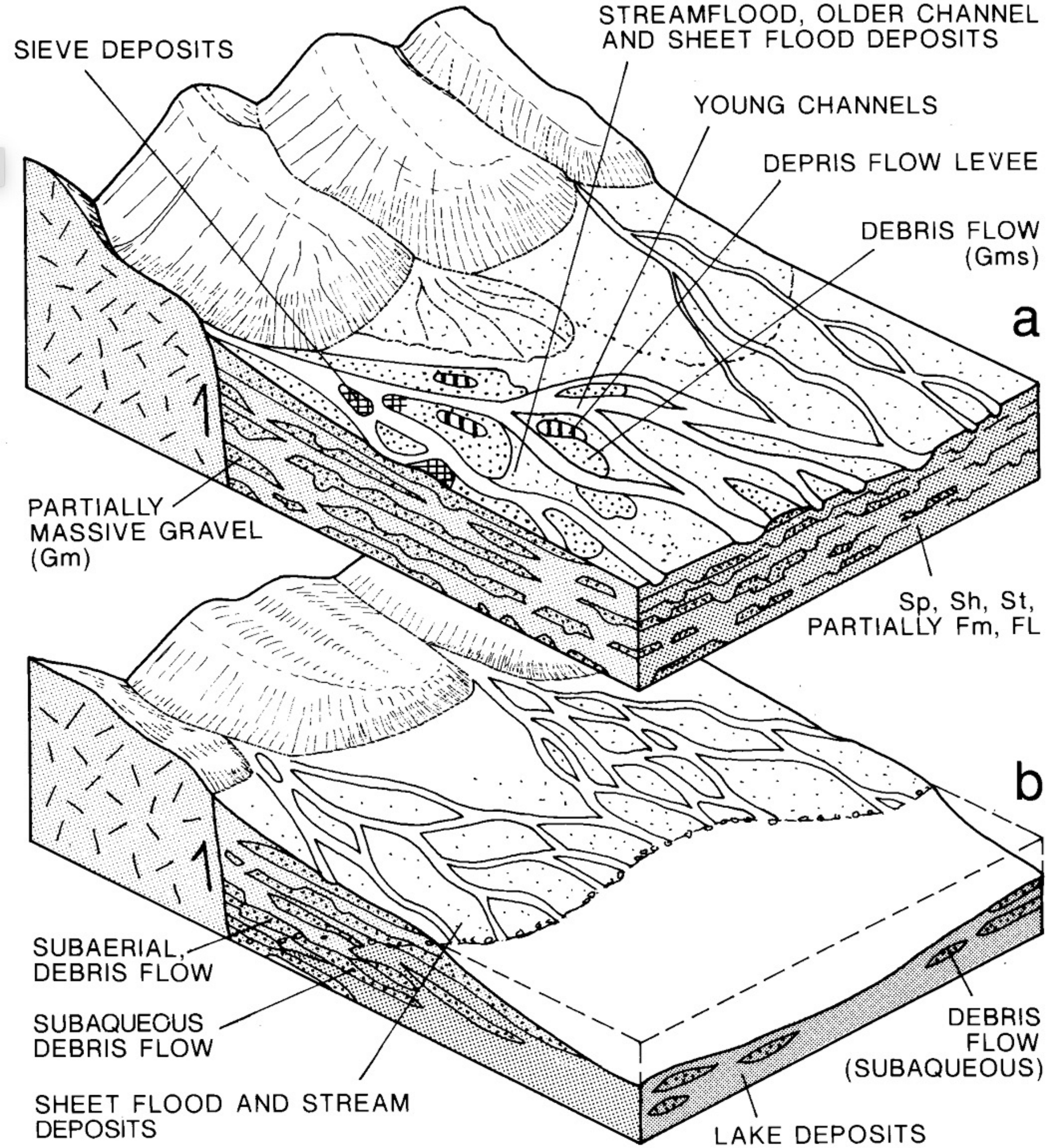
Do not confuse alluvial fan deposits with:

Laminated conglomeratic mudrock: These have a bimodal distribution of gravel and larger clasts interspersed in laminated mudrocks - typically as dropstones are deposited in fine deep marine or lacustrine sediment. They typically don't record indications of current flow (stream, debris flow).

Tillite: Unsorted sediments of all sizes with no indication of current flow.

Stream deposits: Although basal channel conglomerates and current flow sed structures may be present, conglomerates are a minor portion of the sediment volume and deposits show a fining upward pattern.

Simplified facies model of (a) alluvial fan (proximal to mid fan region) and (b) fan delta

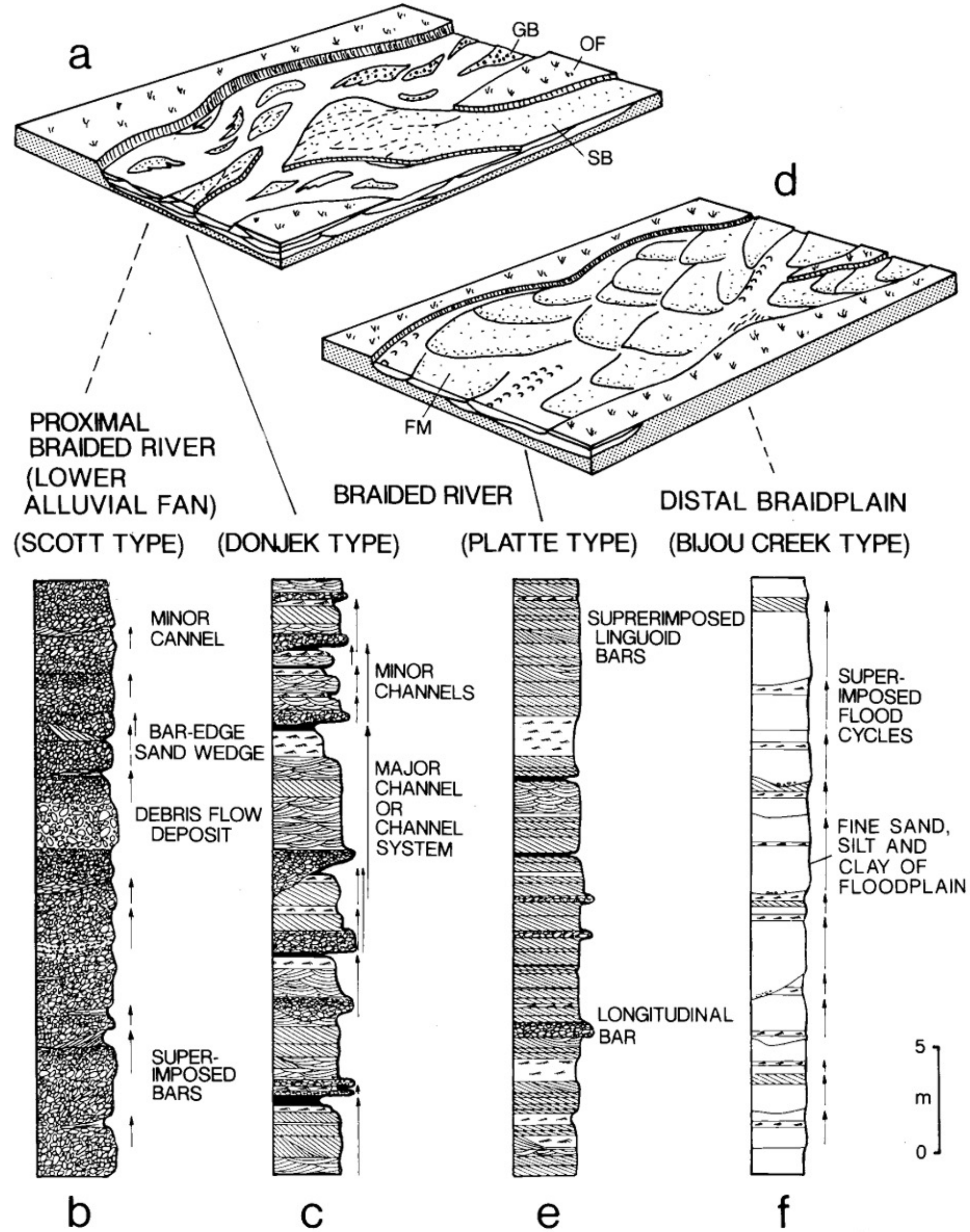


Einsele. Sedimentary Basins, 1992

Braided river systems

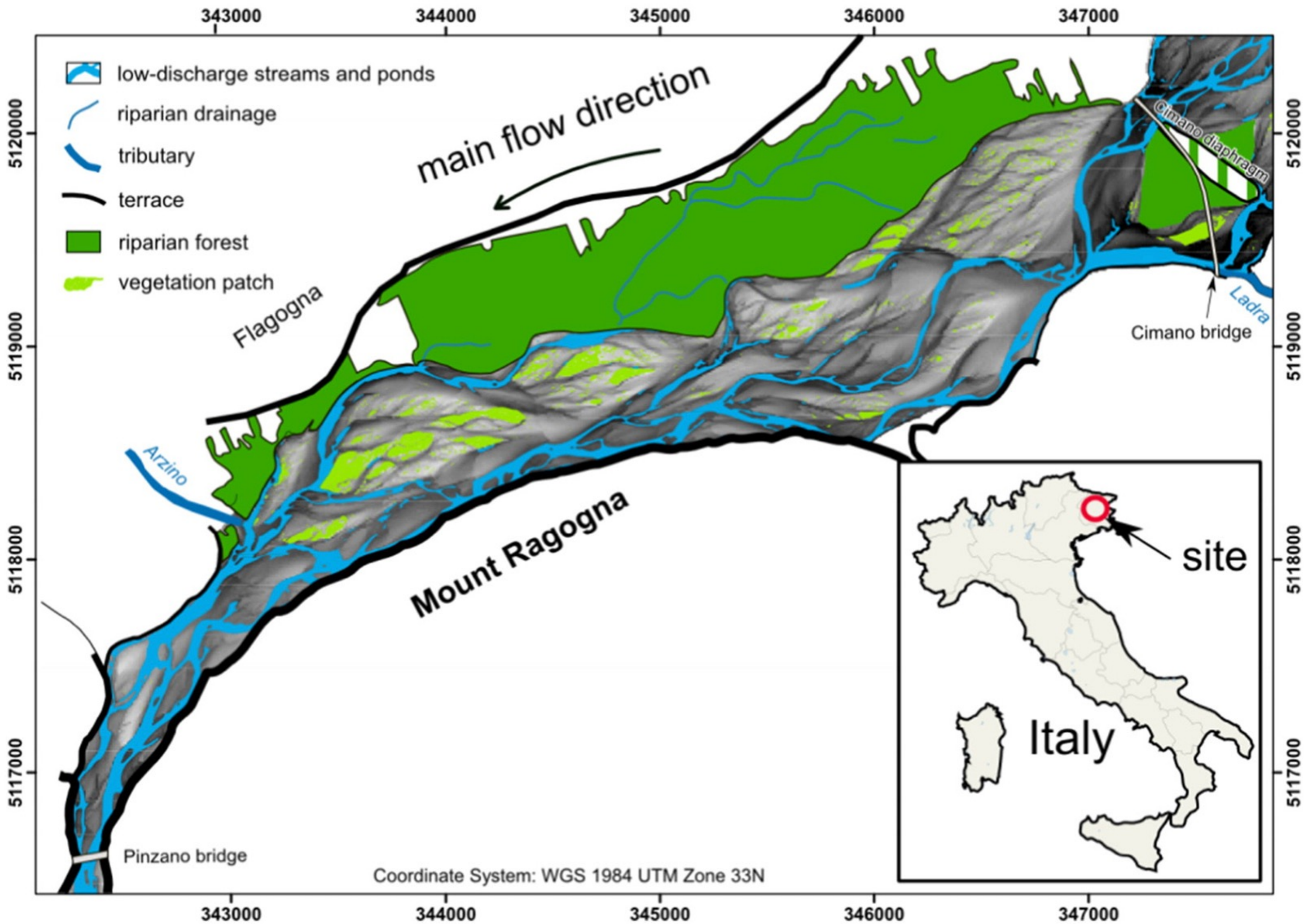
(a-c) Proximal to middle reaches, gravel-dominated (b), or sand-dominated (c) with minor proportion of gravel. (d-f) Distal, sand-dominated system with wide channels and flat, linguoid sand bars (d and e), or wide floodplain rarely inundated by flash floods (f)

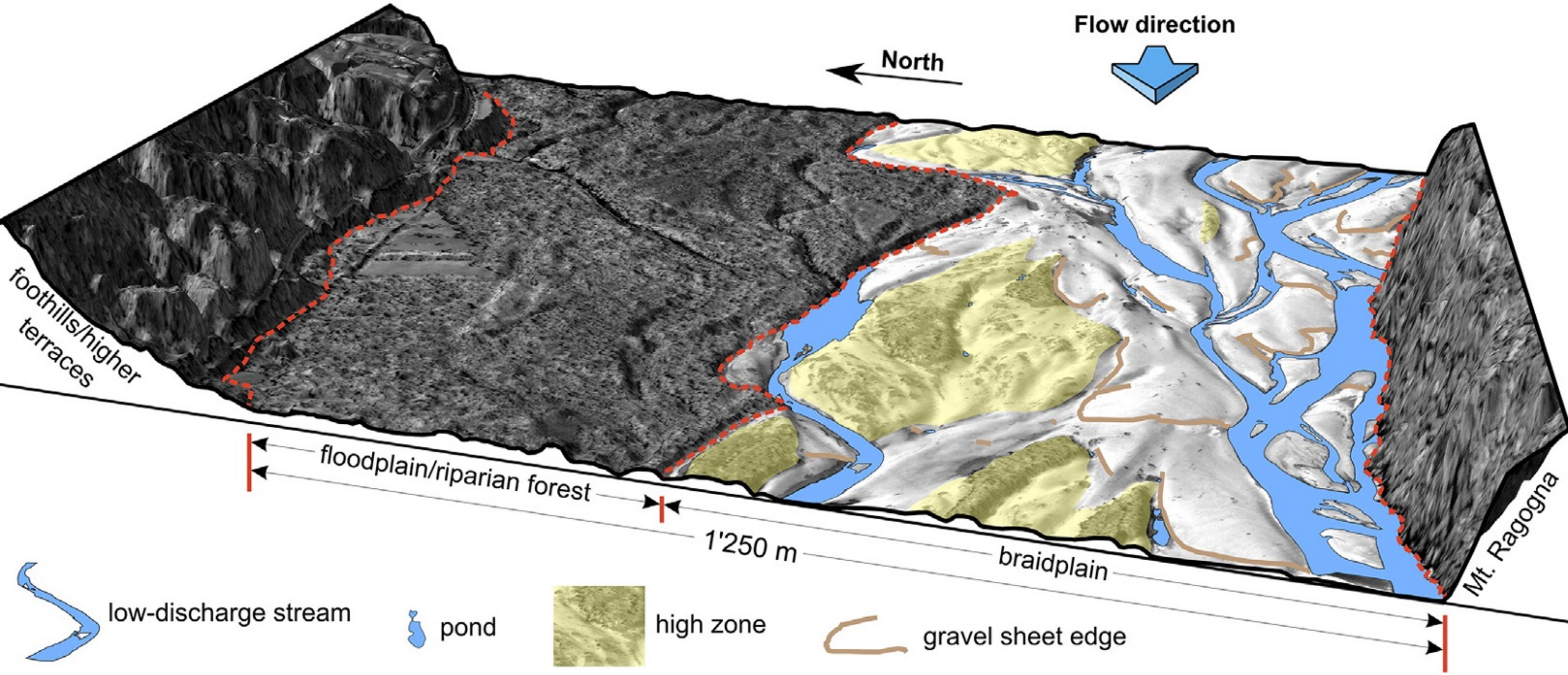
Einsele. Sedimentary Basins, 1992



Tagliamento River

Huber & Huggenberger (2015), Morphological perspective on the sedimentary characteristics of a coarse, braided reach. Geomorphology 248, 111–124



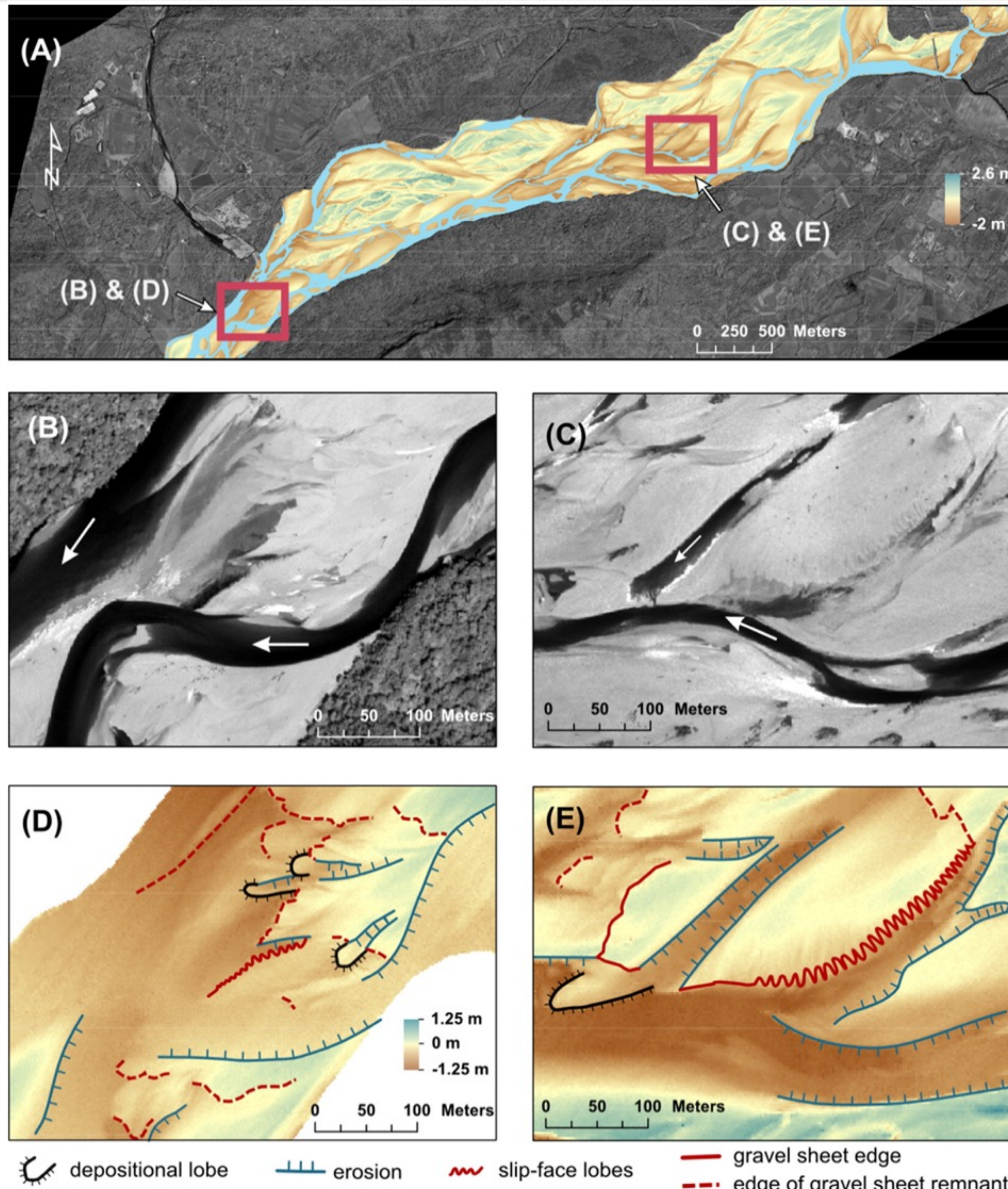


The braided river plain (or braidplain) is defined as the area that has been subjected to recent morphological changes by the river

Huber & Huggenberger (2015),

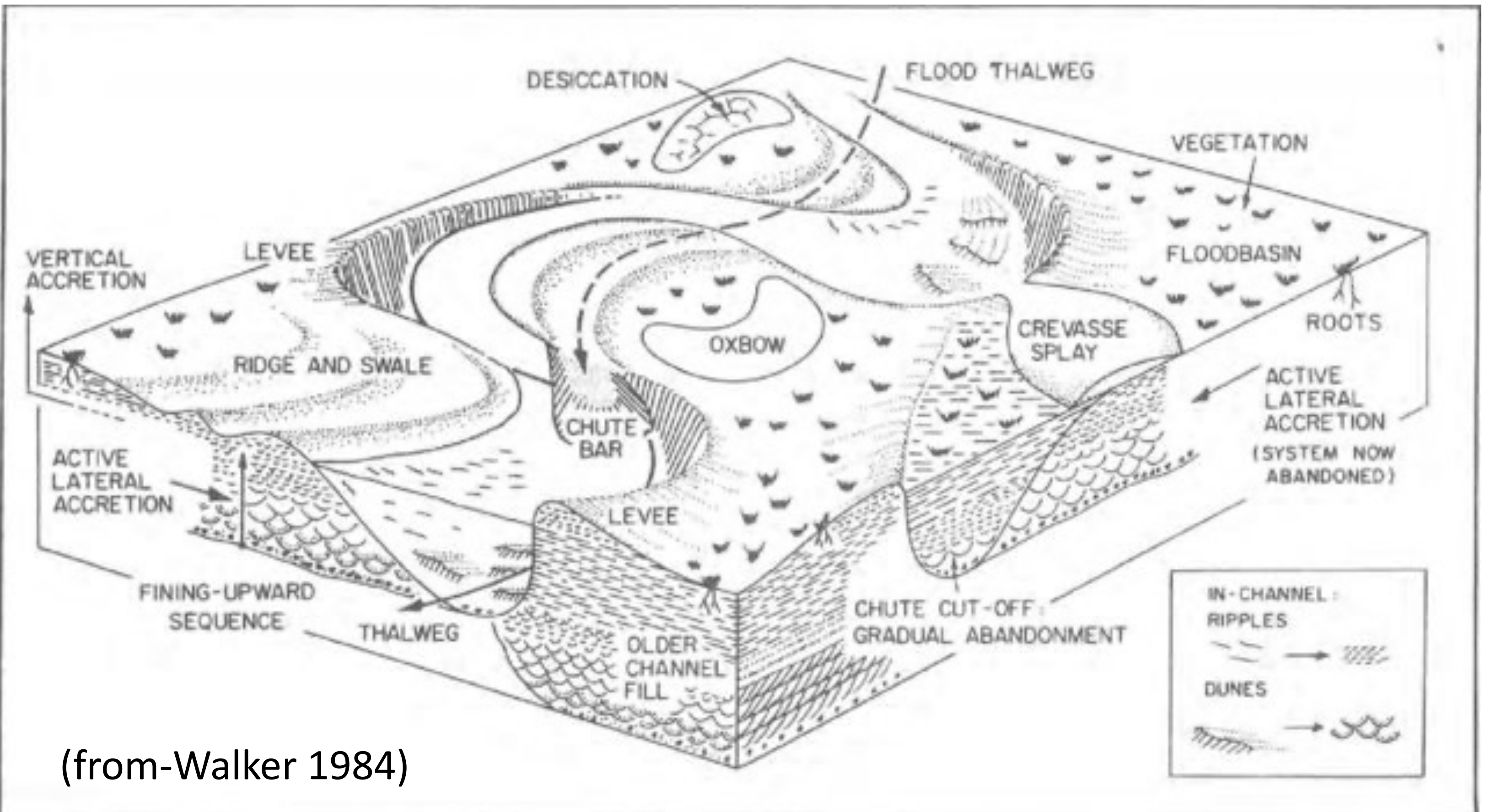
Two examples of gravel sheet reworking andoverlapping.(A) Position of the two locations in the. (B) and (C) panchromatic photographs. (D) and (E) LiDAR-derived DEM with superposed interpretations.

Interpretation: B) and D) = a complex overlapping of remnants of gravel sheets; C) and E) = well preserved gravel sheet dissected in its middle by a low-discharge incision.



Block diagram showing morphological elements of a meandering river system

Erosion on the outside bend of a meander loop leads to lateral accretion on the opposite point bar.



(from-Walker 1984)

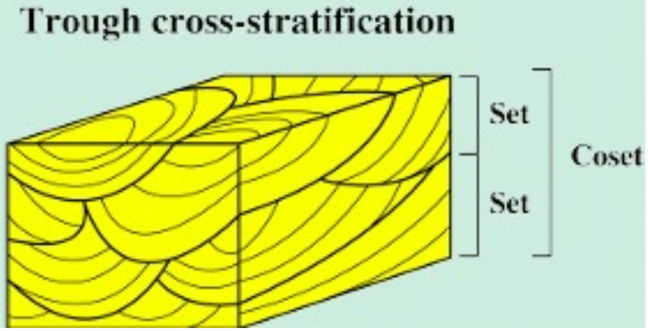
The dunes and ripples in the channel give rise to trough cross bedding and ripple cross lamination respectively (inset, lower right), which are preserved in a fining-upward sequence.

What is the most disgnostic sedimentary feature of (meandering) rivers?

What kind of stratification?

Trough cross-stratificaton:

Bounding surfaces are curved or trough shaped.

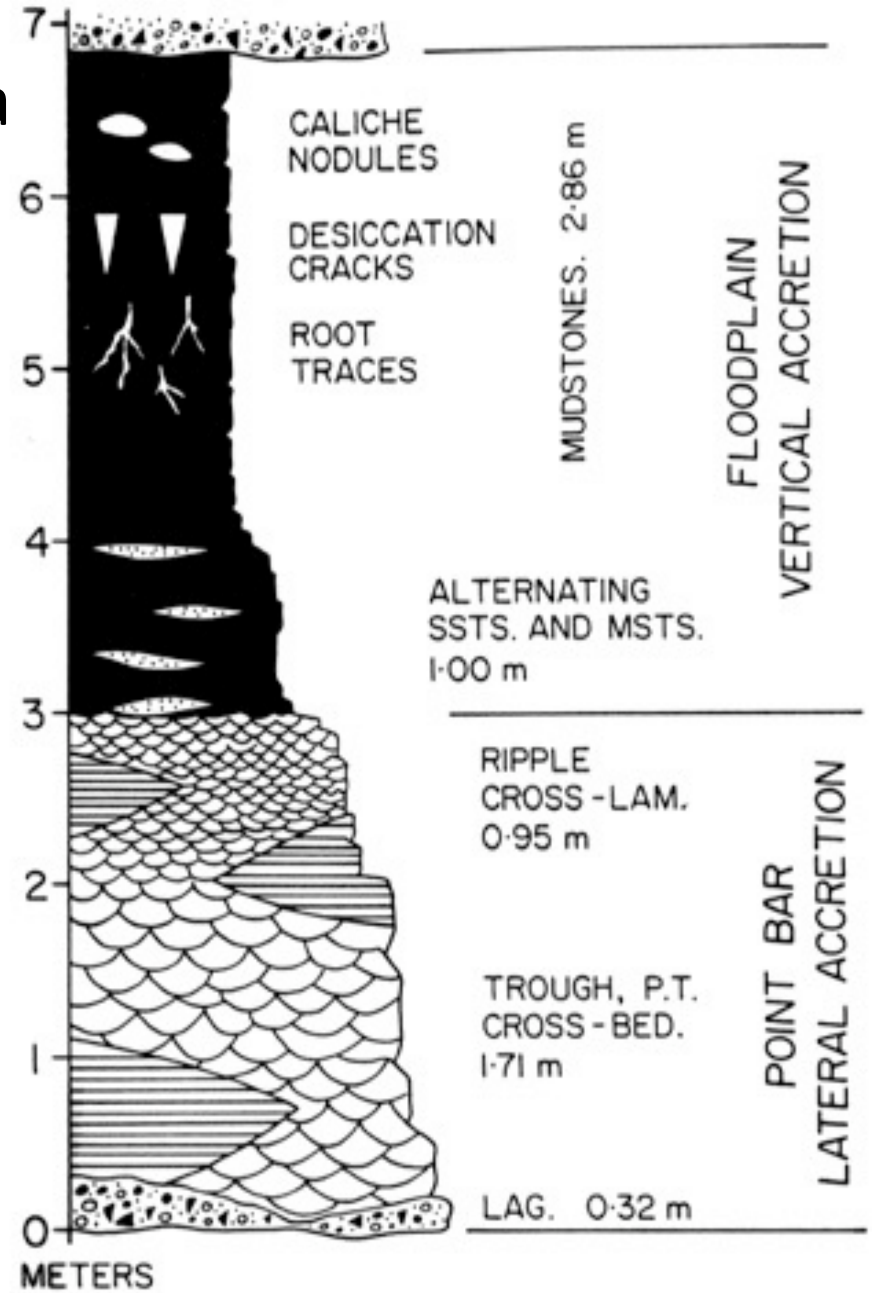


During average discharge, the typical bedform on the channel floor consists of sinuous-crested dunes ranging in height from about 30 cm to one metre. Preservation of these dunes results in trough cross-stratification

Cross-Bedding, Bedforms, and Paleocurrents by David M. Rubin and Carissa L. Carter

typical stratigraphic column for a meandering river system

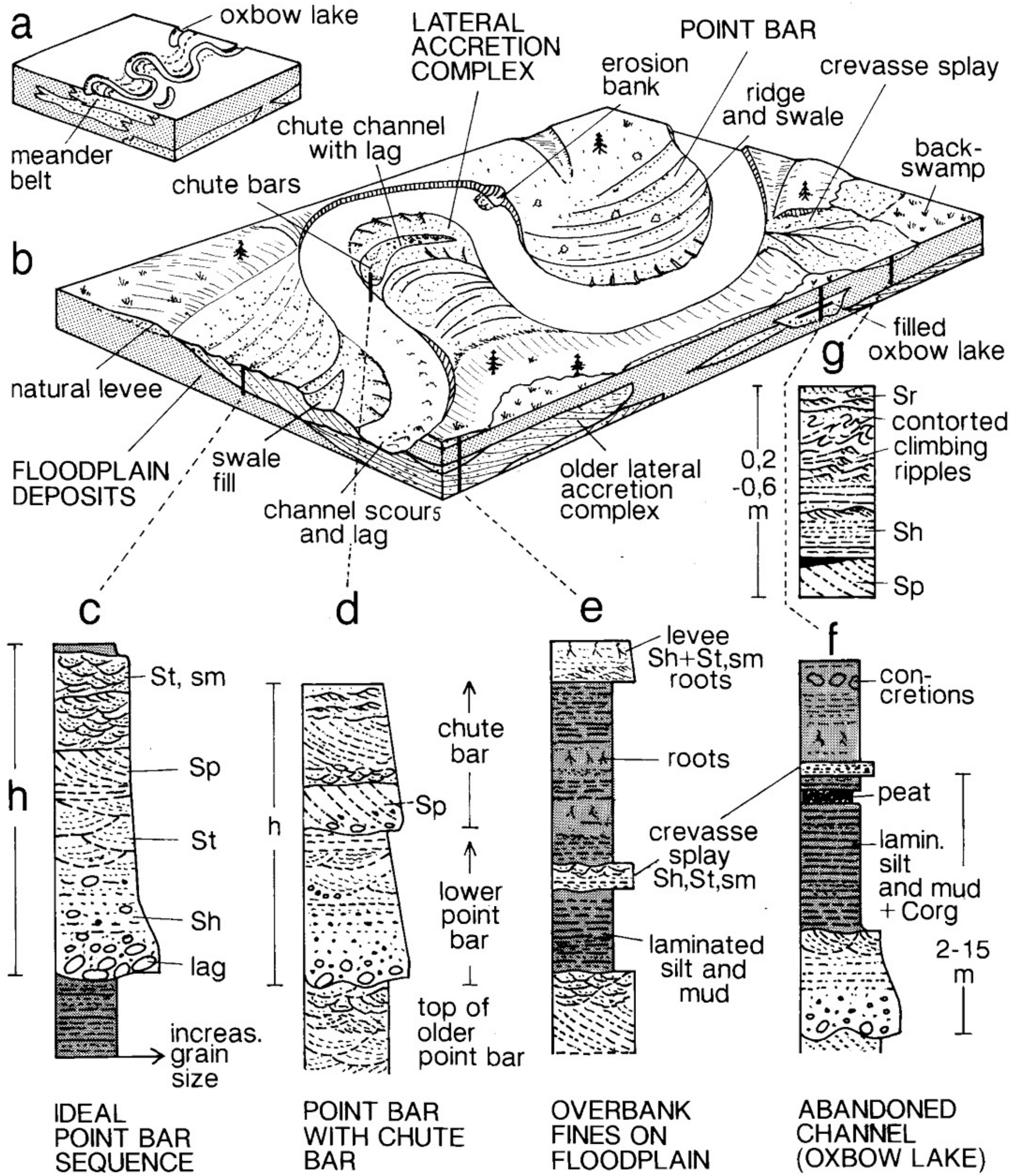
Typically: the lag deposits on the bottom, followed by trough cross stratification and ripple cross lamination, overlain by a floodplain facies composed of mud cracks and root traces in a fine grained sediment.
In shallower parts of the flow, higher on the point bar, the bedform is commonly ripples. As a broad generalization, the preserved deposits will pass from trough cross-bedded coarser sands to small scale, trough cross- laminated finer sands upward. The development of a plane bed (without ripples or dunes, resulting in horizontal lamination) can occur at various river stages, and hence parallel lamination can be preserved interbedded with trough cross-bedding, or small scale trough cross-lamination



(from-Walker 1984)

Meandering river system

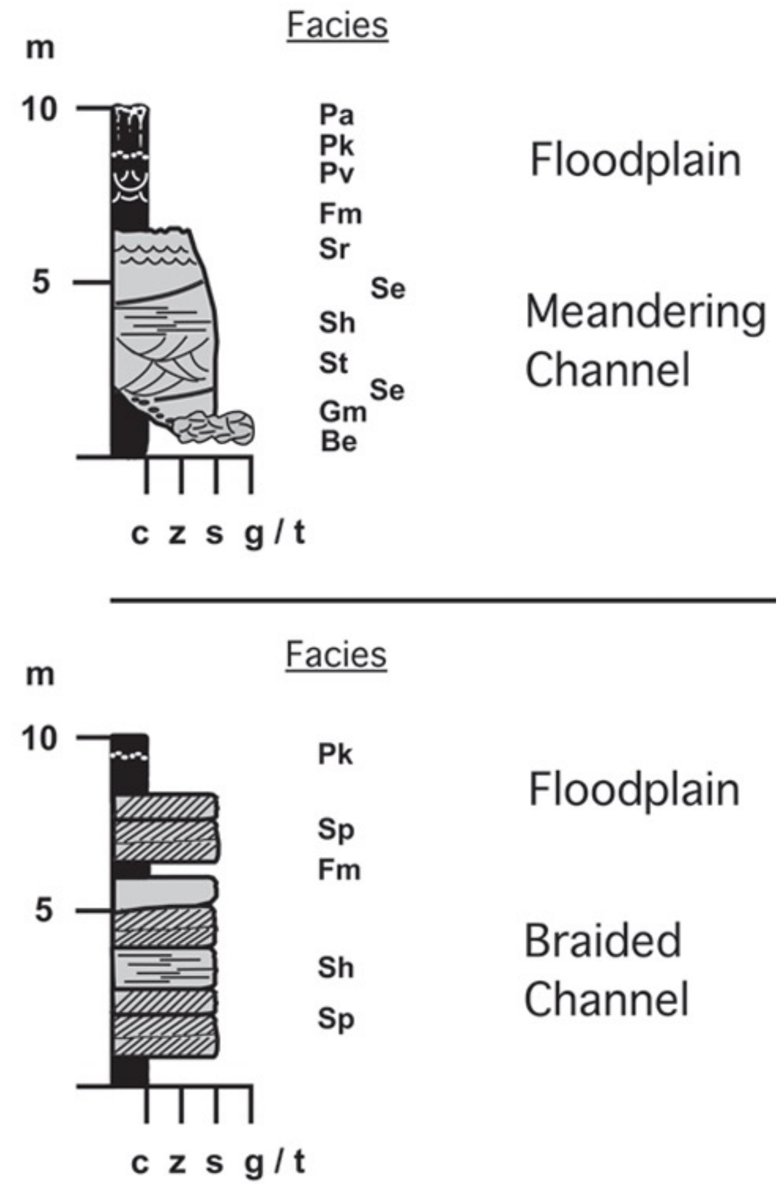
(a) Formation of sandy meander belt within a flood basin. (b) Different sub-environments of meandering channel. (c-g) Characteristic vertical sections of the youngest sediments of the flood basin. (h) One fluvial cycle (autocyclic).



Einsele. Sedimentary Basins, 1992

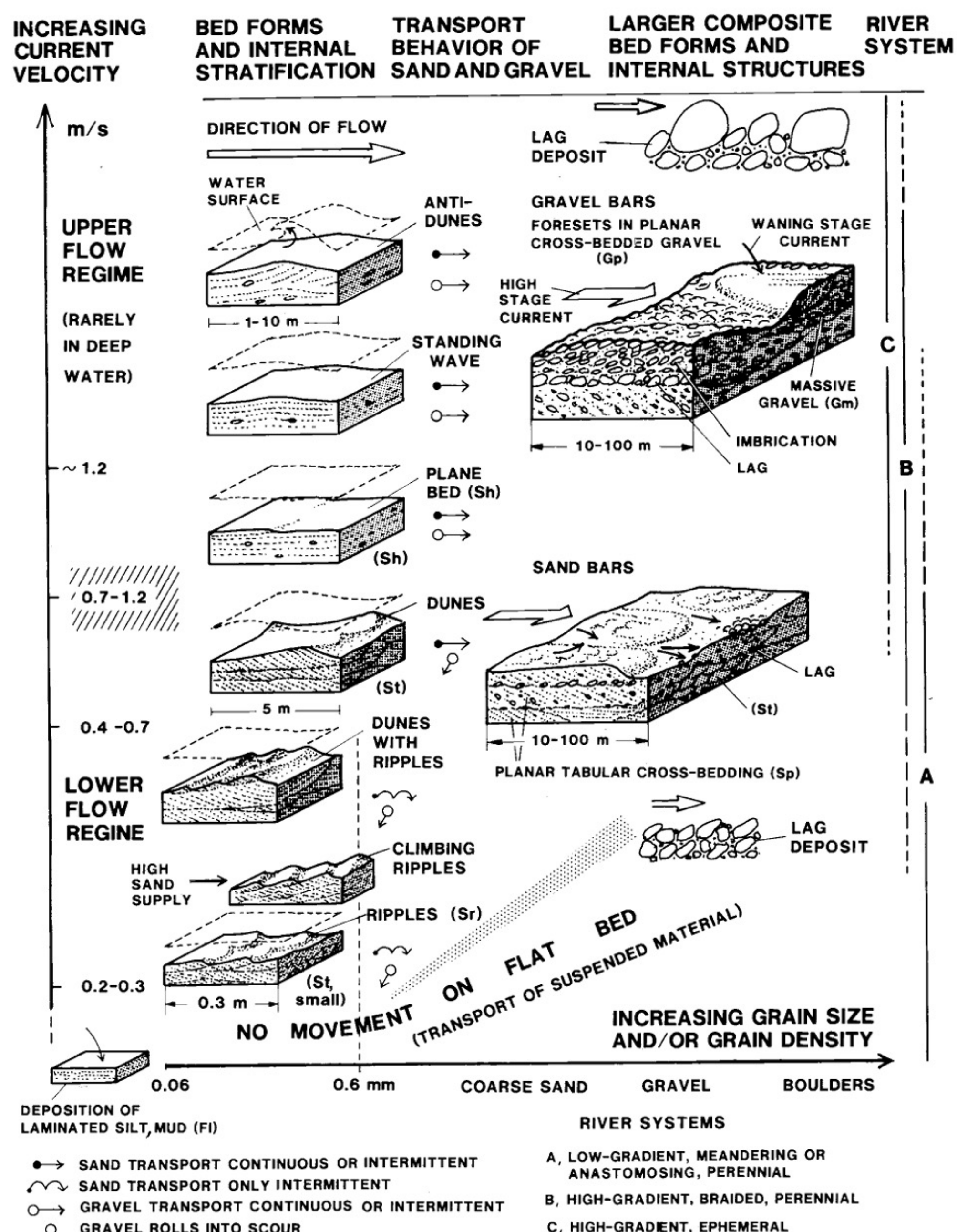
meandering versus braided river channel

There are also key differences in the facies for a meandering river channel and a braided river channel. Braided river channels will have coarser grain sizes due to their faster flow speeds. Meandering rivers carry lots of sediment within suspension that will be deposited in the structures associated with this environment, including point bars and oxbow lakes. Lastly, the migration of meandering rivers is more uniform in direction than a braided river because it will always migrate towards the eroding bank. A braided channel will migrate in many directions at the same time.



Characteristic features and sequences of the alluvial facies associations. Idealized stratigraphic columns are depicted, showing thickness and dominant lithology (c ,clay; z, silt; s, sand; g, gravel; t, tu).

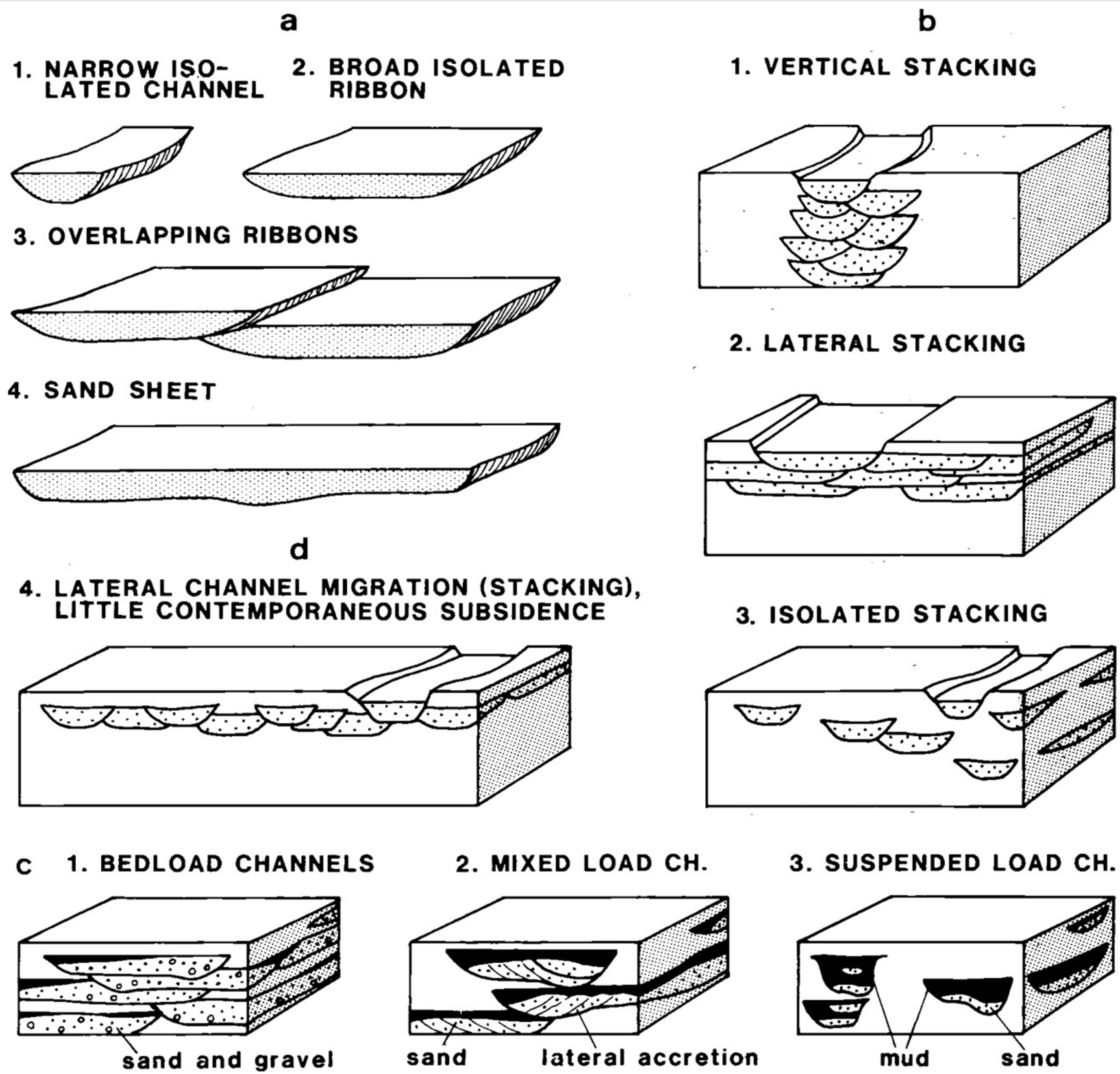
Relationship between current velocity (hydraulic regime), grain size, minor and medium-sized bed forms, and internal sedimentary structures of fluvial deposits. The larger bed forms and their internal structures result from fluctuating water stages and current velocities, and therefore cannot be attributed to certain flow conditions. Small ripple forms develop only in fine to medium sands (< 0.6 mm). For transport of sand and gravel, current velocities higher than 70 to 120 cm/s (upper flow regime) are needed. The resulting beds are either horizontally stratified sands with some matrix-supported gravel, or planar cross-bedded gravelly sands. Gravel exposed to currents which are only capable of eroding and transporting sand roll into developing scours. If all sandy material is eroded, gravel may form lag deposits, which protect underlying finer material from further reworking.



Einsele. Sedimentary Basins, 1992

Principal types of sand and sandstone reservoir geometries generated by channel fills in fluvial systems

a) Single sandstone bodies. B) Different types of stacked channel sands. B1) is associated with rapid subsidence, b4) with little subsidence. c) Channel fills of bed-load, mixed-load, and suspended-load rivers.

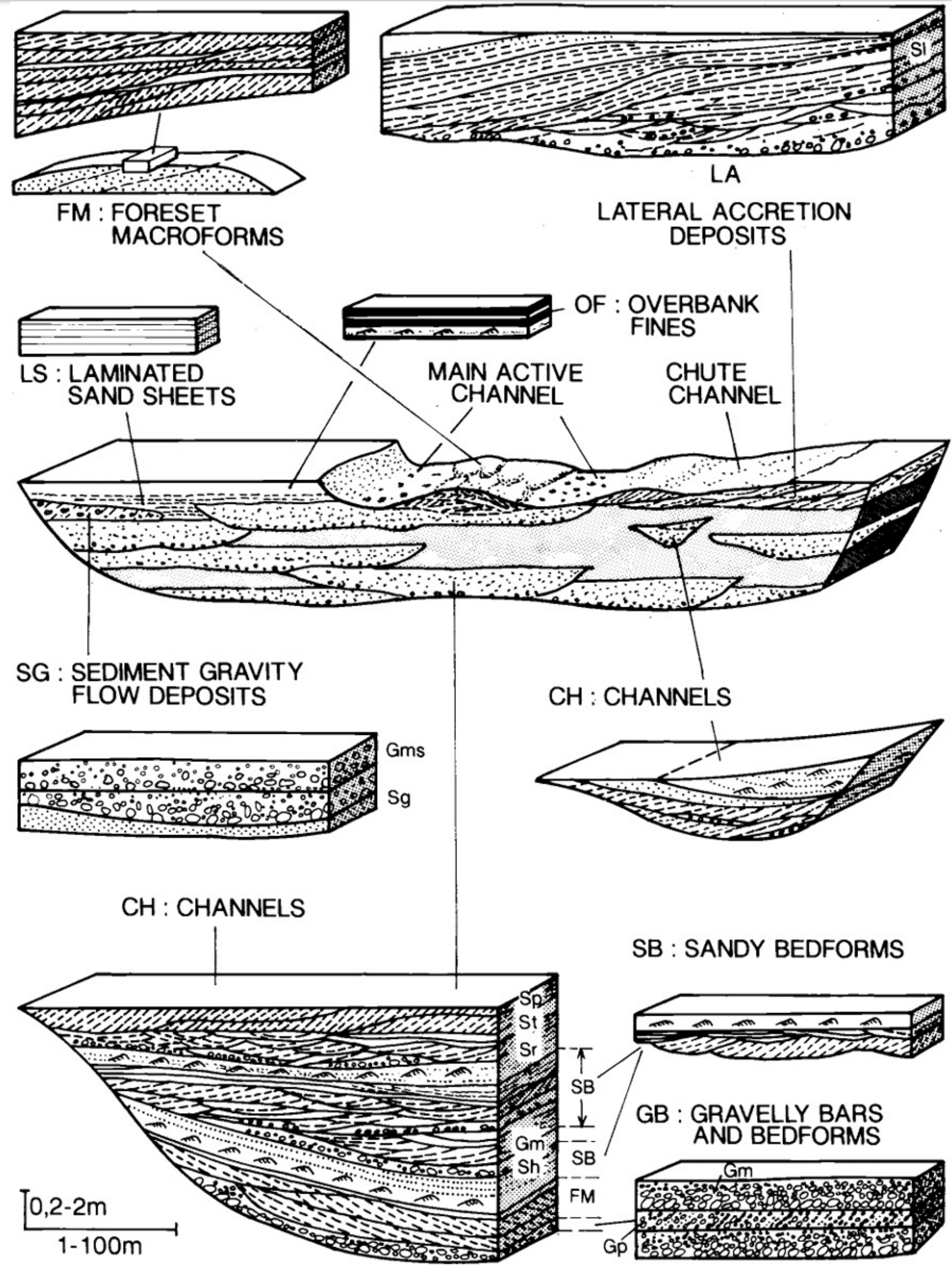


Einsele. Sedimentary Basins, 1992

Basic architectural elements of fluvial deposits

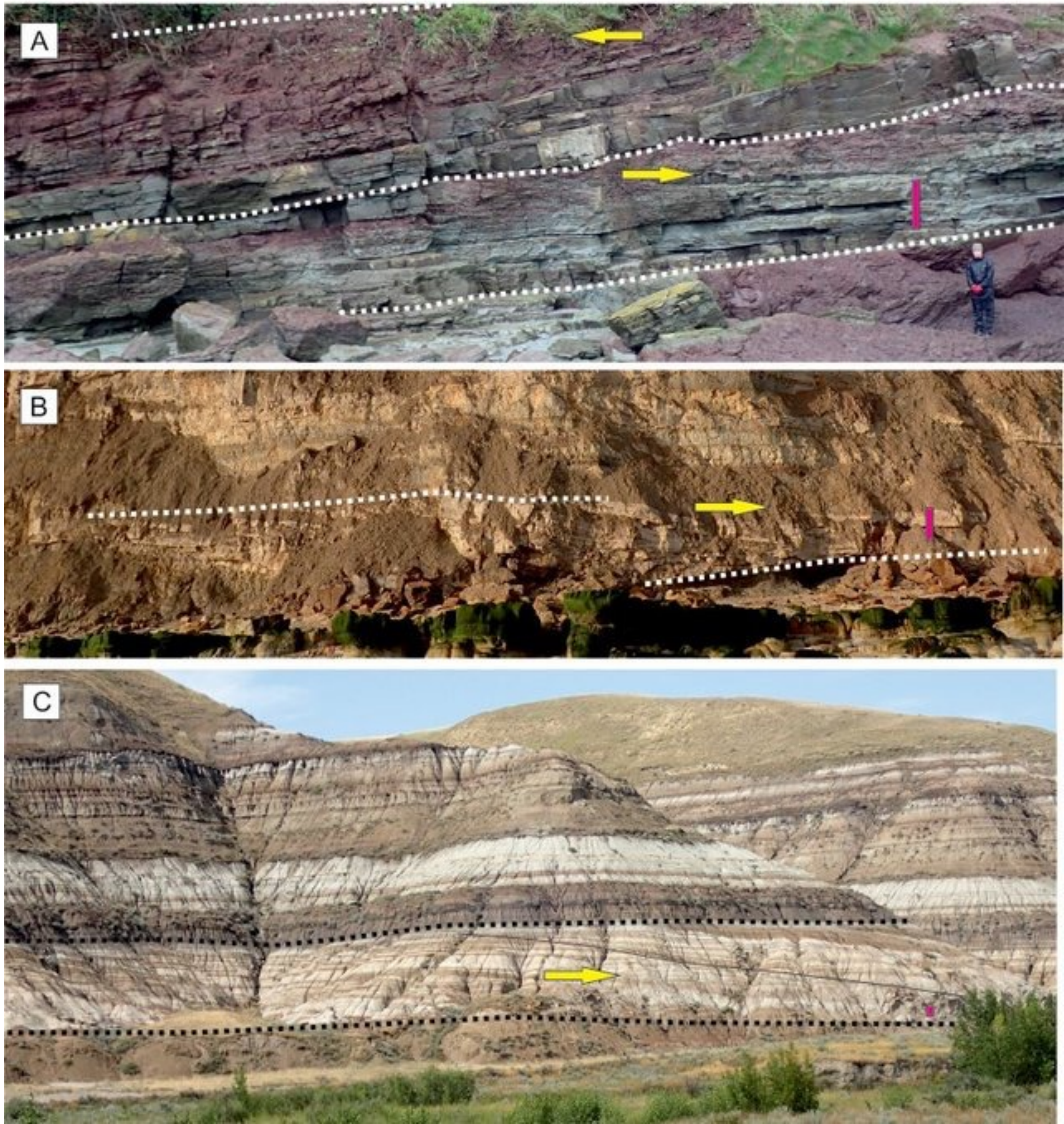
Einsele. Sedimentary Basins, 1992

OF Overbank fines, sheet-like geometry, predominantly vertical aggradation of lithofacies Fl, mud or silt with thin lenses or laminae of silt to fine sand, commonly showing ripple cross- lamination; LS Laminated sand sheets, up to several meters thick, produced by flash floods, Sh lithofacies, and other sandy bedforms. SB Sand bedforms, including Sh, St, Sp, and Sr lithofacies. GB Gravelly bars and bedforms comprising lithofacies Gm and Gp, frequently alternating with SB and MF (in proximal regions); FM foreset macroforms of the active main channels, i.e., large compound bar forms, consisting of several co-sets of presumably upper flow regime bed forms; predominantly smaller-scale element in SB. LA Lateral accretion deposits (including point bar deposits), with variable internal geometry and lithofacies, consisting of different smaller-scale elements, for example GB (at the base) and SB, gently dipping surfaces toward the main channel. CH Channel fills of different size and geometry. MF Mass flow deposits, mainly Gms lithofacies, frequently associated with GB.



laterally-accreting inclined heterolithic stratification

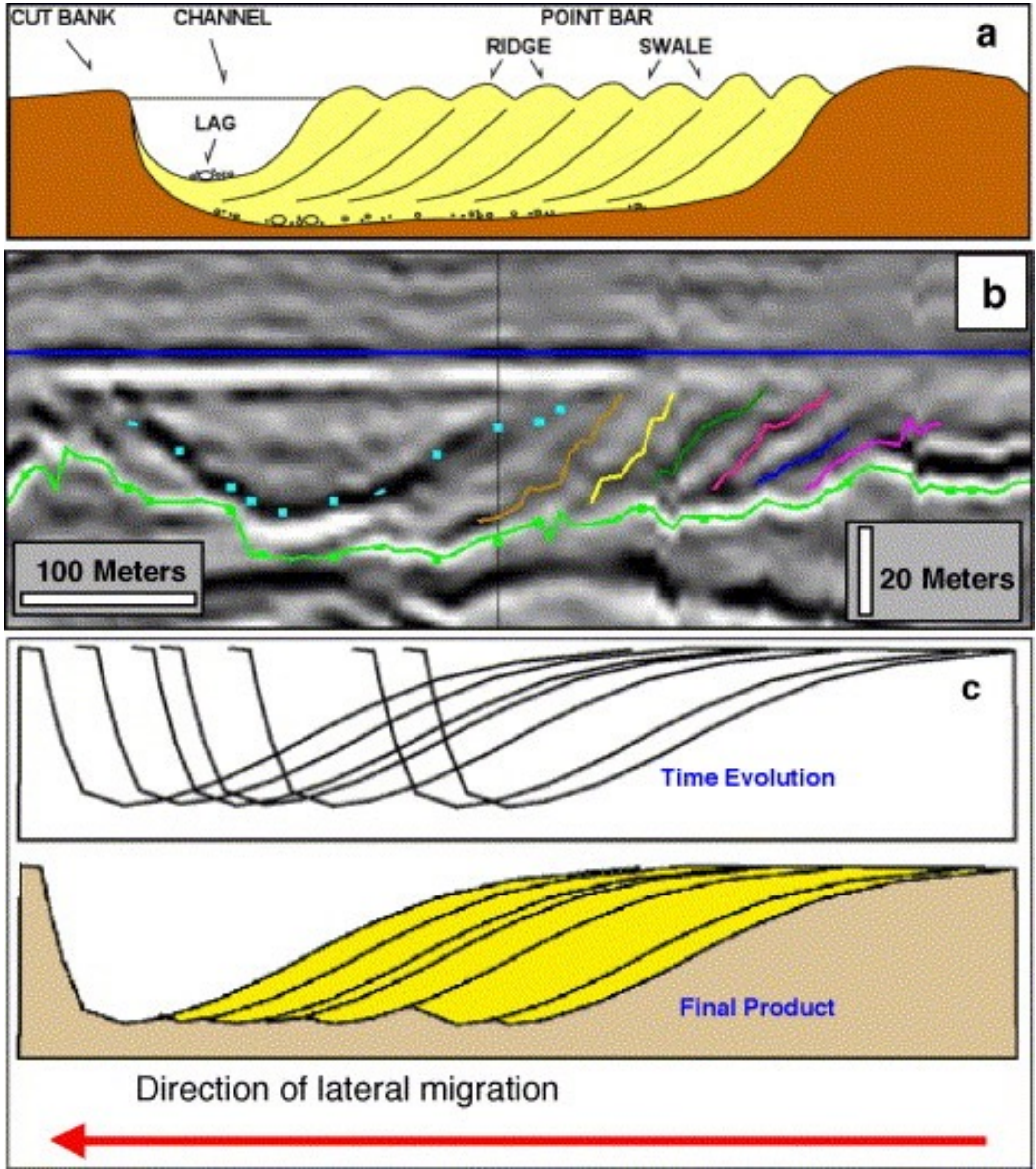
Outcrop expressions of LA-IHS recording point bar deposits of various scales.
In each image, dashed line shows bounding surfaces of the LA-IHS element, yellow arrow shows general direction of migration and pink bar represents one metre vertically: (A) Two superimposed LA-IHS packages in broadly opposed directions; strata deposited in a fluvial floodplain environment. Milford Haven Group, Wales; (B) Isolated LA-IHS within estuarine facies. Ashdown Formation, England; (C) Large scale LA-IHS with internal erosion surface, recording deposition within a tidally-influenced meandering point bar. Horseshoe Canyon Formation, Canada.



Lateral accretion packages

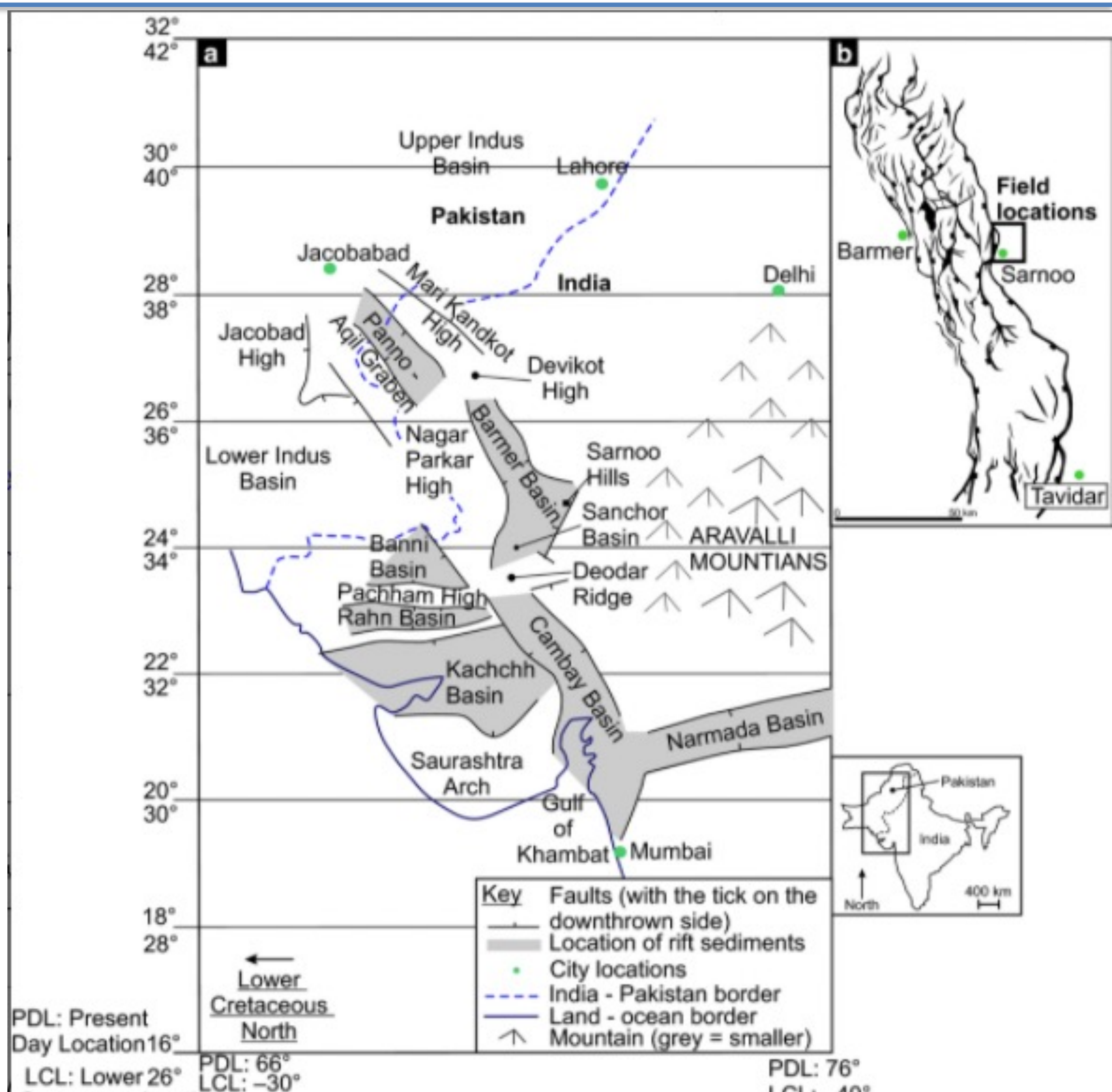
(a) Fluvial point-bar model. (b) The cross-section view of a LAP in a deepwater, sinuous, erosionally confined channel resembles the geometry of a fluvial point-bar. (c) Depositional model proposed for the LAPs. The accretion surfaces would be formed by relatively continuous lateral sweep of channel bends by systematic erosion of the outer banks and deposition along inner banks (the classic point-bar model).

Abreu et al., 2003, Lateral accretion packages (LAPs): an important reservoir element in deep water sinuous channels. Marine and Petroleum Geology 20, 631-648

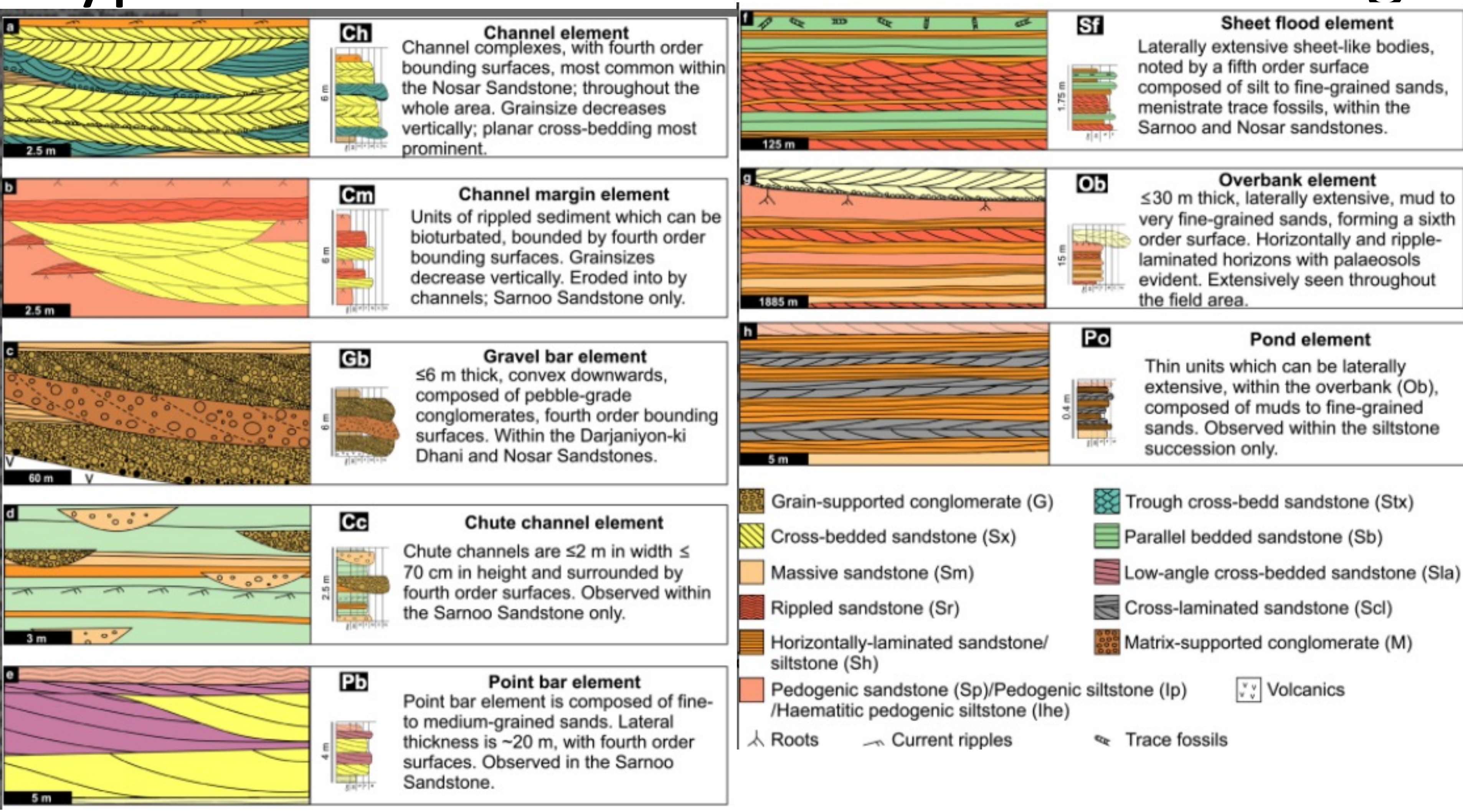


channel belt sandstone packages

Beaumont et al. (2018) The Depositional Record Sedimentology and the facies architecture of the Ghaggar-Hakra Formation, Barmer Basin, India

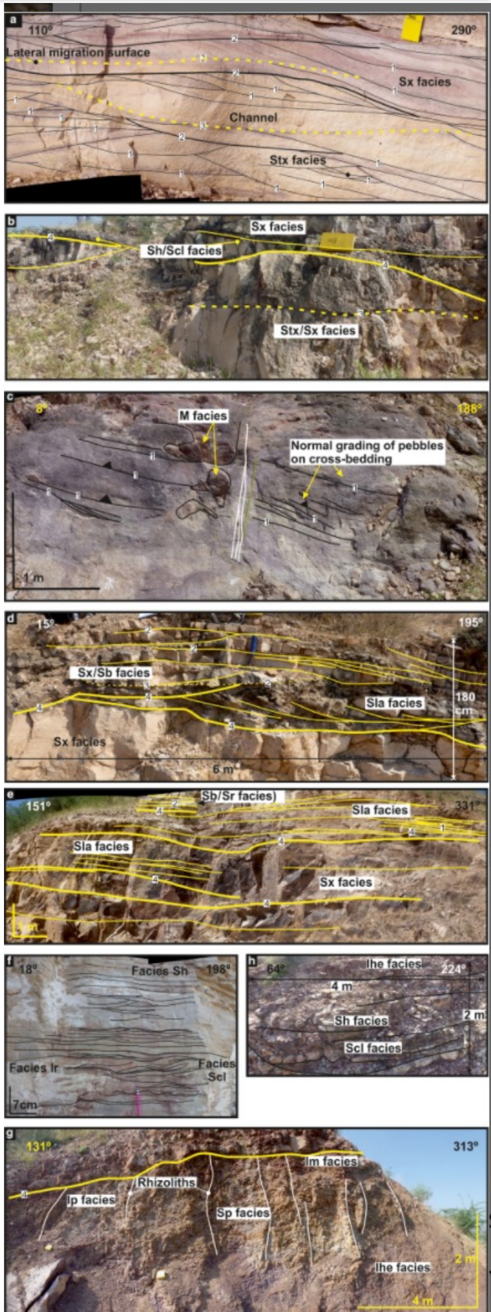


Typical two-dimensional sketches and logs



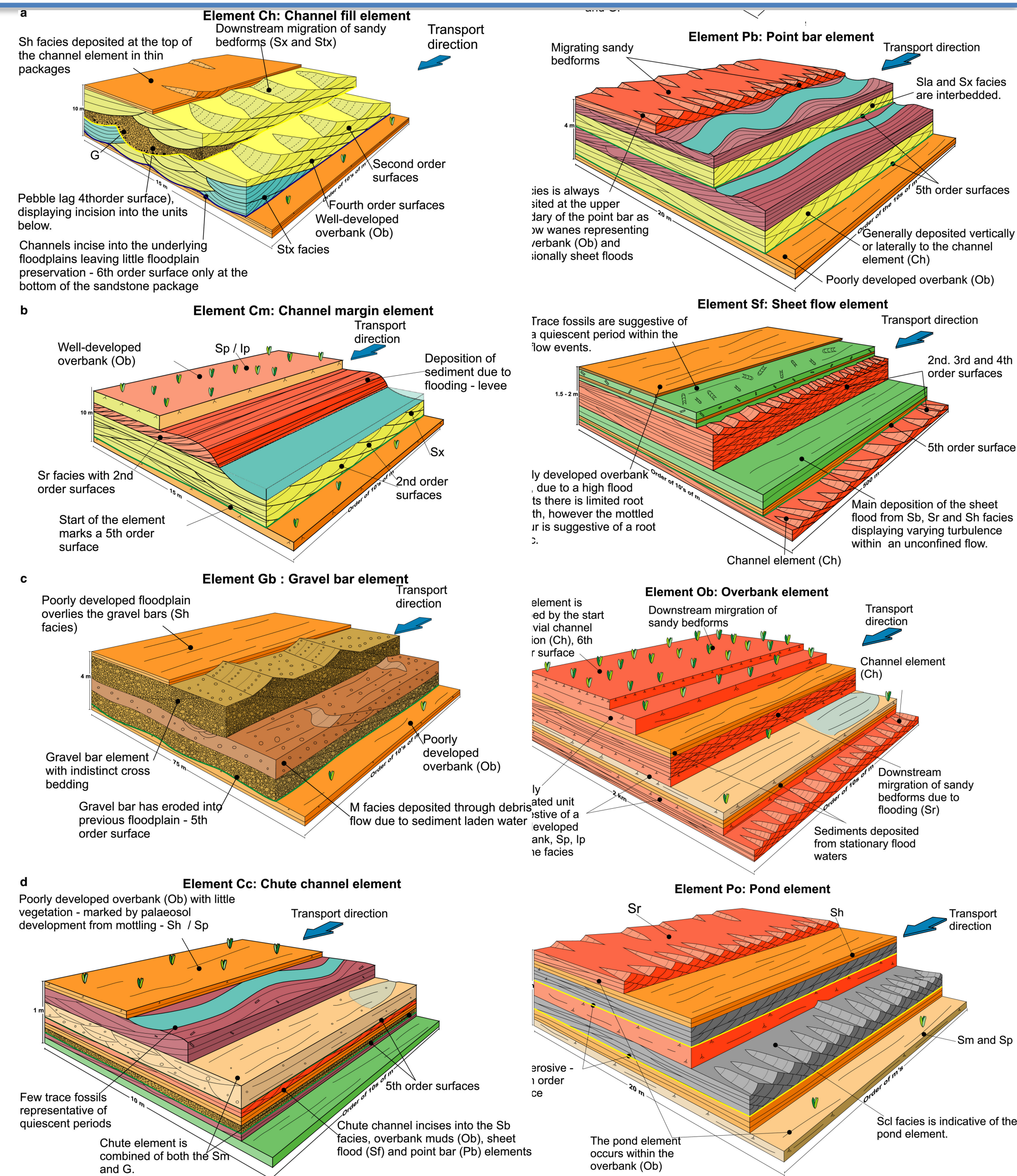
(a) Channel, Ch; (b) Channel margin, Cm; (c) Gravel bar, Gb; (d) Chute channel, Cc; (e) Point bar, Pb; (f) Sheet flow, Sf; (g) Overbank, Ob, and; (h) Pond, Po

Interpreted photographs of the architectural elements (a) Channel element (Ch) displaying first- to third-order bounding surfaces with the trough and planar cross-bedded sandstone facies; (b) Channel margin element (Cm) displaying the gradational change from the cross-bedded facies (Stx/Sx) into the cross/horizonal-lamination facies (Sh/Scl) overlain by an erosional surface and the planar cross-bedded facies; (c) Gravel bar element (Gb) displaying the conglomerate facies (M & G) with indistinct cross-bedding and upon some of the cross-beds there are graded clasts; (d) Chute channel element (Cc) this image depicts the channel element indicated by the planar cross-bedded facies (Sx), the Point bar element indicated by the low-angle cross-bedded facies (Sla) and the chute channel indicated by the thick, thin solid lines and the planar cross-bedded and planar horizontally bedded facies (Sx/Sb); (e) Point bar element (Pb) with low-angle cross-bedded facies (Sla) with second- and fourth-order bounding surfaces laterally migrating into the channel element (Ch); (f) Sheet flow element (Sf), here the element displays the horizonal-laminated and cross-lamination facies (Sh/Scl) with various types of ripples; (g) Overbank element (Ob) indicated by the rhizoliths and the pedogenic facies (Sp/Ip/Ihe), and; (h) Pond element (Po) indicated by the horizonal-laminated and cross-lamination facies (Sh/Scl)



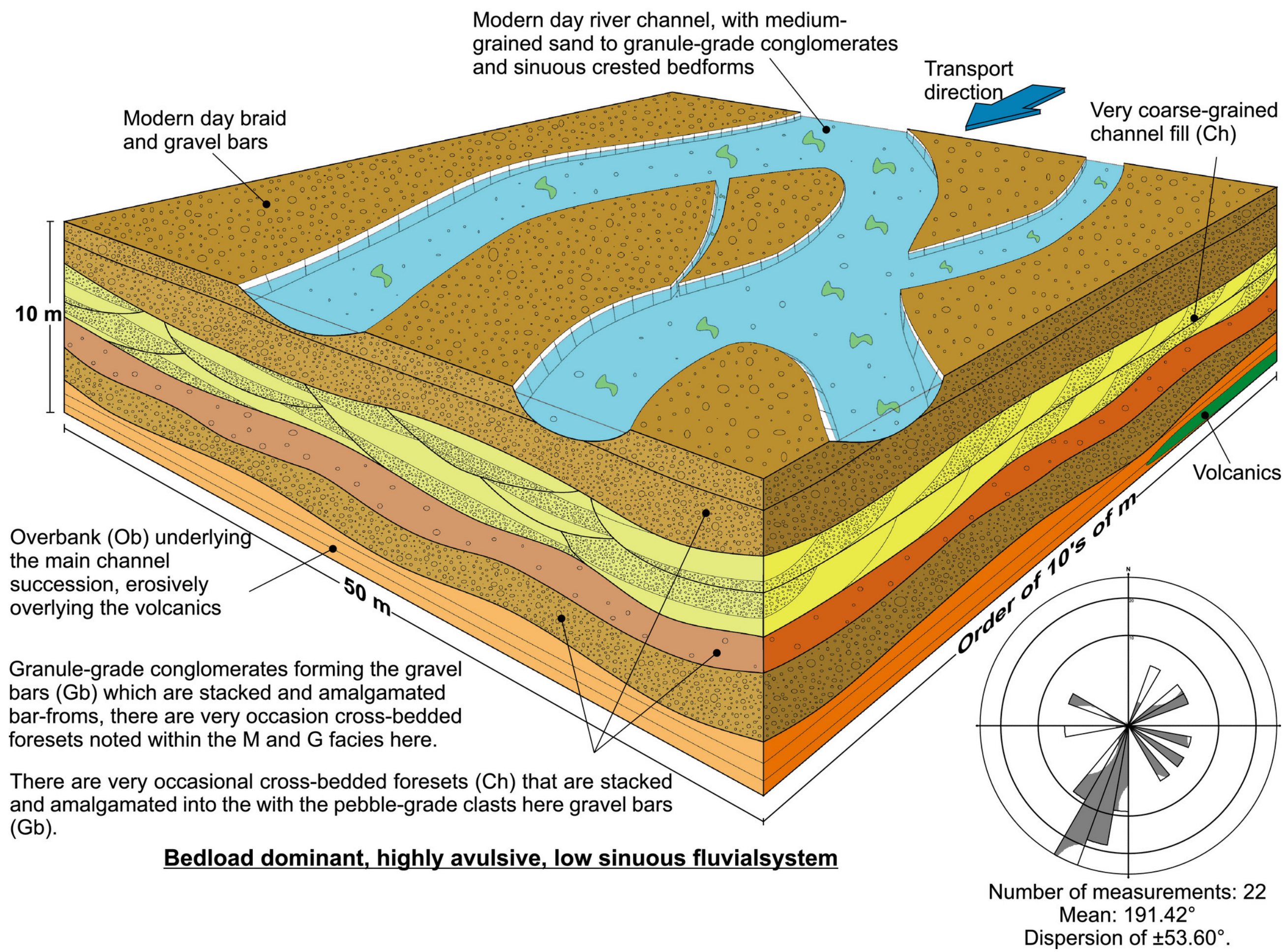
Three-dimensional facies models of the architectural elements

(a) The channel element (Ch) with an erosive lower base contains first- to third-order surfaces internally. (b) The channel margin (Cm) element with an erosive lower base and first- to third-order surfaces internally, the succession grades into the overbank. (c) The gravel bar (Gb) element with an erosive lower boundary and first- to second-order surfaces within. (d) The chute channel (Cc) element with an erosive lower boundary and occasional first order boundaries within. (e) The point bar (Pb) element with an erosive fourth order boundary with first- to third-order surfaces internally. This succession grades into the overbank. (f) The sheet flow (Sf) element starting with a lower fourth order bounding surface with first- to third-order surfaces within. There are quiescent periods here evidenced by trace fossils. (g) The overbank (Ob) element with first, second, and fourth-order surfaces within. (h) The pond (Po) element has a fourth order base and first- to second-order surfaces internally



Facies model of the gravel bedload dominant low sinuosity fluvial system

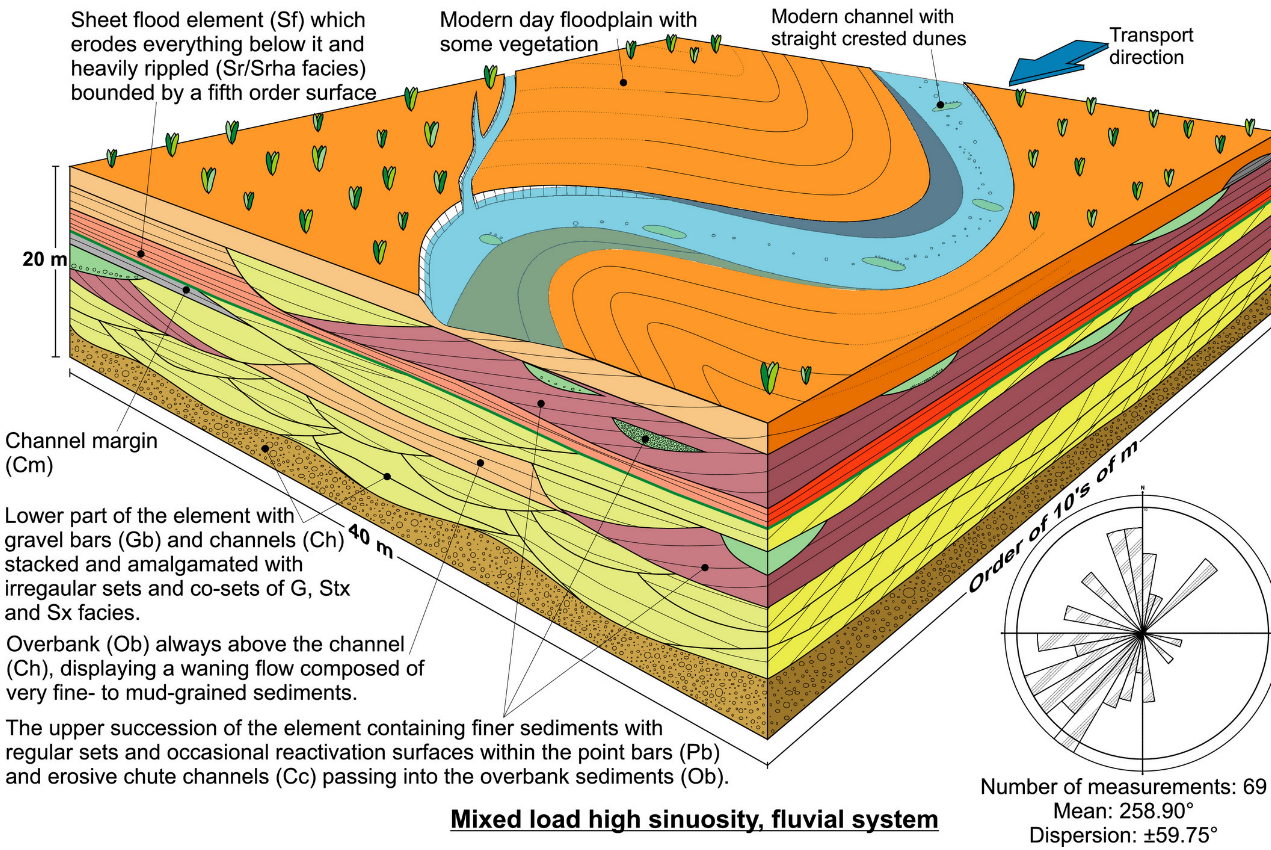
The Darjaniyon-ki Dhani Sandstone contains the channel (Ch), gravel bar (Gb) and the overbank (Ob) architectural elements. There are 4th to 6th order bounding surfaces within. The sets and cosets within are inconsistent suggesting the gravel bars are transient, suggesting fluvial immaturity. The proportion of channels to floodplain is 90% to 10%, respectively



Bedload dominant, highly avulsive, low sinuous fluvialsystem

Facies model of the mixed load high sinuosity fluvial system

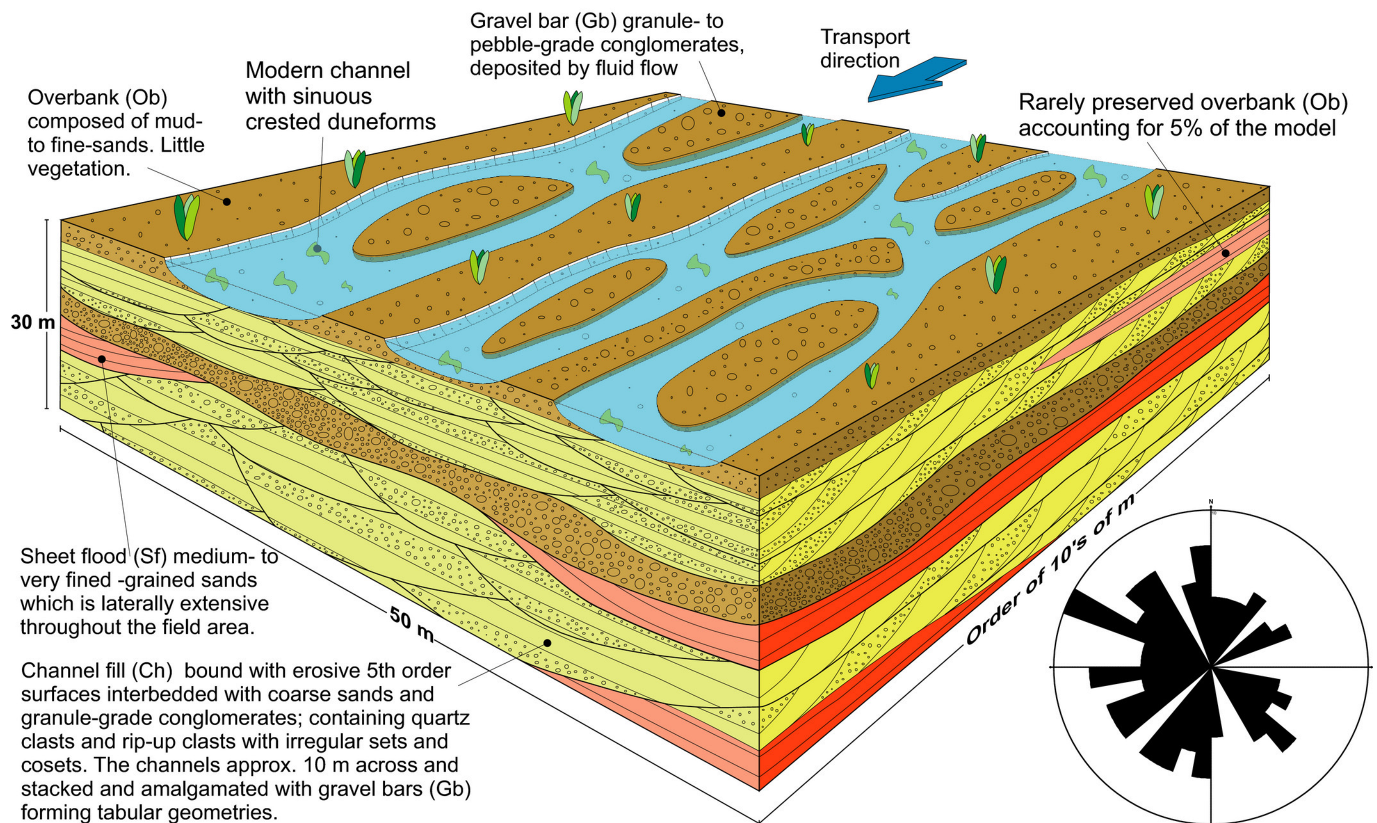
The Sarnoo Sandstone contains the channels (Ch), channel margin (Cm), gravel bars (Gb), chute channels (Cc) sheet flows (Sf), and overbank (Ob) elements. The consistency of sets and cosets representing the migration of in-channel bedforms suggests discharge stability. The proportion of sand to mud increases from 80% sand and 20% mud to 60% sand and 40% mud vertically throughout the facies model.



Mixed load high sinuosity, fluvial system

Facies model of a well-developed, bedload dominant, low sinuosity fluvial system

The Nosar Sandstone displays channel (Ch), floodplain (Ob), gravel bars (Gb) and sheetflow (F6) elements. There are all six types of bounding surfaces within indicating erratic surfaces and multiple truncations. This suggests discharge irregularity and a high level of channel migration. The proportion of sand to mud is at 90:10

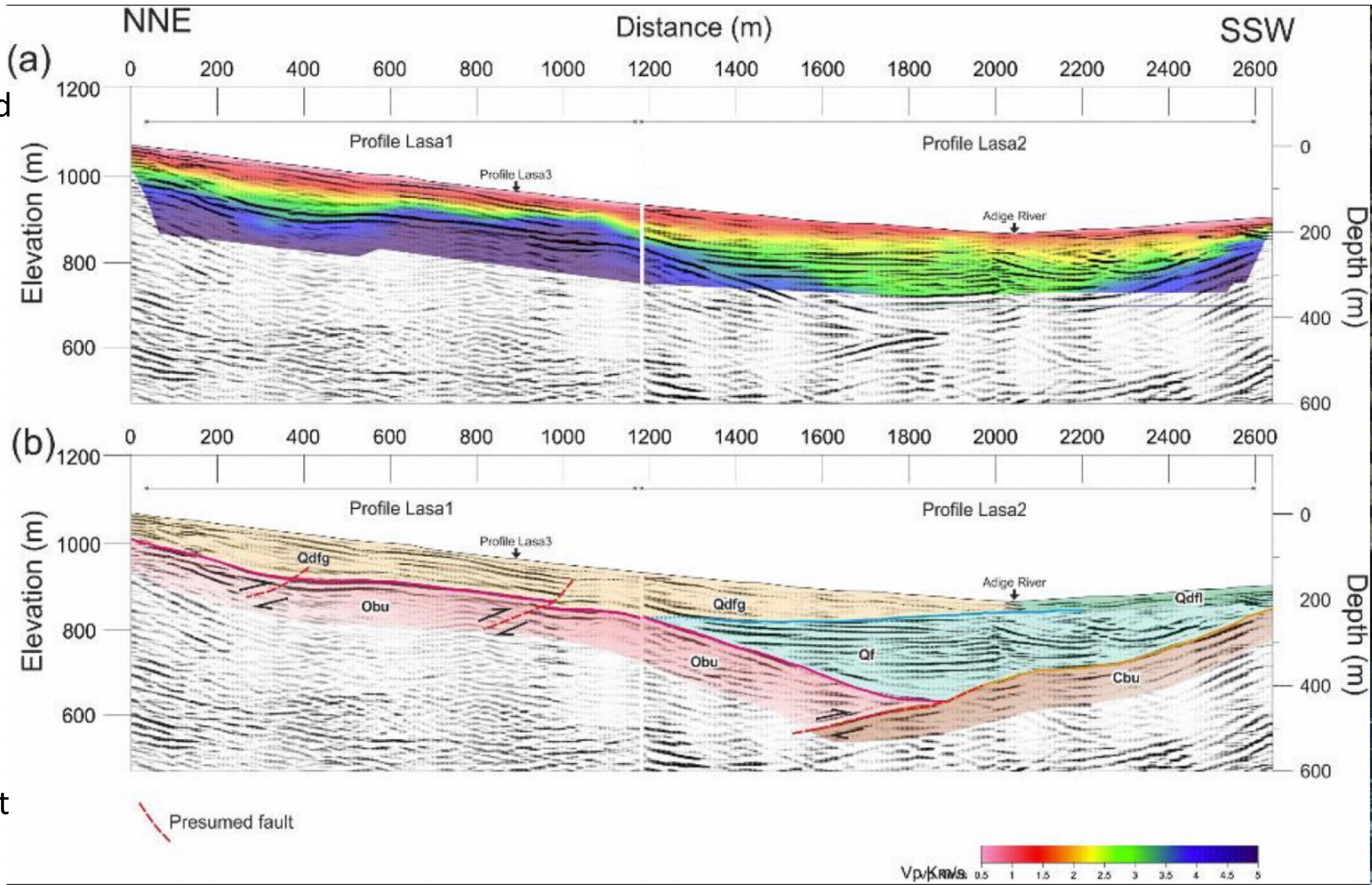


Number of measurements: 62
Mean: 272.01°
Dispersion: ±69.38°

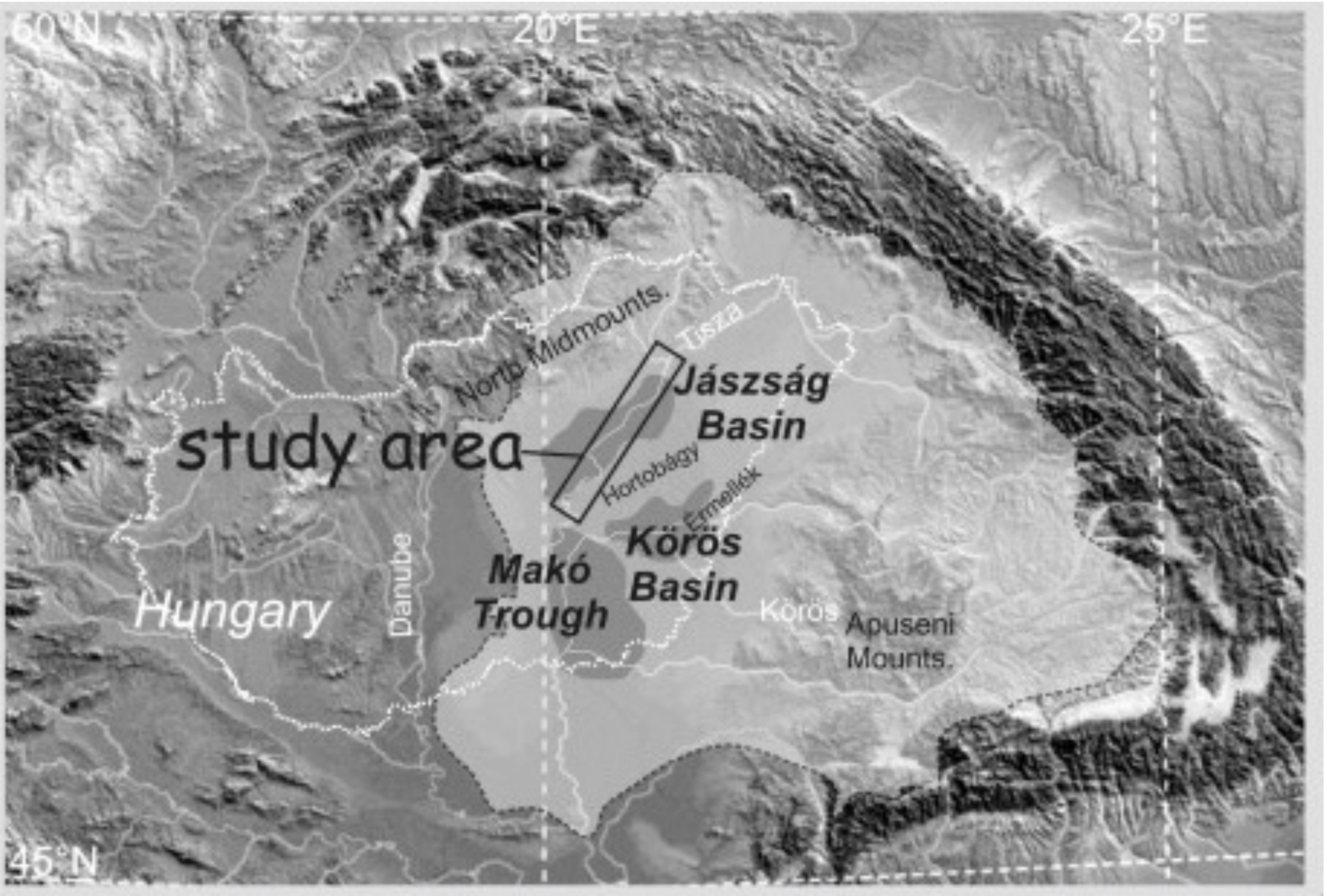
Bedload dominant, low sinuosity fluvial system

Maraio et al., 2018. High-resolution seismic imaging of debris-flow fans, Val Venosta,Journal of Applied Geophysics

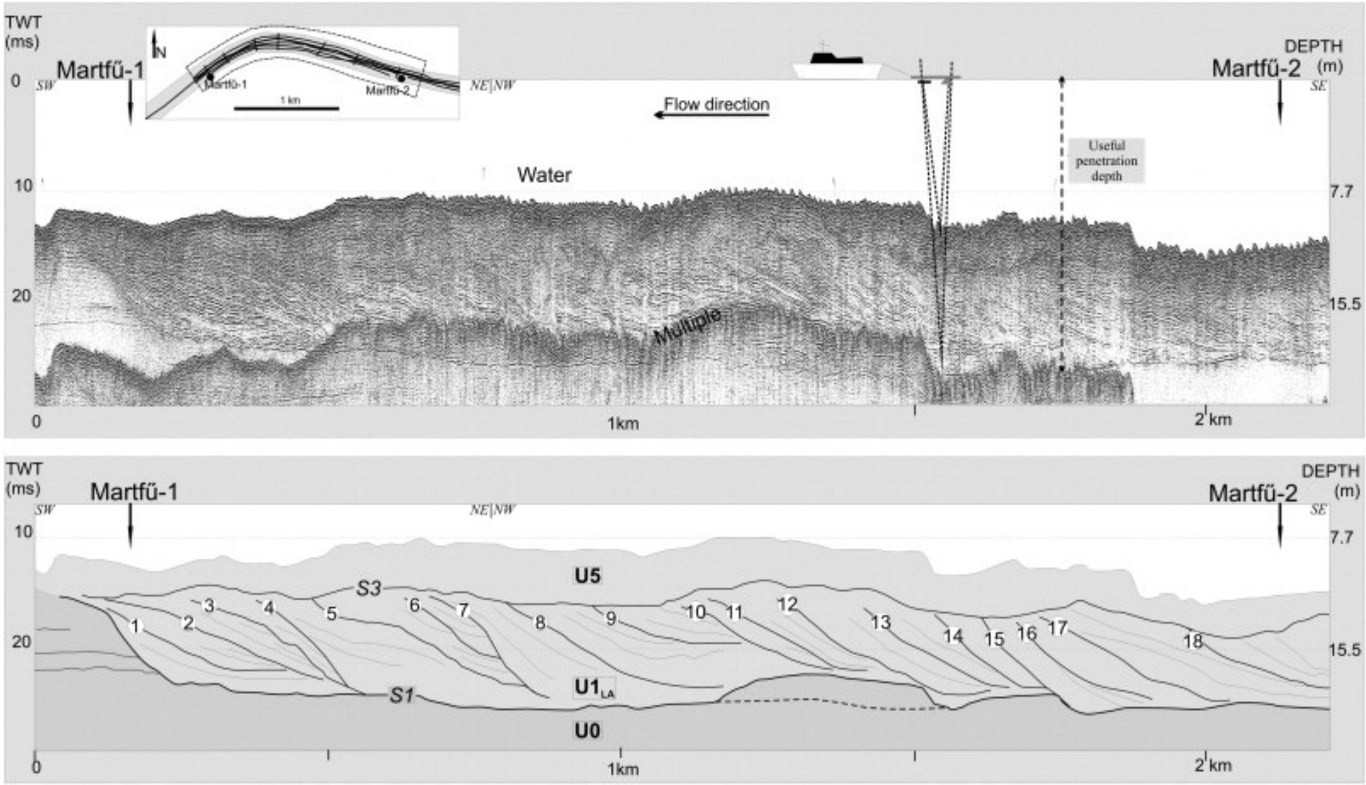
(a) uninterpreted (overlaid with the results of refraction tomography) and (b) interpreted seismic profiles. Qdfg: Quaternary debris-flow fan deposits (Gadria); Qdfl: Quaternary debris-flow fan deposits (Lasa); Qf: Quaternary fluvial deposits; Obu: Ötztal basement unit; Cbu: Campo Nappe basement unit.



meandering river in seismic images



Cserkész-Nagy et al., 2012, Reconstruction of a Pleistocene meandering river in East Hungary by VHR seismic images, and its climatic implications, Geomorphology 153–154, 205-218.

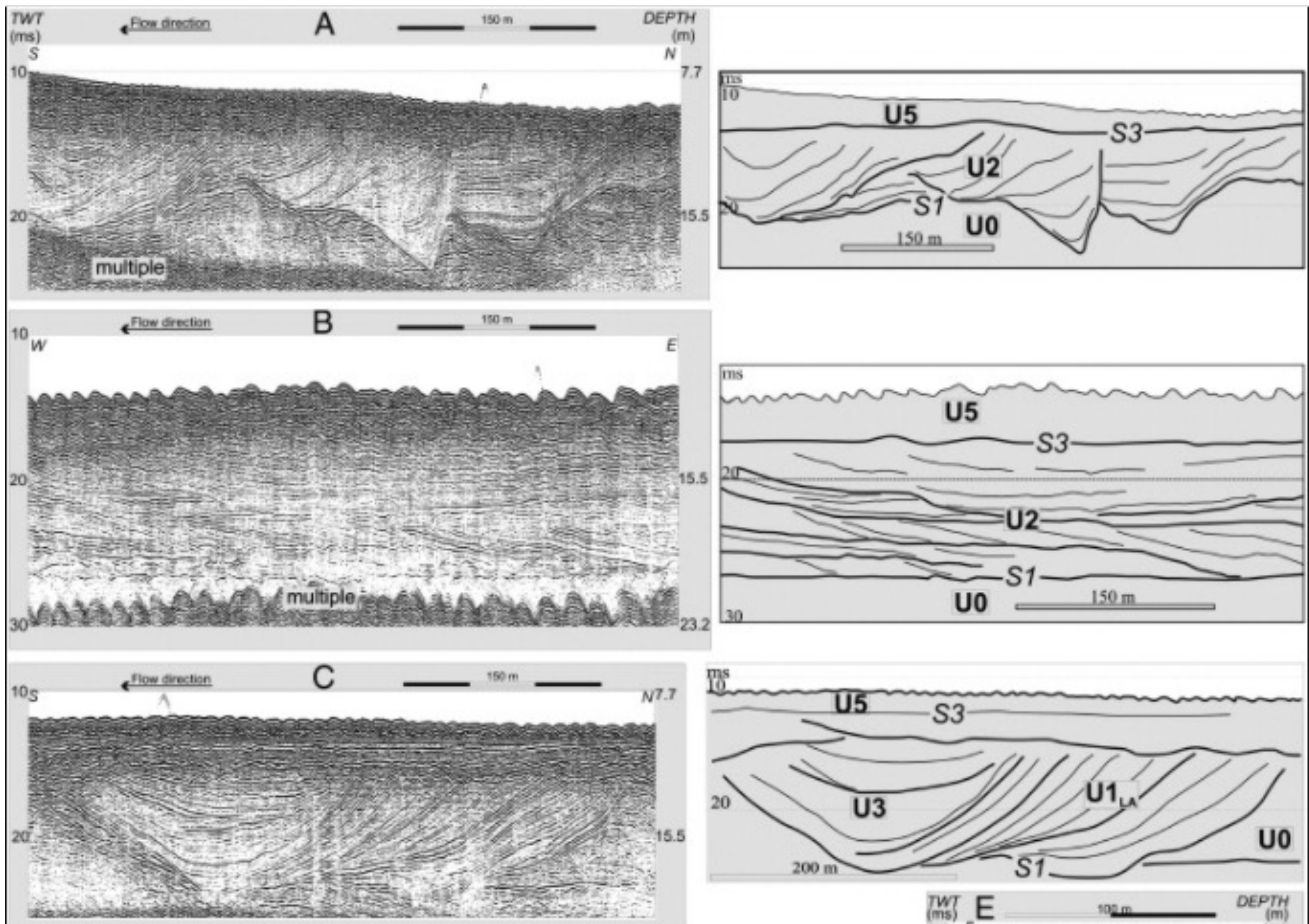


The principle of seismic data acquisition. The depth range of observations depends on actual water depth influencing the position of riverbed multiples. The longitudinal profile at Martfű displays the 2.2 km-long part of one of the well-developed inclined strata sets (U1LA) interpreted as lateral accretion surfaces of point bars. The series is divided into several bundles bounded by significant erosional and onlap surfaces

seismic units and associated internal configuration (1)

B: multi-storeyed, low dip angled, inclined sets (U2) appear in low rate in the study area; C: Series of tangential inclined reflections of point bars (U1LA) incising into horizontally bedded floodplain deposits (U0) corresponds with the upward converging trough-shaped reflections (U3), which are interpreted as passive channel-fill following the natural cut-off.

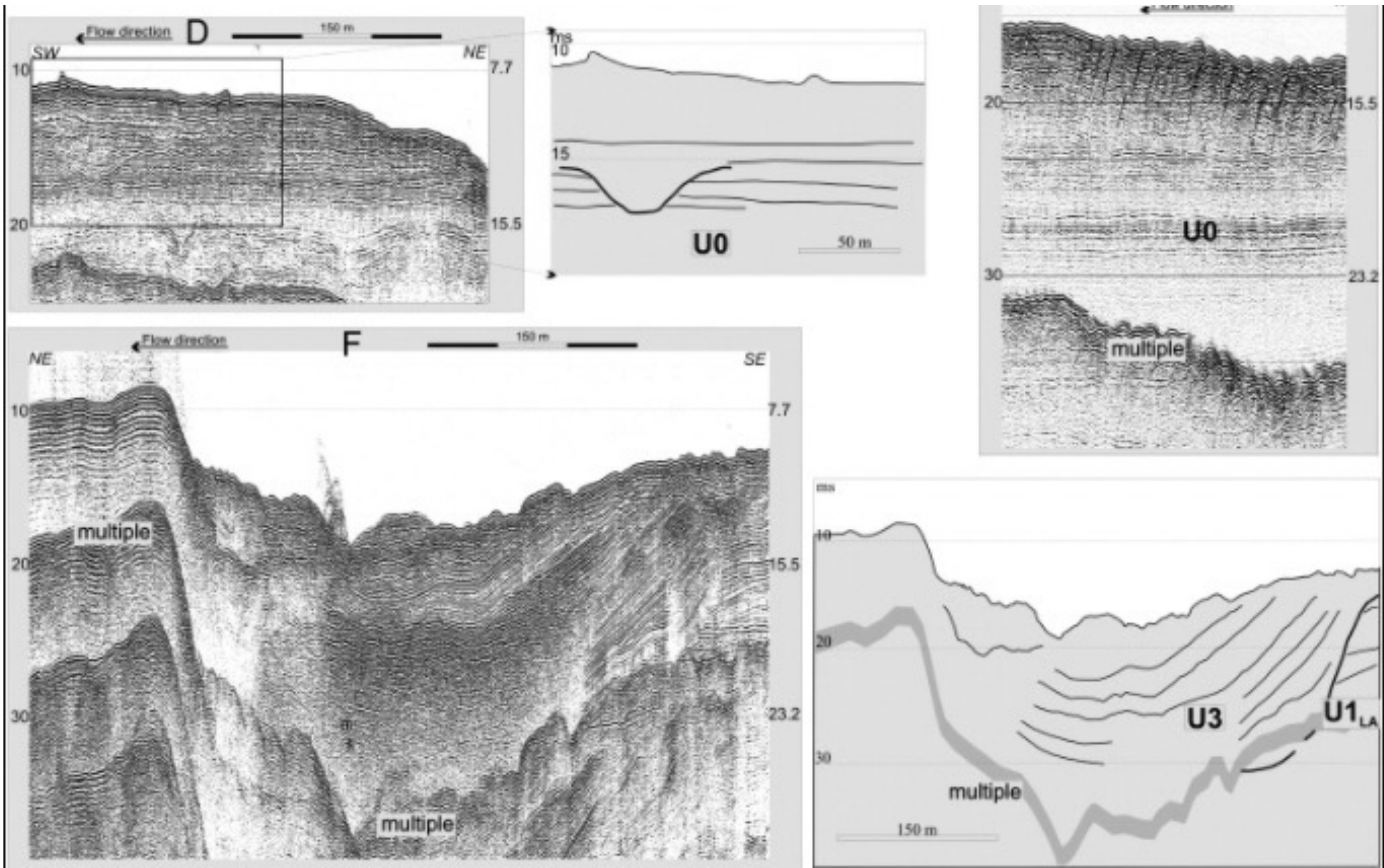
A: High dip angled, inclined strata sets above uneven, repeatedly incising erosional surface (U2)



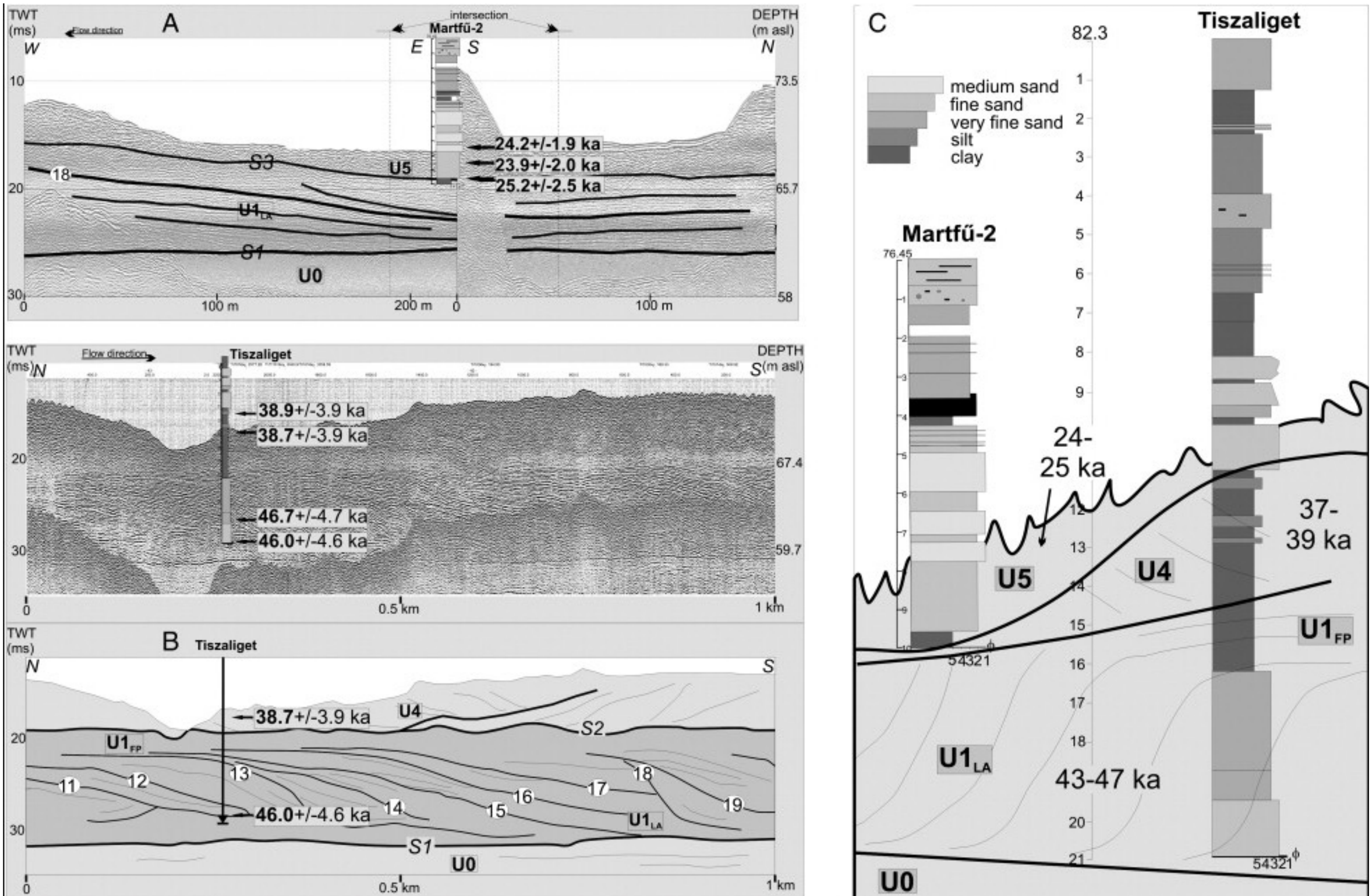
seismic units and associated internal configuration (2)

D and E show the seismic view of horizontally aggrading floodplain deposits (U0), which can reach the thickness of 10–15 m.

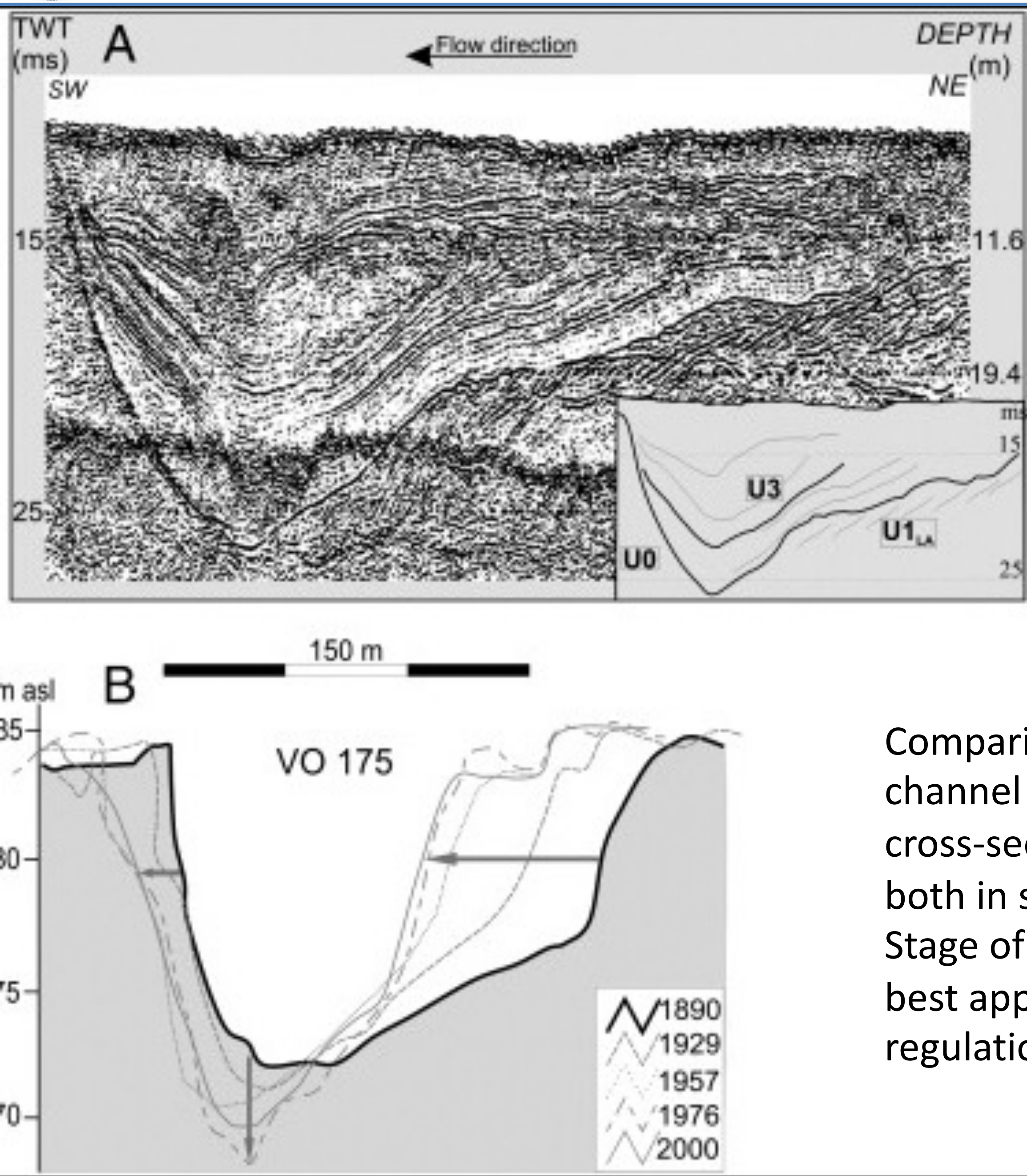
High amplitude, parallel, slightly undulating horizontal reflections mean the sand sheets spreading in the floodplain by floods. Crevasse channel generated by natural cut-off of the levee and its infill is shown; F: Giant trough-shaped structures (U3) are interpreted as infill of fossil scours of meanders.



Correlation between the seismic units and drill cores



Abandoned and recent channel comparison



Comparison between an abandoned channel (A) and a recent channel cross-section (B) show a good match both in shape of profile and sizes. Stage of the channel in 1890 is the best approach of the natural (pre-regulation) stage of the recent Tisza.

Modulo	Argomento	Docente	Data
1.1	introduzione al corso e argomenti	Rebesco	05/10/21
1.2	metodi (geofisica, affioramenti, geologia marina, ambienti attuali)	Volpi/Rebesco	06/10/21
1.3	meccanismi di formazione dei bacini (geodinamica, tettonica...)	Lodolo	12/10/21
1.4	Interpretazione sismica, facies e strutture primarie	Rebesco	13/10/21
	Martedì 19 Ottobre non c'è lezione		
1.5	Energy storage e CCS	Volpi/Donda	20/10/21
2.1	Processi sedimentari nei fiumi e nei delta	Rebesco	26/10/21
2.2	Azione di maree e onde, del ghiaccio e del vento	Rebesco	27/10/21
	Martedì 2 Novembre non c'è lezione		
	Mercoledì 3 Novembre non c'è lezione		
2.3	Correnti di densità e correnti di fondo, trasporto di massa	Lucchi/Rebesco	09/11/21
3.1	pianure abissali (decantazione emipelagica) e margini continentali	Rebesco	10/11/21
3.2	Conoidi sottomarine (flussi gravitativi dalla scarpata continentale)	Lucchi/Rebesco	16/11/21
3.3	Sediment drifts (correnti di fondo lungo la scarpata continentale)	Rebesco	17/11/21
3.4	Mass transport deposits (accenni a risoluzione/penetrazione)	Ford	23/11/21
3.5	Piattaforme continentali (onde, tempeste, tsunami)	Rebesco	24/11/21
3.6	Sistemi deposizionali in ambiente polare	De Santis	30/11/21
3.7	Sistema di barriera	Rebesco	01/12/21
3.8	Depositi alluvionali	Rebesco	07/12/21
	Mercoledì 8 Dicembre non c'è lezione		
3.9	faglie, vulcani e corpi intrusivi	Rebesco	14/12/21
4	esercitazione	Rebesco	15/12/21
5.1	stratigrafia sequenziale	Zecchin	21/12/21
5.2	livello del mare e spazio di accomodamento	Zecchin	22/12/21
	Dal 23 Dicembre al 9 Gennaio non c'è lezione		
5.3	discontinuità e paraconformità e altre superfici significative	Zecchin	11/01/22
5.4	system tracts (apparati deposizionali) e diversi modelli	Zecchin	12/01/22
5.5	applicazioni (es. reservoirs di idrocarburi)	Zecchin	18/01/22
6	visita a CoreLoggingLAB e/o SEISLAB (assieme a Geologia Marina)	Rebesco	19/01/22