Facies Characterization and Stratigraphic Prediction of Proximal Fluvial Systems in Endorheic Basins - The View from the Margins*

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Abstract

Tectonically active continental basins feature large volumes of deposits from short-range, high-energy alluvial systems developed at basin margins, such as alluvial fans and high-gradient ephemeral rivers. The latter are widely distributed in present-day environments, but underrepresented in the mainstream literature and poorly recognized in the rock record. Given their great relative volume in topographically complex basins, they can form important reservoirs for hydrocarbon and water resources. The ‘marginalization' of such systems in fluvial research is probably due to their unconventional facies and architectures, which differ significantly from those of larger rivers fed by regional-scale catchments.

Endorheic basins are ideal settings to analyze proximal fluvial systems, due to the virtually complete preservation of their stratigraphic record and the possibility to relate sedimentological and architectural traits to independently constrained allogenic forcing. The Teruel Basin (Spain) developed during the Neogene as an association of half-grabens under semiarid climate. Ephemeral fluvial systems at basin margins terminated in lower-energy distal environments. Distinct overbank and channel-fill elements characterize these proximal successions as the products of channelized drainage pathways; however, dominant facies consist of coarse, poorly organized deposits from hyperconcentrated flows and possible in-channel debris flows.

Active tectonics at the basin margin and a semiarid climate favored high-gradients, proximity to sediment sources and flash-flood events, which commonly led to poor sediment organization. Triassic claystones in catchment areas produced high concentrations of suspended fines, which damped turbulence and enhanced flow viscosity; this inhibited the development of sorting, bedforms and common architectural elements. This hypothesis is tested by comparing two distinct fluvial systems from the Miocene of the central basin sector and the Quaternary of the northern sector: striking facies differences reveal a prevalence of hyperconcentrated and debris flows in the older system, sourced by the Triassic basement.

The brief lifespans, short range, and direct proximity to catchment areas of ephemeral rivers in the Teruel Basin translated into consistent links with catchment geology and with the progressive evolution of internal base-level. This provides an excellent potential for stratigraphic prediction both at regional and local scales.

FACIES CHARACTERIZATION AND STRATIGRAPHIC PREDICTION OF PROXIMAL FLUVIAL SYSTEMS IN ENDORHEIC SETTINGS: THE VIEW FROM THE MARGINS

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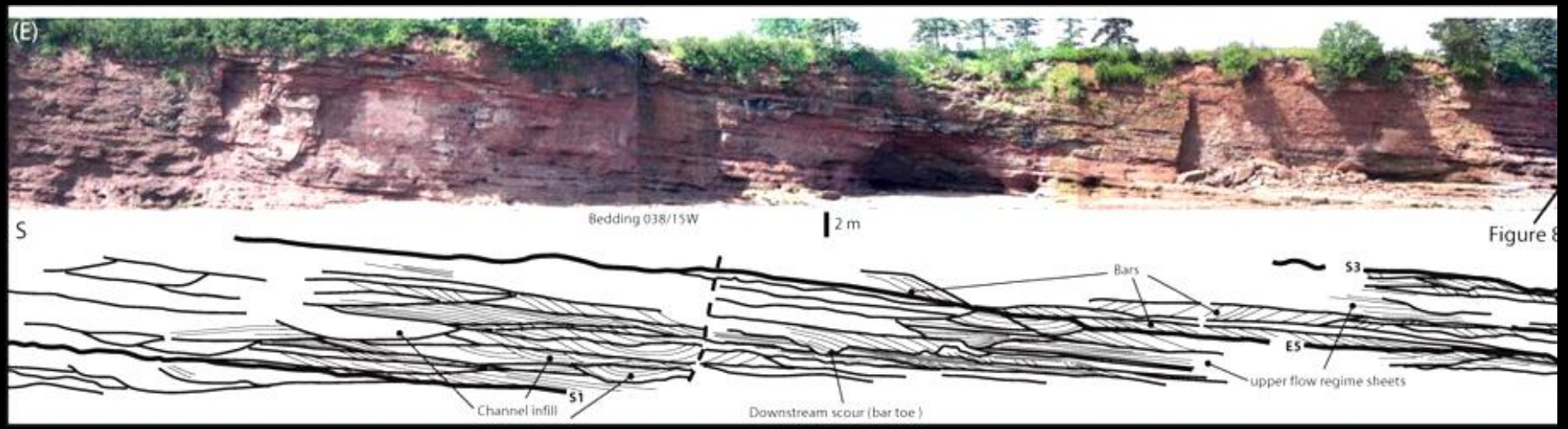
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

MOST EXAMPLES OF FLUVIAL FACIES AND ARCHITECTURES ARE DISCUSSED FROM THE ROCK RECORD OF 'CLASSIC' LONG-RANGE RIVER SYSTEMS FED BY LARGE, WELL-INTEGRATED CATCHMENTS



Triassic Wolfville Formation, Nova Scotia (image courtesy Sophie Leleu)

Pennsylvanian Hyden Formation, SE Kentucky

PRESENT-DAY TECTONICALLY ACTIVE BASIN MARGINS FEATURE A SPECTRUM OF SHORT-RANGE, HIGH-GRADIENT FLUVIAL SYSTEMS FED BY SMALL, SPORADICALLY ACTIVE CATCHMENTS…

Fiumara Precariti
(Calabria, southern Italy)

…WITH GENERALLY LOW PRESERVATION POTENTIAL IN SETTINGS DOMINATED BY LOW ACCOMMODATION AND PREFERENTIAL BYPASS

Dry river bed, Swiss Alps (Berner-Oberland region)

High-gradient fluvial deposits (Plio-Quaternary, Paposo, northern Chile)

Channel-fill (probably Paleogene, Ollagua Basin, northern Chile)

ARE WE OVERLOOKING SOMETHING?

• Significant volumes of sediment in tectonically active basins consist of facies associations deposited by ephemeral alluvial systems, distinctly different from the commonly studied products of long-range, low-gradient rivers with protracted discharge.

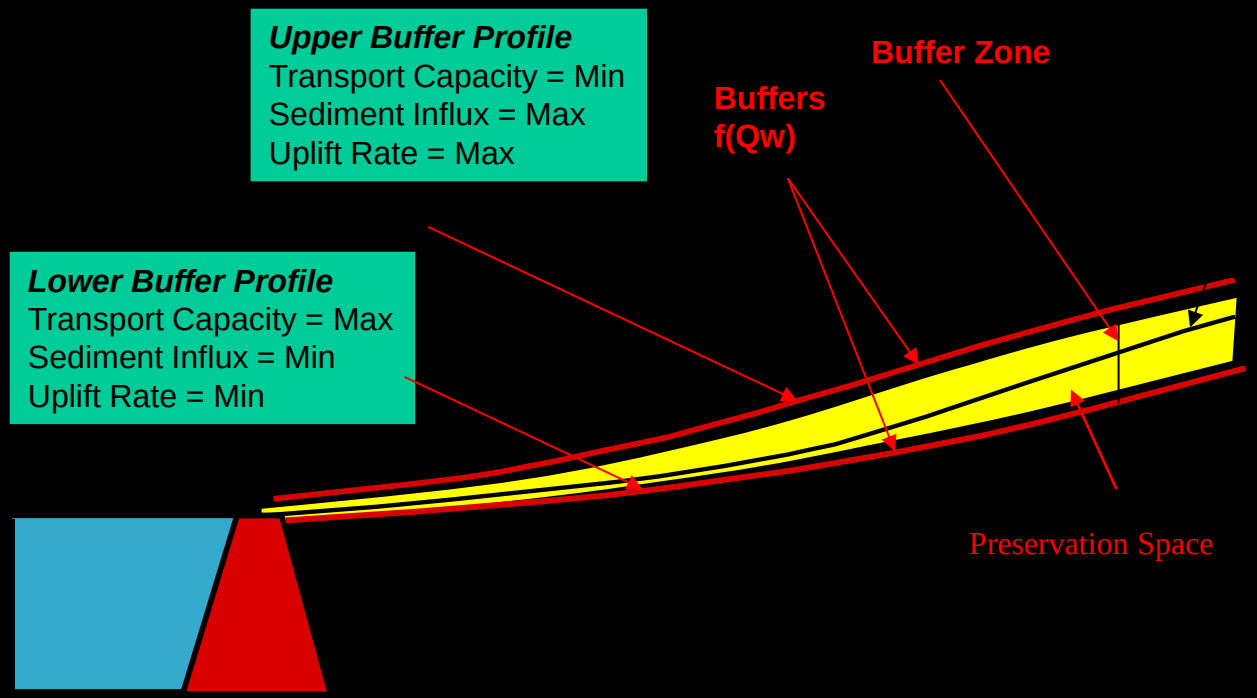
• This has potentially important implications for prediction of:
- facies character and distributions in continental basin fills,
- subsurface patterns of fluid flow and storage, and
- understanding geohazard in flood-prone highland settings.

• **Preservation** is the main issue: identifying settings in which such systems are most likely to be stored in the stratigraphic record, and thus available for analysis of their long-term evolution and response to basinal controls.

REFERENCE CONCEPTUAL MODEL

BASE-LEVEL 'BUFFERS AND BUTTRESSES'

(Holbrook *et al*., 2006, *Journal of Sedimentary Research*)

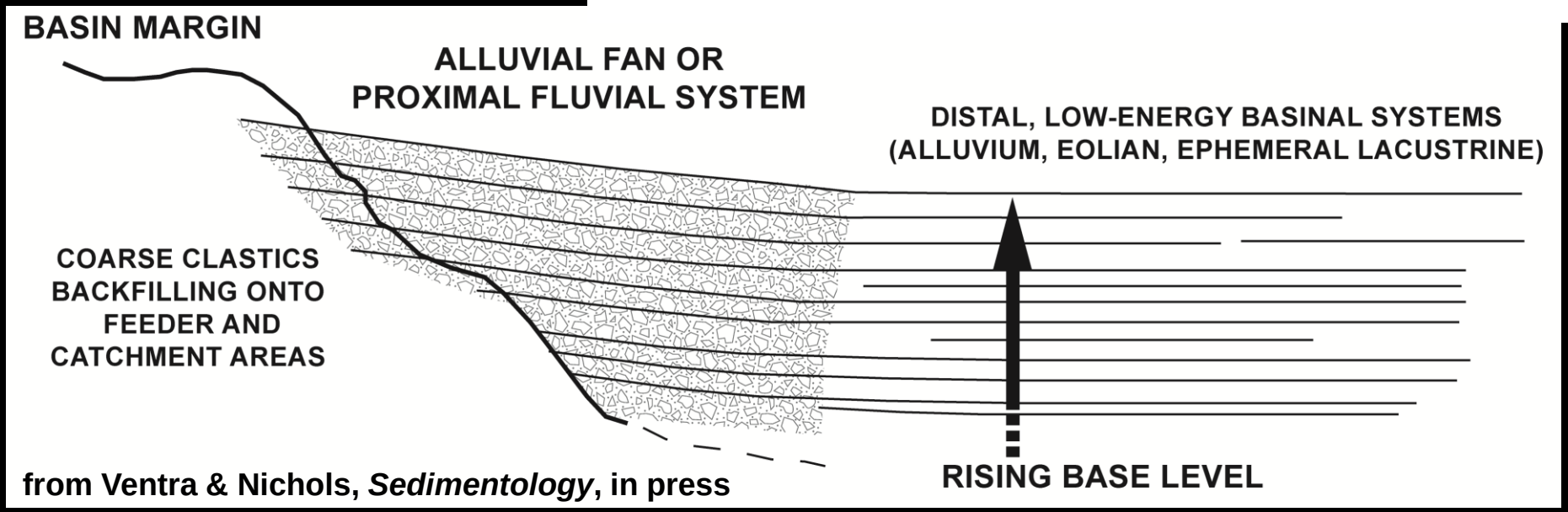


modified from Holbrook *et al.*, 2006 (*JSR*)

Topographically enclosed, internally drained (endorheic) basins tend to promote aggradation and limit sediment bypass from proximal to distal settings.

Aggradation translates into a protracted rise in geomorphic base level (the *buttress*) and thus in rise of graded alluvial surfaces (the *buffers*) downdip along alluvial systems.

from Holbrook *et al.*, 2006 (*JSR*)



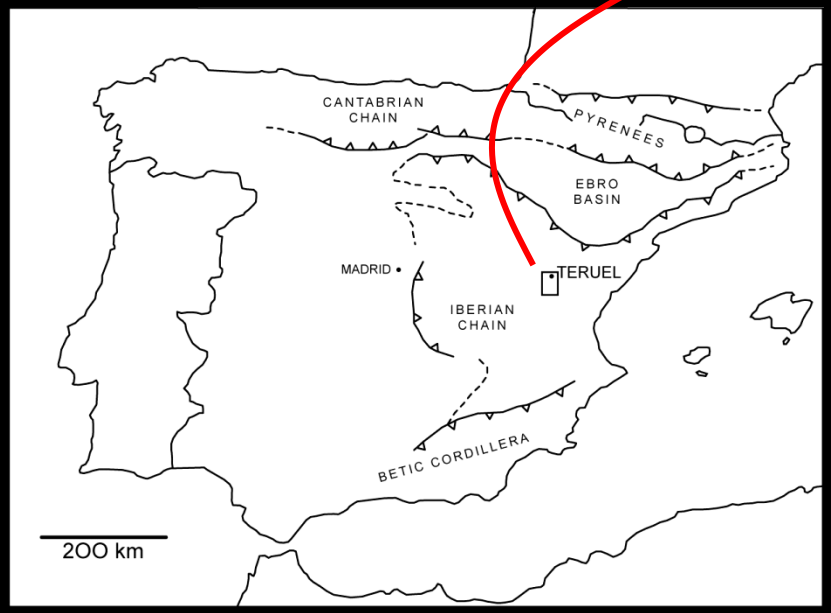
from Ventra & Nichols, *Sedimentology*, in press

EXAMPLES FROM THE NEOGENE TERUEL BASIN (CENTRAL SPAIN)

- **BASIN OUTLINE**
- CENTRAL SUBBASIN: *CASTRALVO-VILLASTAR SYSTEM*
- NORTHERN SUBBASIN: *PERALEJOS-ALFAMBRA SYSTEM*
- COMPARISON AND CONTROLS

TERUEL BASIN

- System of three interlinked half-grabens (early Neogene extension over folded Mesozoic basement Iberian Range);
- developed in a semiarid climate for most of its history;
- internally drained until Early-Middle Pleistocene



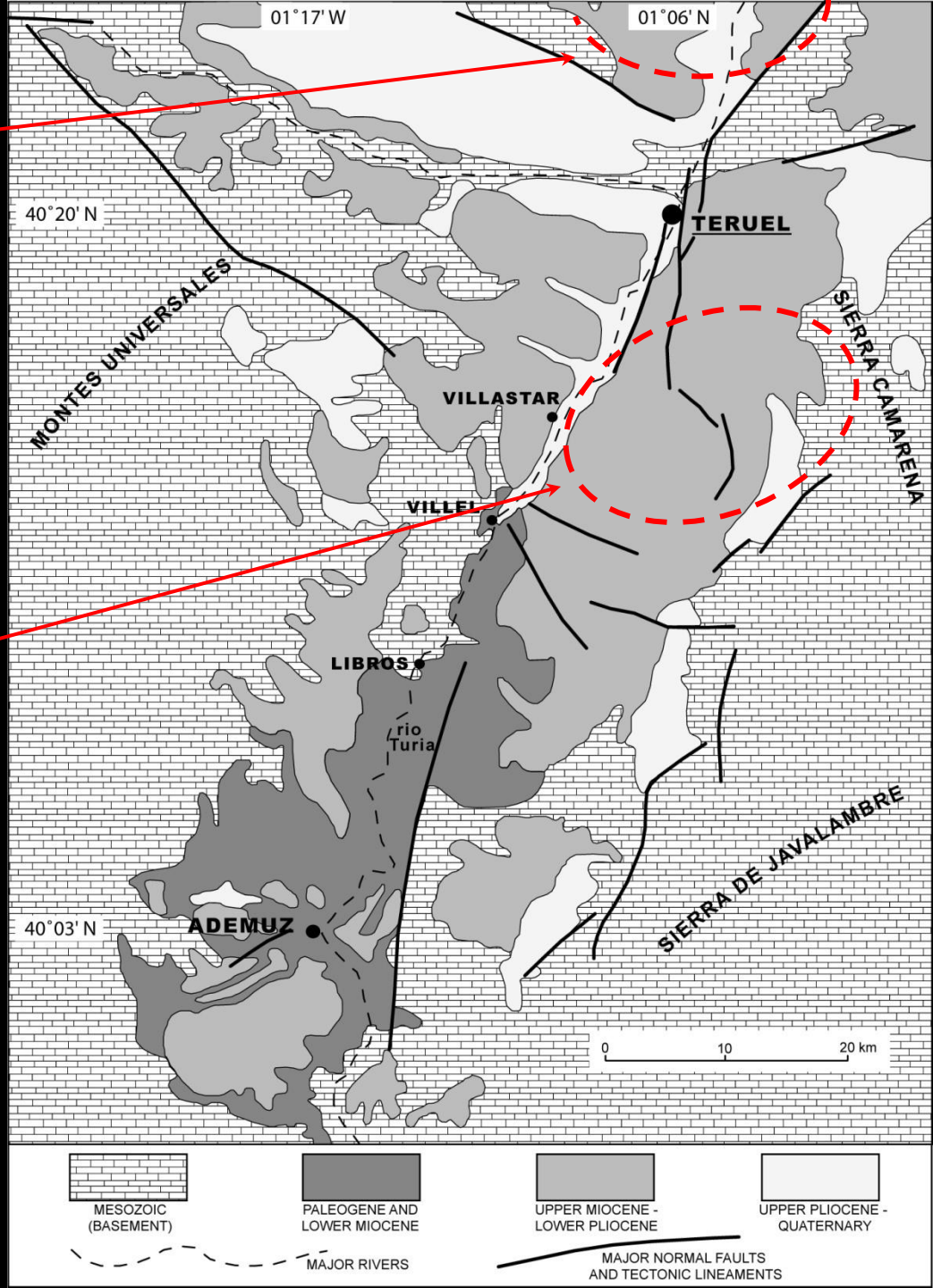
CLOSED BASIN IMPLIES:

- **essentially complete preservation of stratigraphic column (~layer-cake stratigraphy)**
- **fully aggradational architecture**
- **N.B. notice that this does not necessarily translate into high sedimentation rates!**

MESOZOIC BASEMENT TRIAS AND EARLY CRETACEOUS MUDDY (CLAYEY) CONTINENTAL TO COASTAL SILICICLASTICS, UNCONFORMABLY OVERLAIN BY LATE-CRETACEOUS SHALLOW-MARINE CARBONATES

PERALEJOS-ALFAMBRA
PALEODRAINAGE
NORTHERN SEGMENT OF THE BASIN

CASTRALVO-VILLASTAR
PALEODRAINAGE
CENTRAL SEGMENT OF THE BASIN



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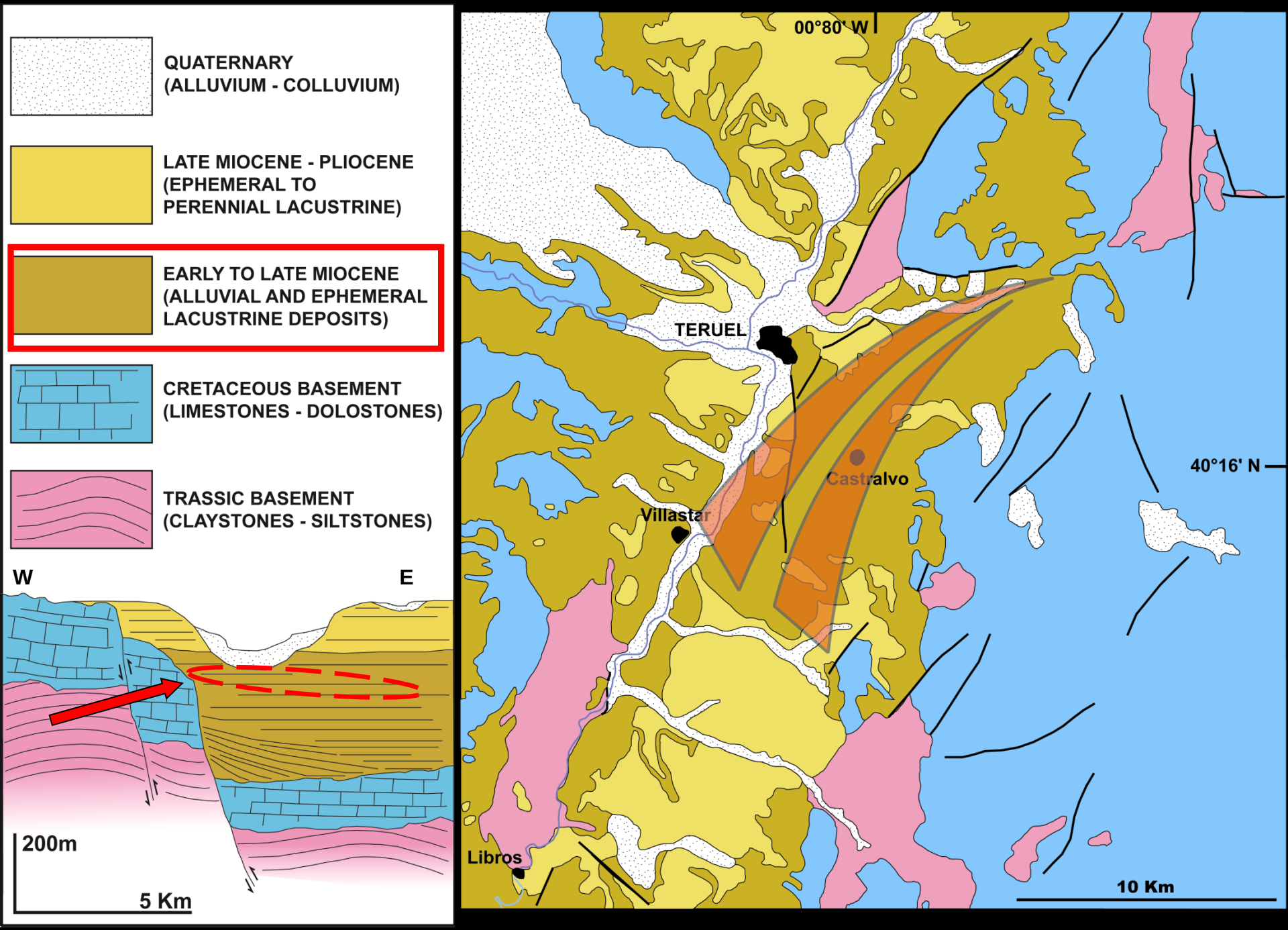
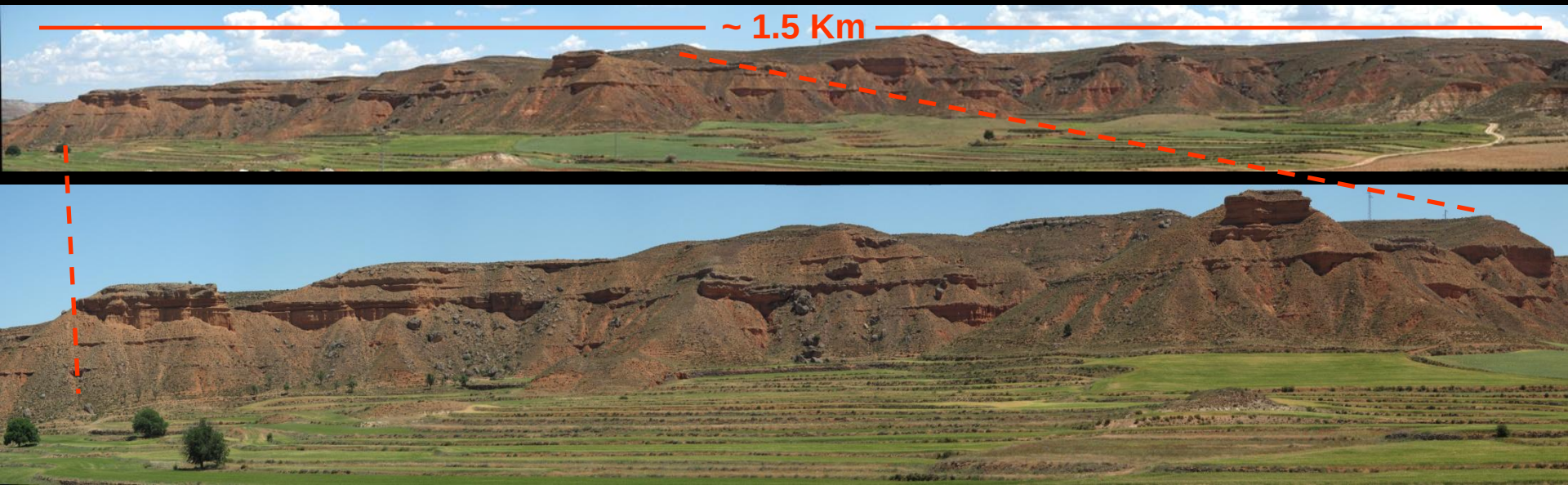

QUATERNARY
(ALLUVIUM - COLLUVIUM)
LATE MIOCENE - PLIOCENE
(EPHEMERAL TO
PERENNIAL LACUSTRINE)
EARLY TO LATE MIOCENE
(ALLUVIAL AND EPHEMERAL
LACUSTRINE DEPOSITS)
CRETACEOUS BASEMENT
(LIMESTONES - DOLOSTONES)
TRASSIC BASEMENT
(CLAYSTONES - SILTSTONES)
W
E
200m
5 Km
00°80' W
TERUEL
Castralvo
Villastar
40°16' N
Libros
10 Km

ABRUPT APPEARANCE AND DISAPPEARANCE

fluvial system spans a narrow stratigraphic interval (~50-60 m) within late Miocene deposits (possible phase of active basin subsidence and high accommodation)

Best 3D exposure: 5 x 5 km outcrops near Villastar

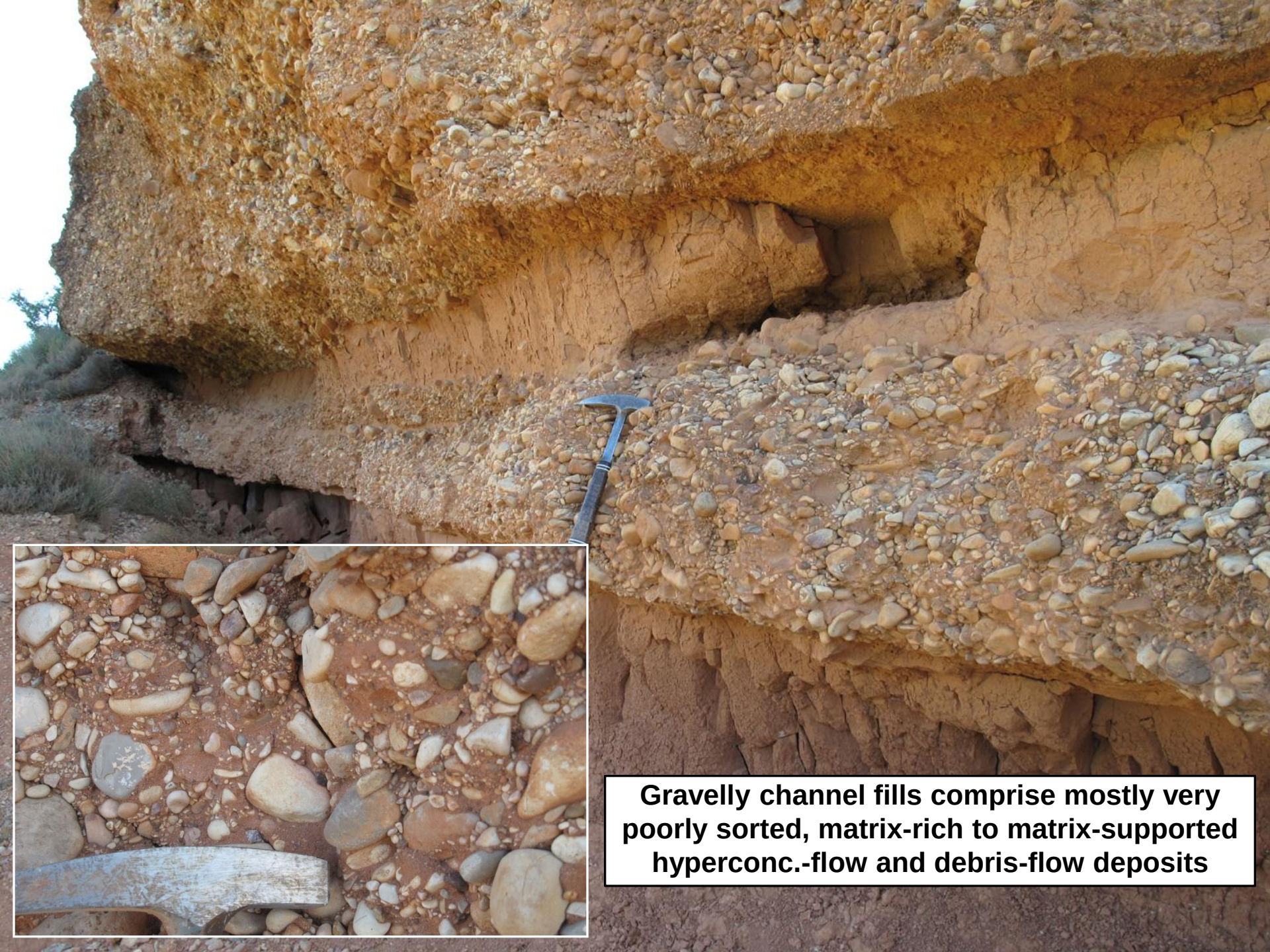


GENERAL ARCHITECTURE

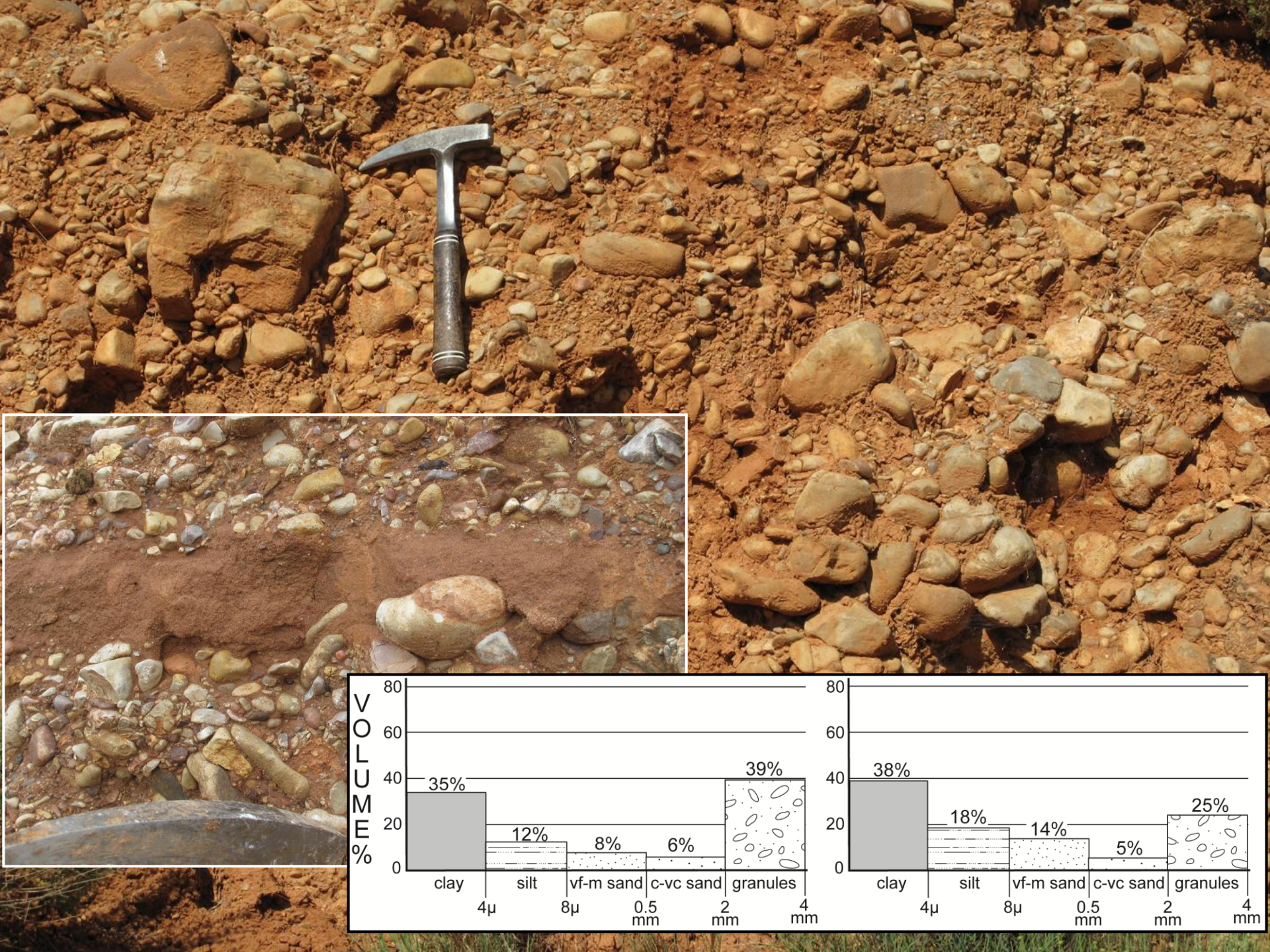
Poorly connected, coarse-grained, sheet- to ribbon-like channel fills within aggrading muddy overbank

Approx. ratio channel to overbank facies by volume: ~ 15-25 %

Low architectural complexity within channel fills, massive or characterized by basic stacking of vertical accretion units



Gravelly channel fills comprise mostly very poorly sorted, matrix-rich to matrix-supported hyperconc.-flow and debris-flow deposits


VOLUME %
80
60
40
20
0
35%
12%
8%
6%
39%
clay
silt
vf-m sand
c-vc sand
granules
4μ
8μ
0.5 mm
2 mm
4 mm
38%
18%
14%
5%
25%

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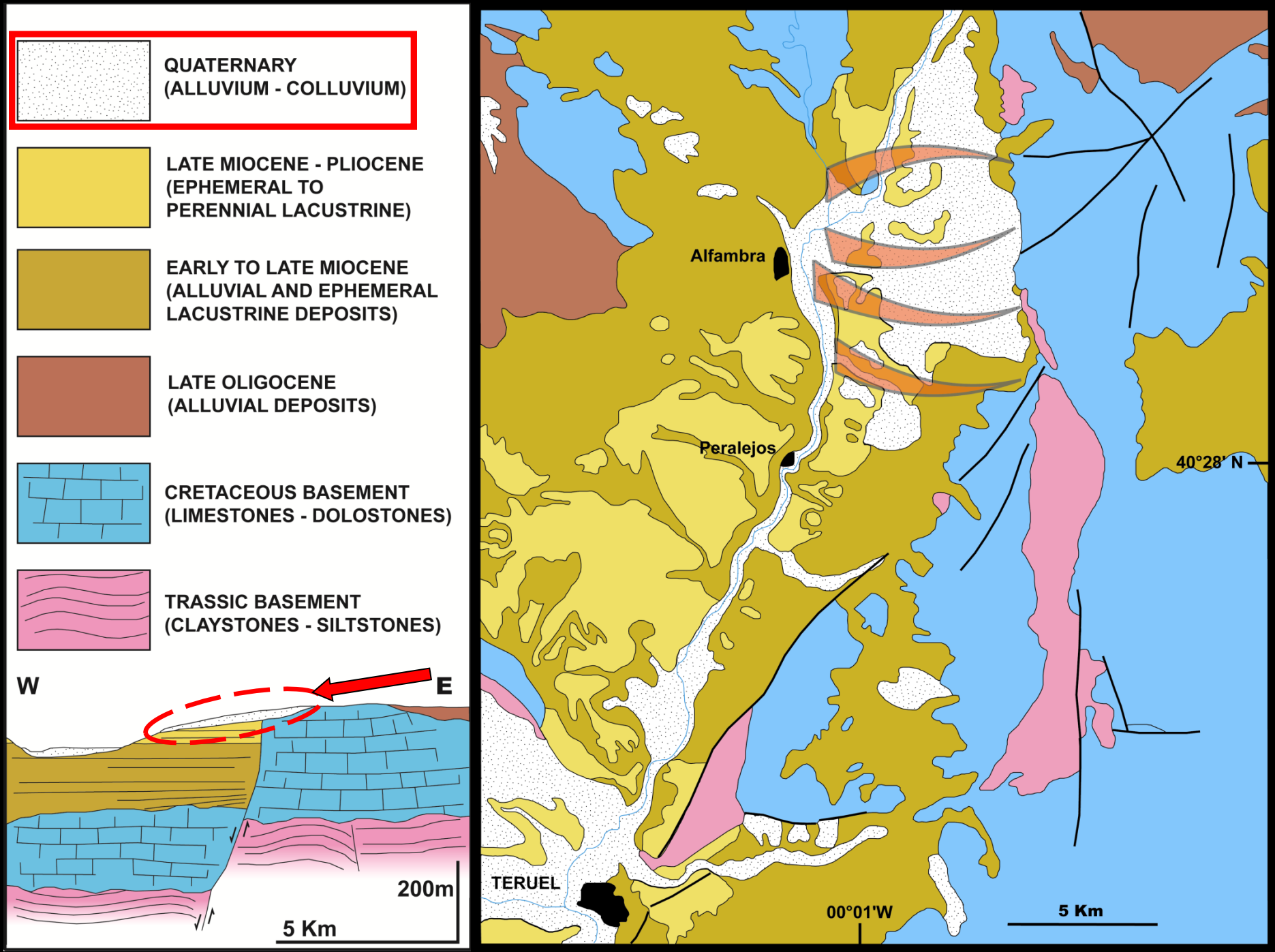
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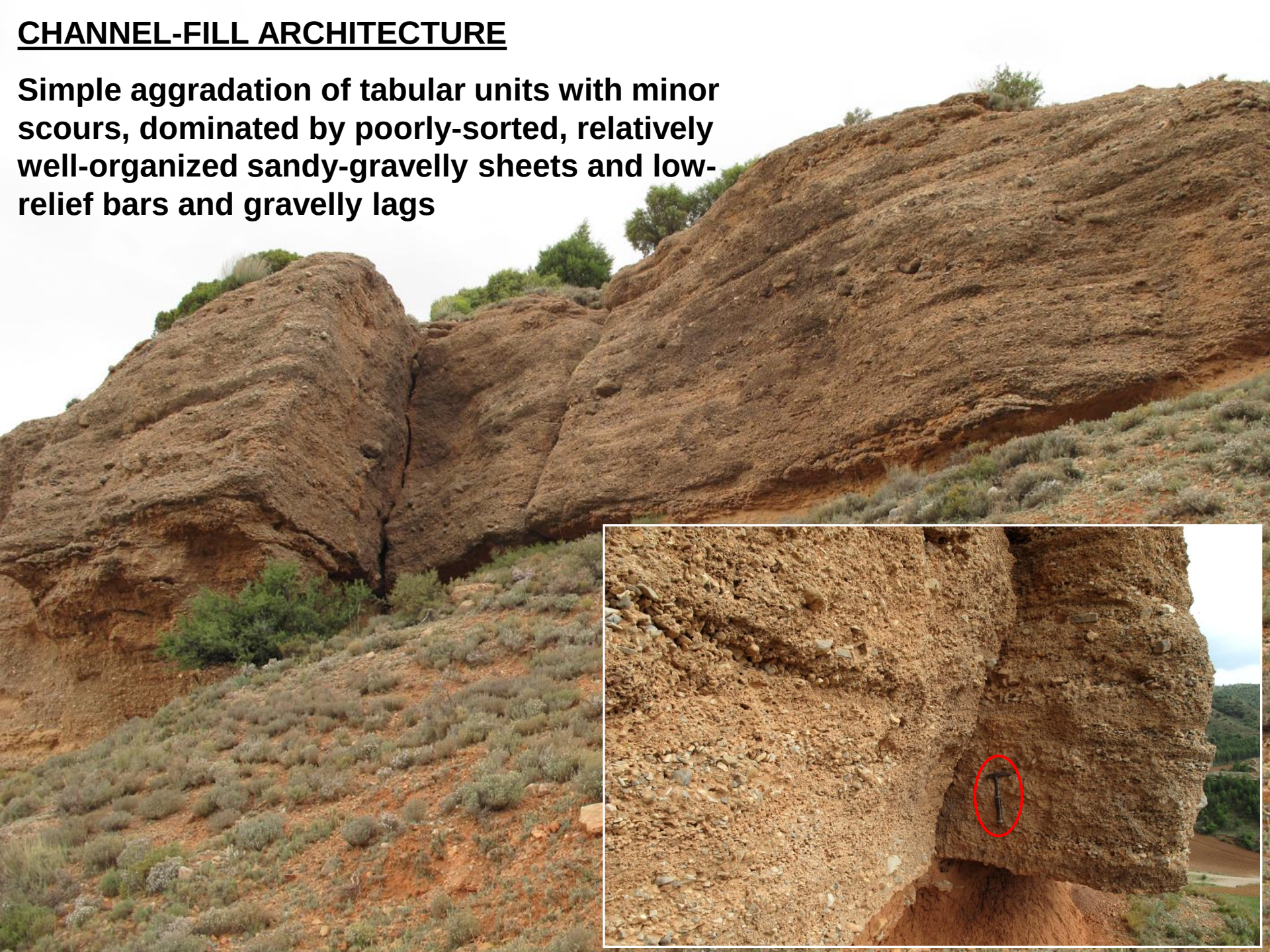
CRETACEOUS BASEMENT
(LIMESTONES - DOLOSTONES)
TRASSIC BASEMENT
(CLAYSTONES - SILTSTONES)
W
E
200m
5 Km
Alfambra
Peralejos
TERUEL
40°28' N
00°01'W
5 Km

SYSTEM ARCHITECTURE

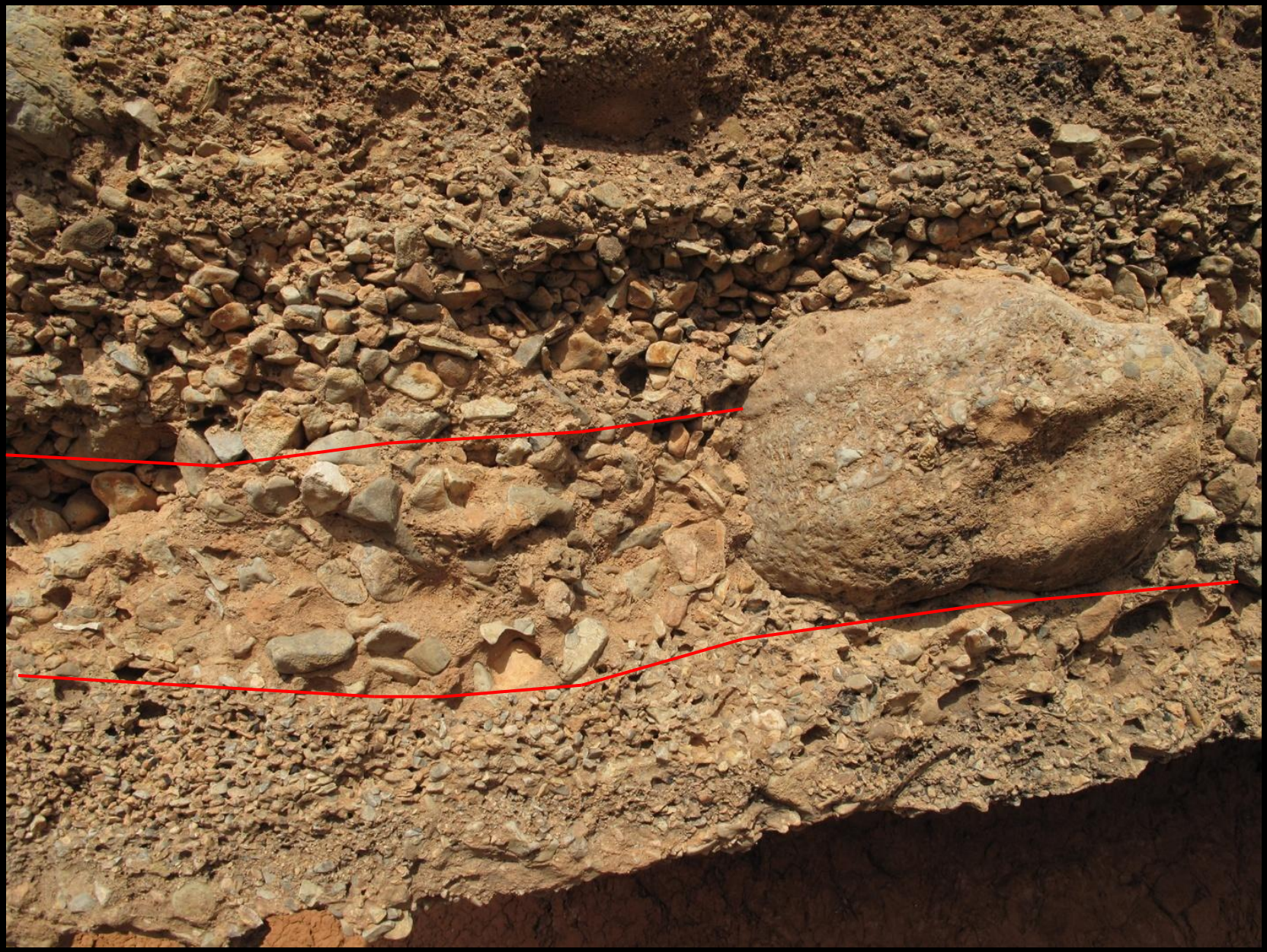
- Developed in the Pleistocene at the transition from endo- to exorheic basin drainage, filling within a broad valley transverse to basin axis
- Sheet-like, shallow, sandy-conglomeratic channel fills within muddy sandy overbank
- Temporarily reduced accommodation: good vertical and lateral connectivity (approx. volume ratio channel / overbank fines ~ 65-75%)
- Low clay % both within overbank and conglomerate matrix

CHANNEL-FILL ARCHITECTURE

Simple aggradation of tabular units with minor scours, dominated by poorly-sorted, relatively well-organized sandy-gravelly sheets and low-relief bars and gravelly lags

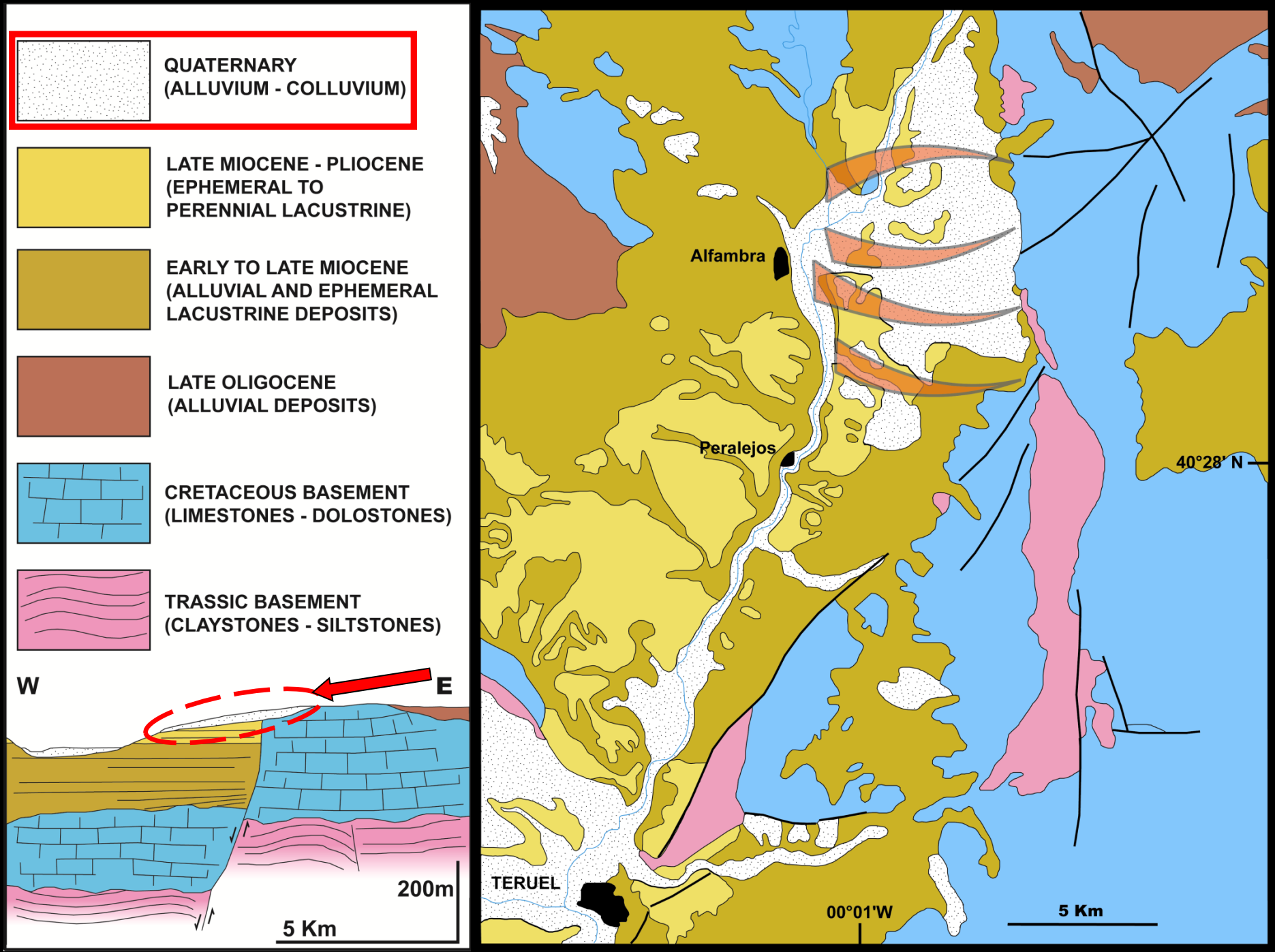


Occasional matrix-rich, very poorly sorted gravel interbeds…



… but in general, relatively good organization:

- distinctly bedded units
- moderate to good sorting
- clast support and openwork fabrics
- clast imbrication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GENERAL CONTROLS

CONSTANT SEMIARID CLIMATE REGIME
(FROM MIOCENE TILL PRESENT DAY)
+
ACTIVE BASEMENT TECTONICS
=
SHORT-LIVED HYDROLOGICAL EVENTS + SMALL, POORLY INTEGRATED CATCHMENTS + HIGH GRADIENTS

↓ ↓ ↓

EPHEMERAL DISCHARGE AND SHORT TRANSPORT DISTANCES

↓ ↓

POORLY ORGANIZED FACIES & LOW ARCHITECTURAL COMPLEXITY

ORIGIN & TIMING IN BASIN'S HISTORY

NEOGENE ACTIVE TECTONIC PHASE (SUBSIDENCE + SEDIMENT SUPPLY)

↓

FORCED BASE-LEVEL RISE IN CLOSED BASIN (AGGRADATION)

↓

PREVALENT 'OVERBANK' & POOR CHANNEL CONNECTIVITY

QUATERNARY TRANSITION FROM ENDORHEIC TO EXORHEIC (INCISION & ALLUVIAL BYPASS)

↓

DEGRADATION & REDUCED ACCOMMODATION

↓

HIGHER CONNECTIVITY CHANNEL BODIES

BASEMENT SOURCES

CRETACEOUS MARLSTONES, LIME- AND DOLOSTONES

TRIAS CLAYSTONES

OLIGOCENE ALLUVIALS

JURASSIC AND CRETACEOUS LIME- AND DOLOSTONES

MUD-DOMINATED SYSTEM
(MAINLY HYPERCONC. AND DEBRIS FLOWS)
VERY POOR POROSITY & PERMEABILITY

CLAY-POOR, COARSE-GRAINED SYSTEM
(CLEAR WATERFLOWS, NEWTONIAN)
GENERALLY VERY HIGH PERMEABILITY

A COUPLE OF GENERAL POINTS…

• Great volumes of coarse-grained facies at the margins of continental basins were deposited by high-gradient, short-range fluvial systems issuing from poorly integrated, areally restricted catchments.

• In spite of notable facies differences with ‘classical’ rivers, the stratigraphic architecture of these marginal alluvial systems can be understood and predicted following the same principles.

• The relatively simple geometry and internal architecture of these systems, their frequently restricted facies range, and strong lithologic dependence from local basement (= catchment) geology, enhance predictivity in a context of basin analysis.

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