Enigmatic Brushy Canyon Formation, Delaware Basin, USA: Poor Outcrop Analog for Deep-Sea Turbidite Reservoirs*

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Abstract

The Brushy Canyon Formation, popular as an analog for deep-sea turbidite oilfields, is reinterpreted here as lake shelf deposits, based on wave ripples, HCS, SCS, lack of in situ marine fossils and scarcity of ichnofossils. In the N, the Brushy onlaps a subaerial (karst) unconformity, reflecting uplift whereby a former marine gulf (Lr San Andres ramp atop Victorio platform, beside a slope and “basin”, beside Val Verde deep-sea flysch trough) shrank to form a fresh-brackish lake (shelf and trough). Like the Black Sea and Lake Maracaibo, the lake was saltier during glacioeustatically-tied highstands (ocean-wedge entry over Hovey spill point) than lowstands (brimful). Most Brushy sand beds are f/vf, massive, ungraded and up to 40cm thick (amalgamated <10m), suggesting river-fed turbidity (hyperpycnal) flows too slow for traction, lasting for weeks (equatorial monsoon). Beds with HCS are storm-modified hyperpycnites. Background varved (?) carbonaceous silt is interpreted as lofting rhythmite, spread by lake circulation (wind drift). Rivers crossed the San Andres outcrop in caves: narrowings jammed logs/leaves (thus scarce in Brushy); deep fissures trapped bedload (>fs); cave walls supplied (buoyant) reworked fusulinids in Brushy sands. Rivers ended at drowned gorges (rias) and underflowed the lake, carving shallow (m) channels, each feeding a hyperpycnite lobe. Lake falls and rises made channels reincise (stack) or backfill. Silt-draped scours reflect lowstand storm erosion (waves+drift). Ria fill includes wall-derived conglomerate. Between rias, receding cliffs left a wave-cut platform onlapped by shelf silt. Eventually, the previous “basin-margin” slope disappeared (onlapped by Brushy). Younger lake-shelf facies (Cherry-Bell) interfinger landward with Goat-Capitan carbonates reciprocally (arid highstand marine ramp; humid lowstand lake shelf clastics). “Forereef” clinoforms are artifacts of Cherry-Bell preferential compaction (c. 50%; accommodating Castile shallow-lake evaporites). Caves and gorges that fed the Cherry-Bell contain Capitan “breccia”. The Brushy-Cherry-Bell (BCB) are poor analogs for deep-sea turbidites, whose dissimilar processes (surge-type flows; no waves) produce fan lobes differing from lake-shelf lobes in area, heterogeneity and grain size, and channels that are leveed and sinuous. The lake model is crucial for BCB exploration and development, e.g. sustained slow flows are prone to Coriolis veering (left or right, depending on paleoequator position).

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ENIGMATIC BRUSHY CANYON FORMATION, DELAWARE BASIN, USA:

POOR OUTCROP ANALOG FOR DEEP-SEA TURBIDITE RESERVOIRS

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FINANCIAL RISK OF USING IMPROPER ANALOGS...

Causes poor prediction of reservoir volume, geometry & internal architecture, leading to (in order of decreasing cost)...

1. Inaccurate predictions of reserves & flow rates, hence potentially wrong economic decision to develop or abandon field (possible losses of $billions either way)

2. Non-optimum placement, spacing & number of development wells

3. Poor choice of perforation intervals, causing lower flow rates & lower ultimate recovery

Brushy Canyon Fm (M Permian)

Beauboeuf et al. 1999

Controversial – previously interpreted as shallow water (10s m)

-now popularly interpreted as deep-sea (100s m) slope & fan; used as an ‘outcrop analog’ for passive-margin (*sic*) deep-sea-turbidite reservoirs

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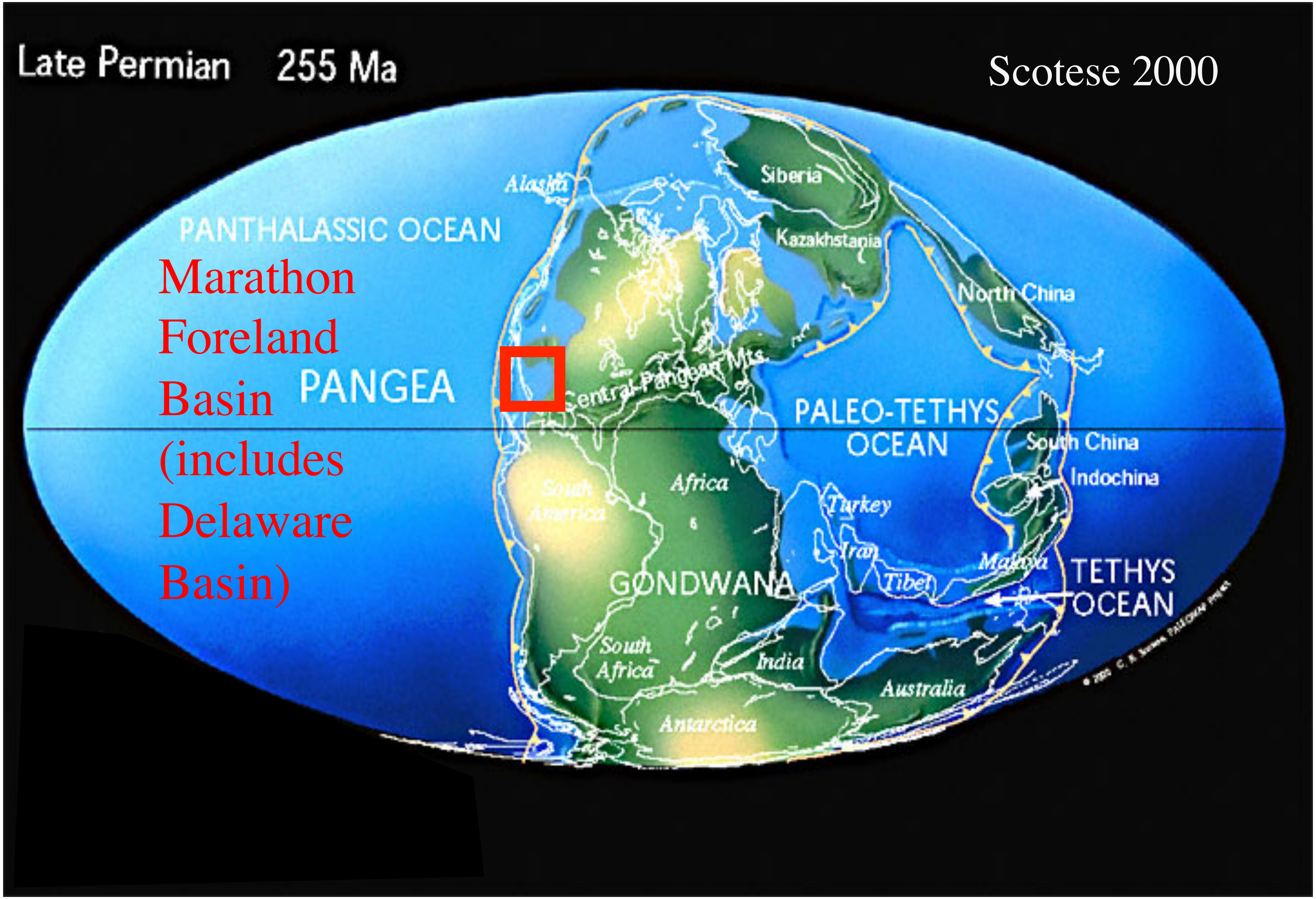

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Brushy superficially resembles deep-marine turbidites

BUT...

Observation:	Interpretation:
Has HCS & other wave-influenced structures (e.g. near-symmetrical ripples)	-not deep
Indigenous marine fossils absent ... a few sandstone beds contain (abraded) reworked marine fossils	-not marine (lake)

"Wave-dominated combined flow ripples from the Brushy Canyon Formation" (Harms 1969)

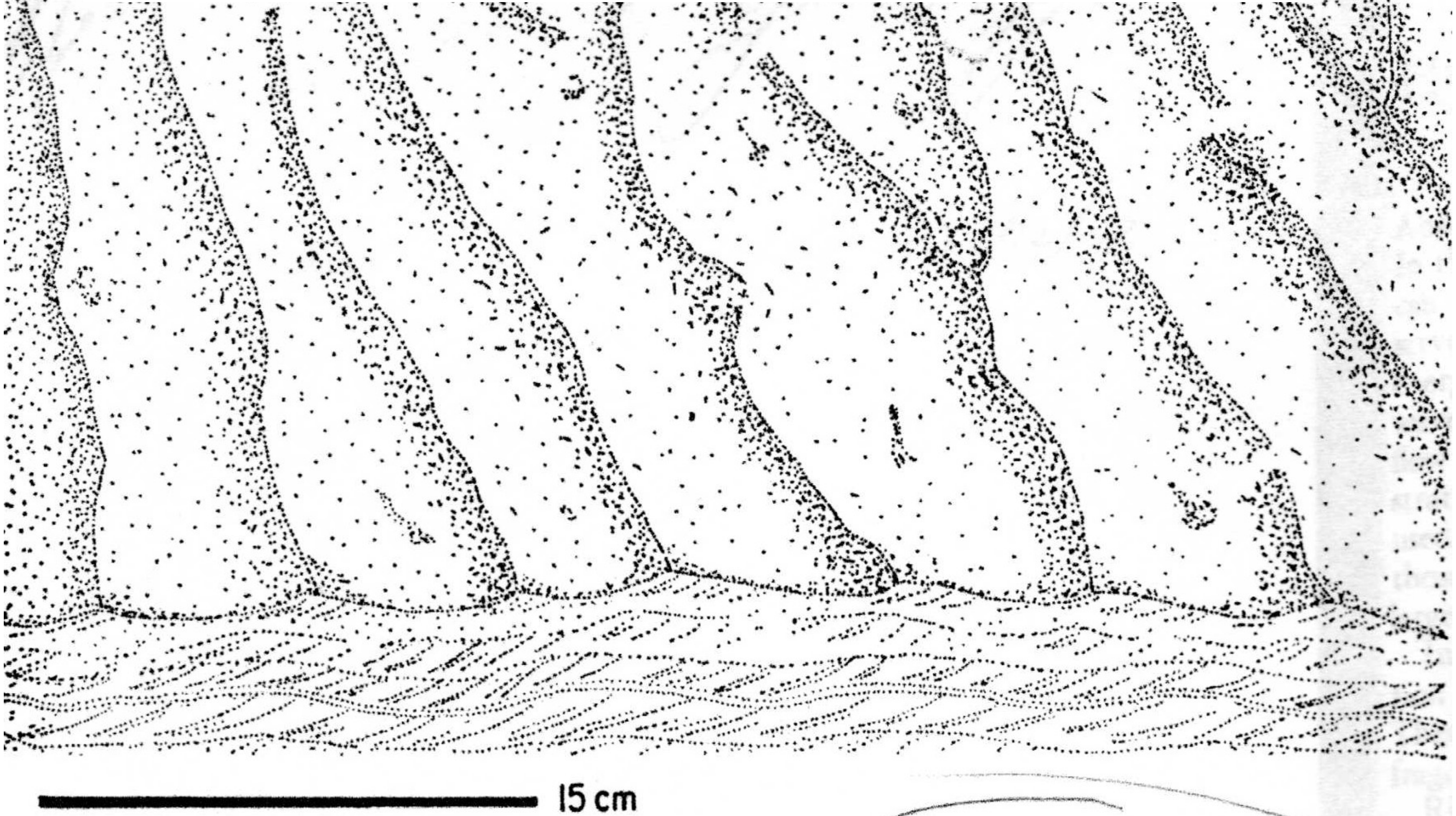

Figure 17. Wave-dominated combined-flow ripples from the Brushy Canyon Formation, Texas.

Harms 1969

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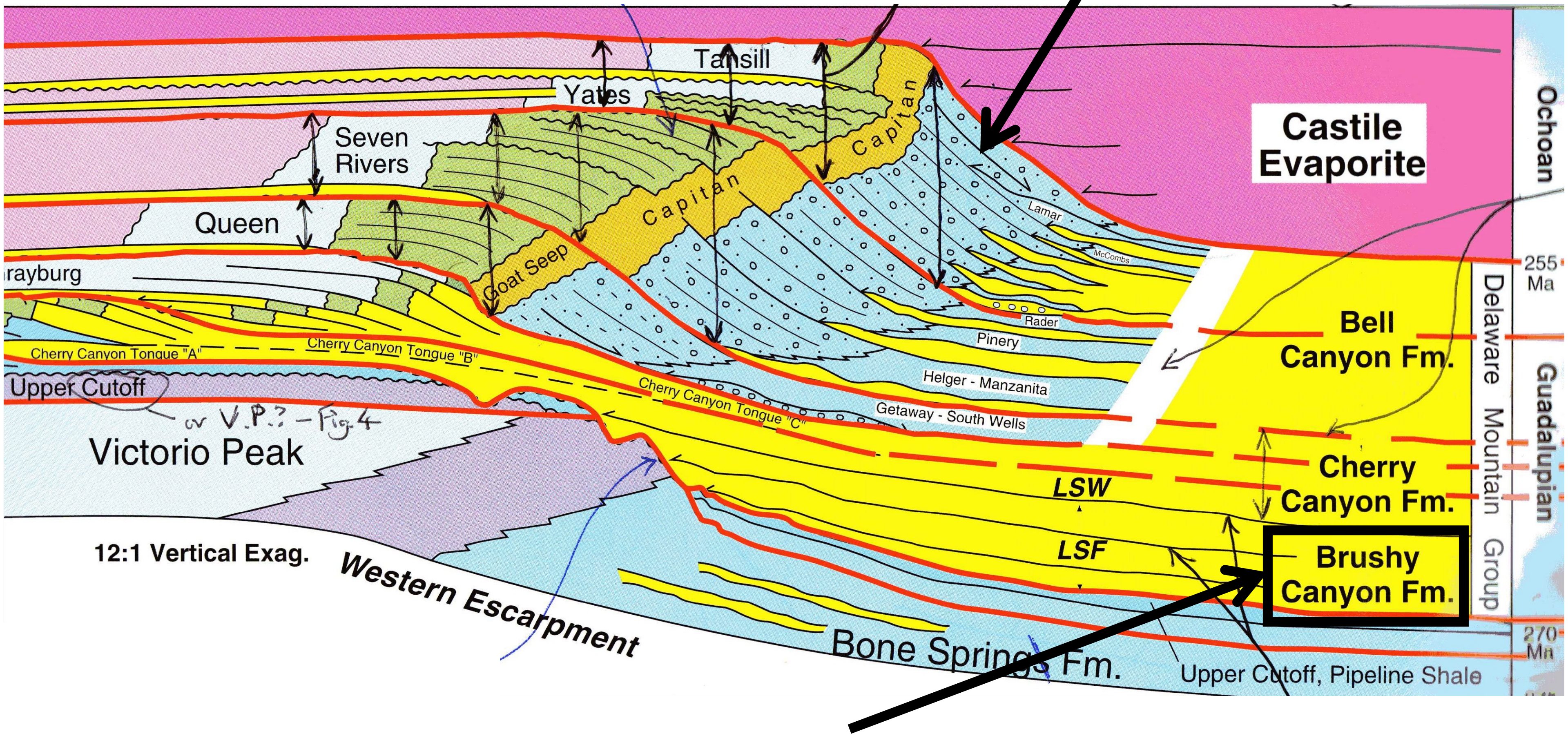
N.B. Capitan 'forereef' - artifact of differential compaction

Beauboeuf et al. 1999



BRUSHY CANYON FM - STRATIGRAPHIC CONTEXT

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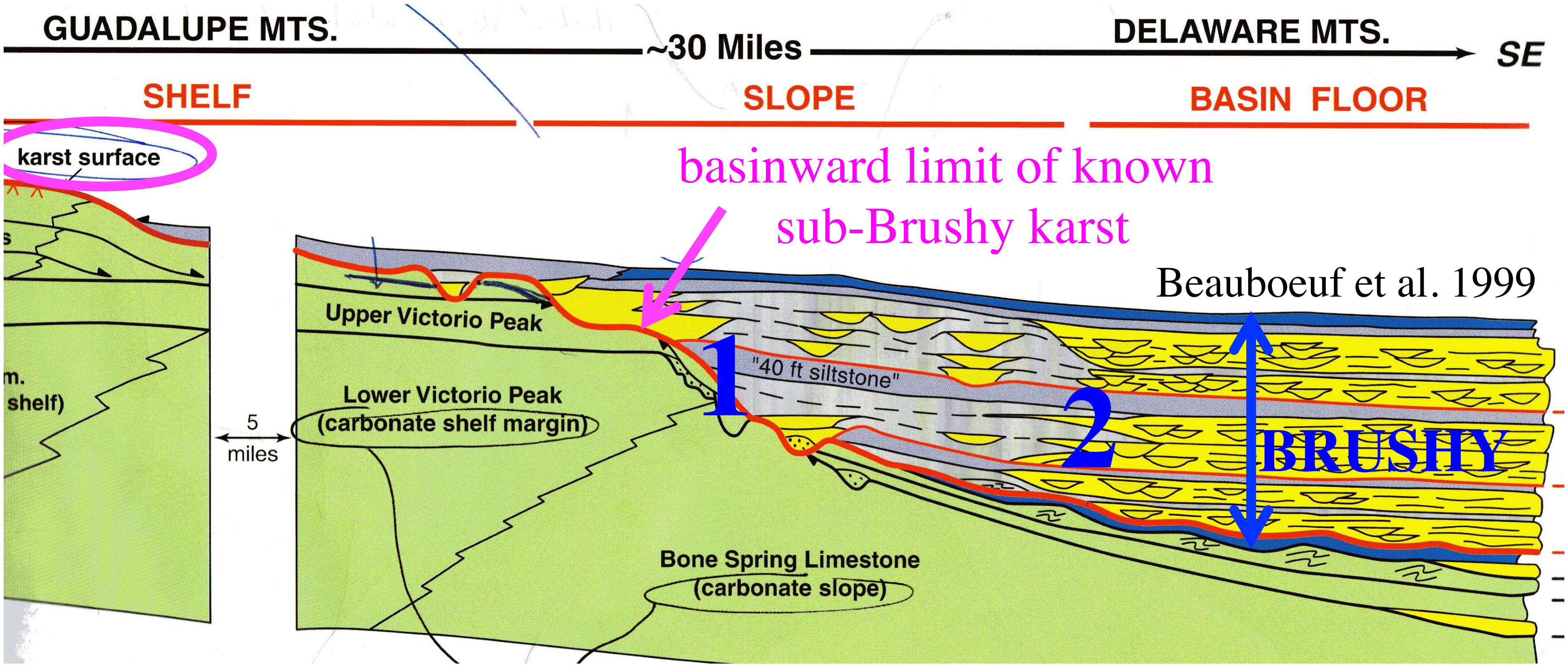

Brushy basin-fill architecture contradicts slope-&-fan model:

1. onlap, atypical of deep-sea-slope deposits (moreover, the onlapped unconformity is subaerial [karsted])

2. proximal muds (with channels) interfinger distally with sand lobes, instead of downlapping as do slope muds onto fans

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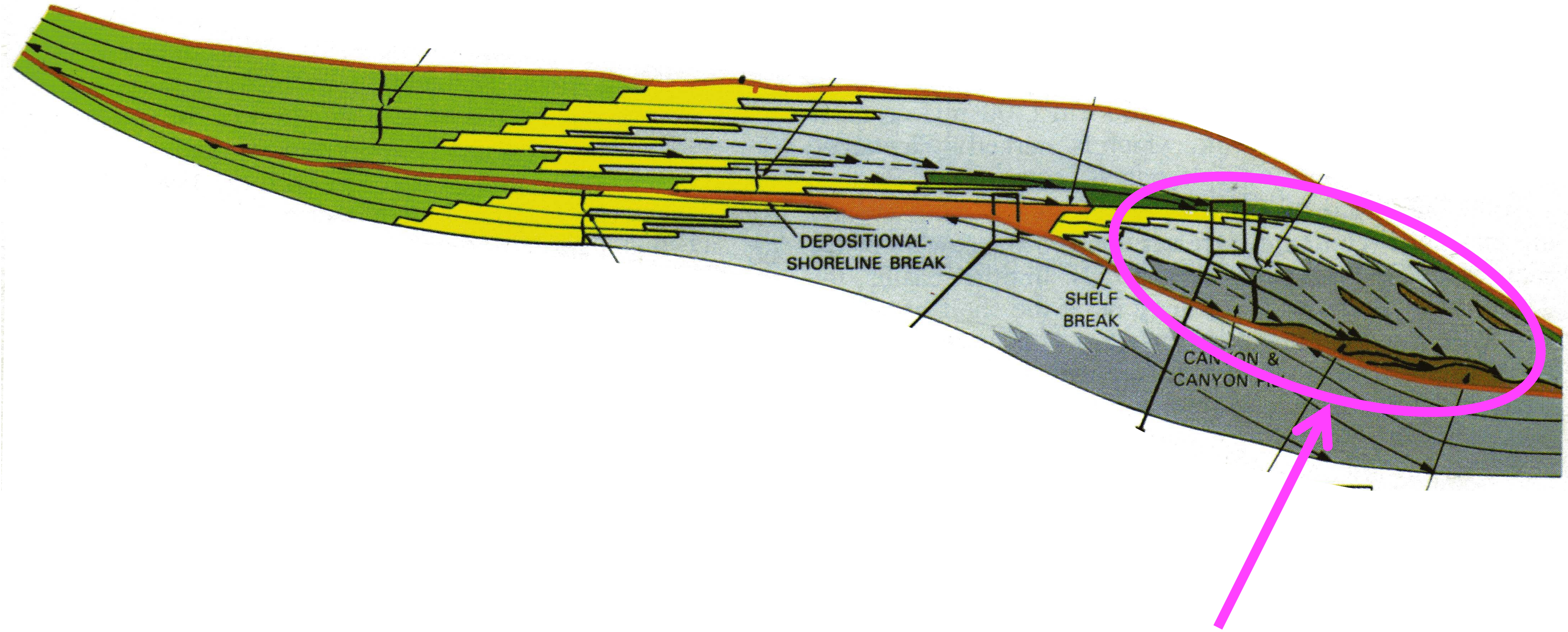
Contrast classic Exxon model...

Van Wagoner et al. 1988



Slope does not onlap landward

Slope downlaps onto fan

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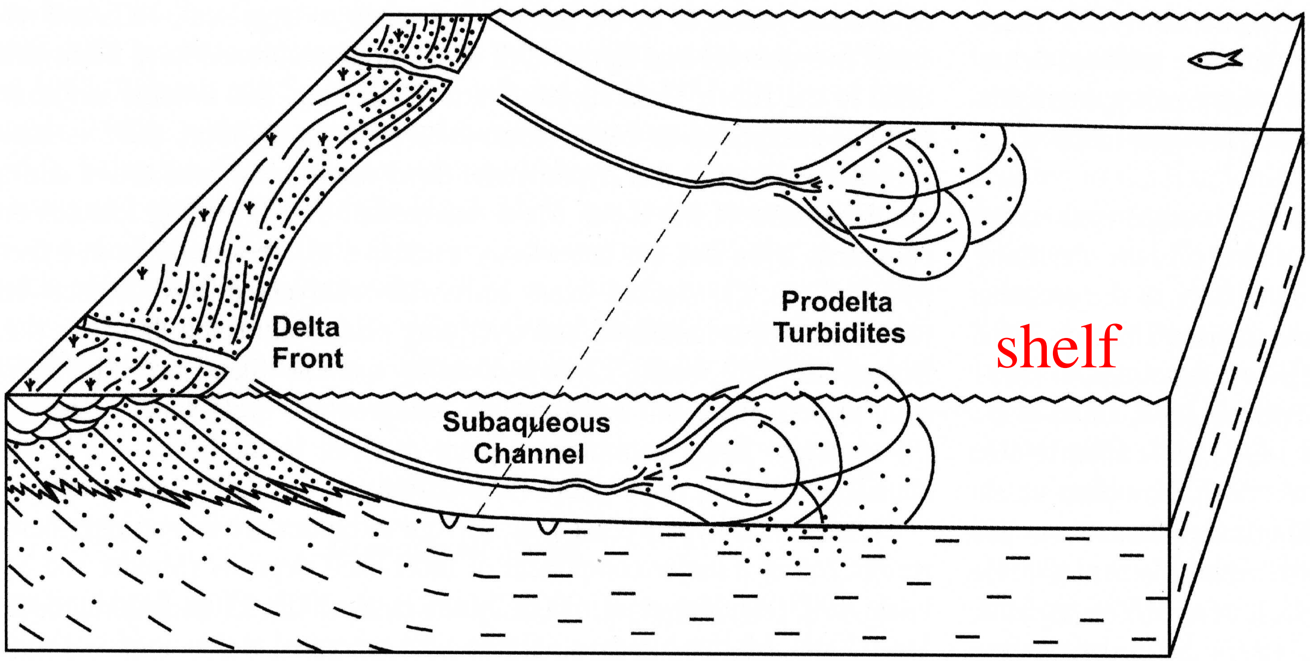
Alternative interpretation:

Lacustrine inner-shelf hyperpycnal channels feeding outer shelf sand lobes comprising hyperpycnites (river-fed turbidites) & wave-modified hyperpycnites,

cf. Pattison 2005, Campanian, Book Cliffs, USA (marine?; or lacustrine late phase of Western Interior Seaway?):



14 attributes shared with other ‘Bude-type* turbidite’ outcrops i.e. Bude, Ross, Laingsburg, Skoorsteenberg formations

(*Bude Fm has longest history of purely sedimentological study, dating back to H.G. Reading 1963)

1. Carbo-Permian

2. intra-Pangea foreland basins

3. adjacent “flysch trough”, known or inferable (e.g. phantom eroded upper Val Verde Basin)

4. 100s m thick

5. interbedded mudstone & turbidite-like vf/f sand

6. thinning- /thickening-up sequences rare. Instead, 'packets' (dm-m) of amalgamated thin (5-40cm) sand beds alternate with mudst containing thin (1-30cm) sand beds

7. two packet geometries: (i) incised channels (m thick, 10s m composite; <1km wide), (ii) distal tabular lobes (m thick, km wide)

8. most sand beds are Bouma A or AB, but...

9. some interspersed beds, both within & between packets, have wave-influenced structures, e.g. HCS, near-sym ripples

10. indigenous marine fossils, if any, confined to rare, thin (<20cm) shale bands

11. burrows scarce

12. common undulating, mud-draped discordances (storm-wave erosion?)

13. rare pseudo-slumps, with gradational base & vertical folds (i.e. *in situ*; earthquakes? wave loading?)

14. paleocurrent evidence for flow veering (Coriolis?)

Beauboeuf et al. 1999

BRUSHY CANYON FM

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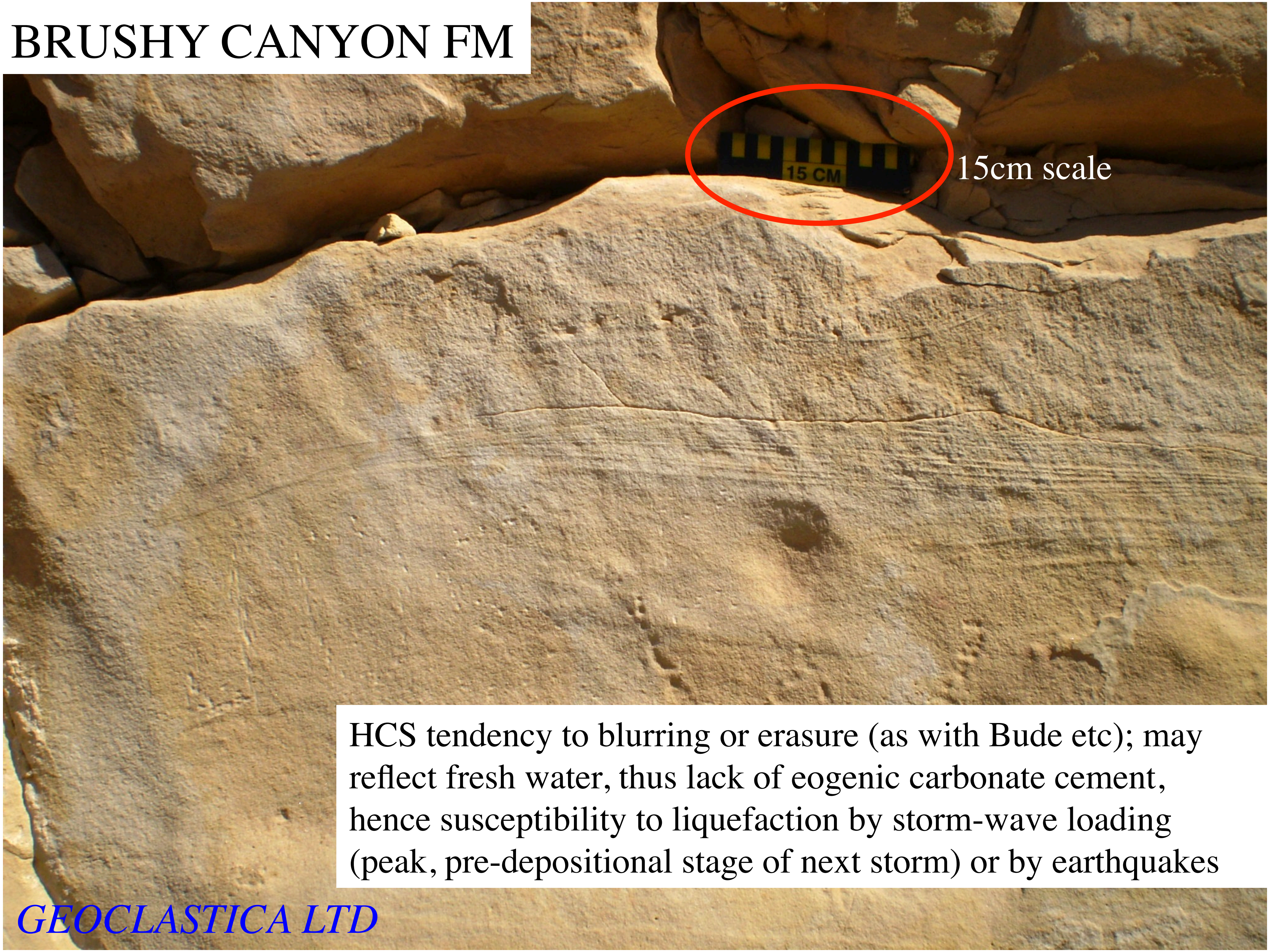
HUMMOCKS & HCS IN THE BRUSHY CANYON FM.....

i.e. evidence for deposition above storm wave base

Hendrix 2007, Geology 432 lecture slides, online

BRUSHY CANYON FM



HCS tendency to blurring or erasure (as with Bude etc); may reflect fresh water, thus lack of eogenic carbonate cement, hence susceptibility to liquefaction by storm-wave loading (peak, pre-depositional stage of next storm) or by earthquakes

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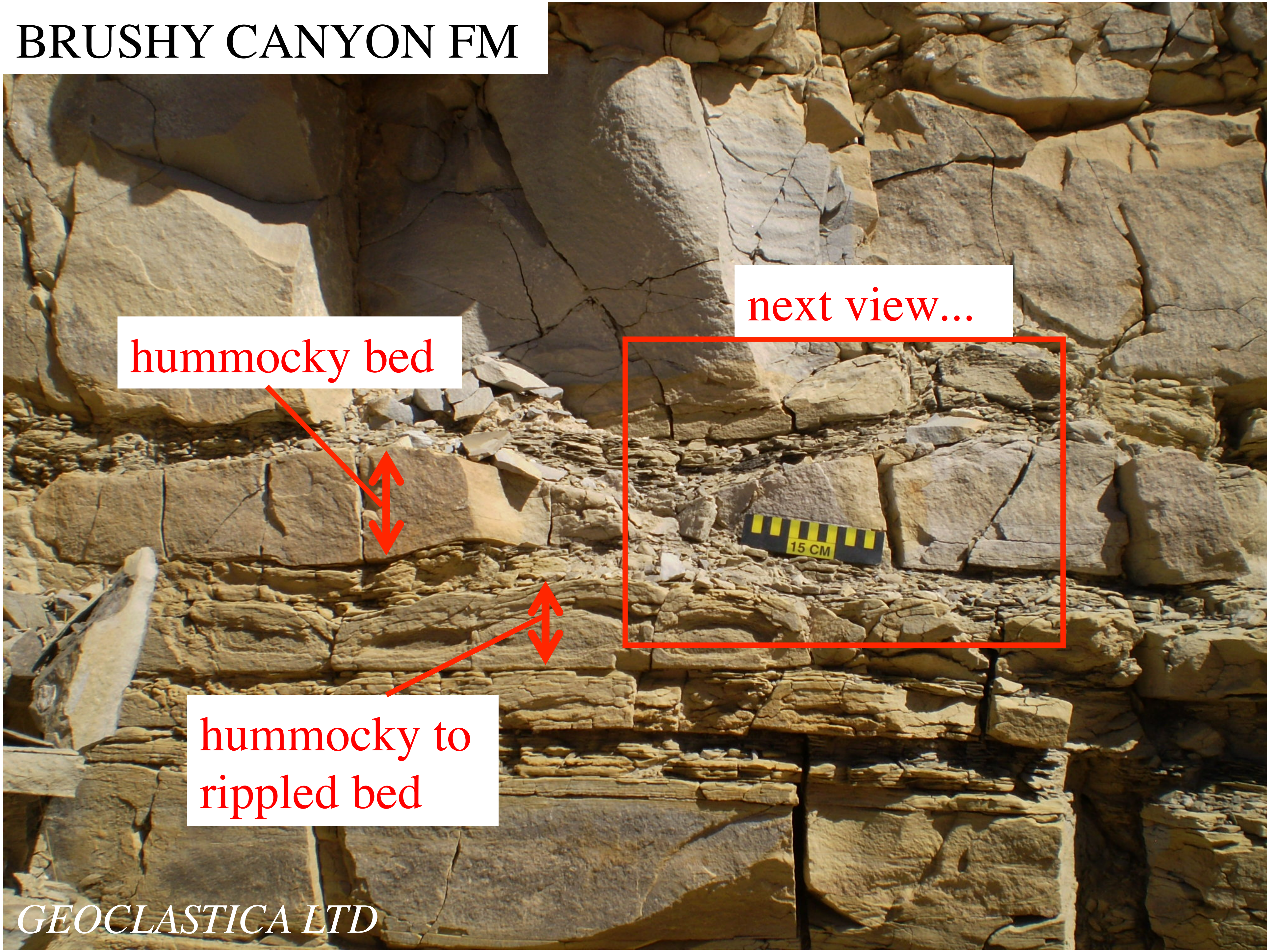
BRUSHY CANYON FM
hummocky bed
next view...
15 CM
hummocky to
rippled bed
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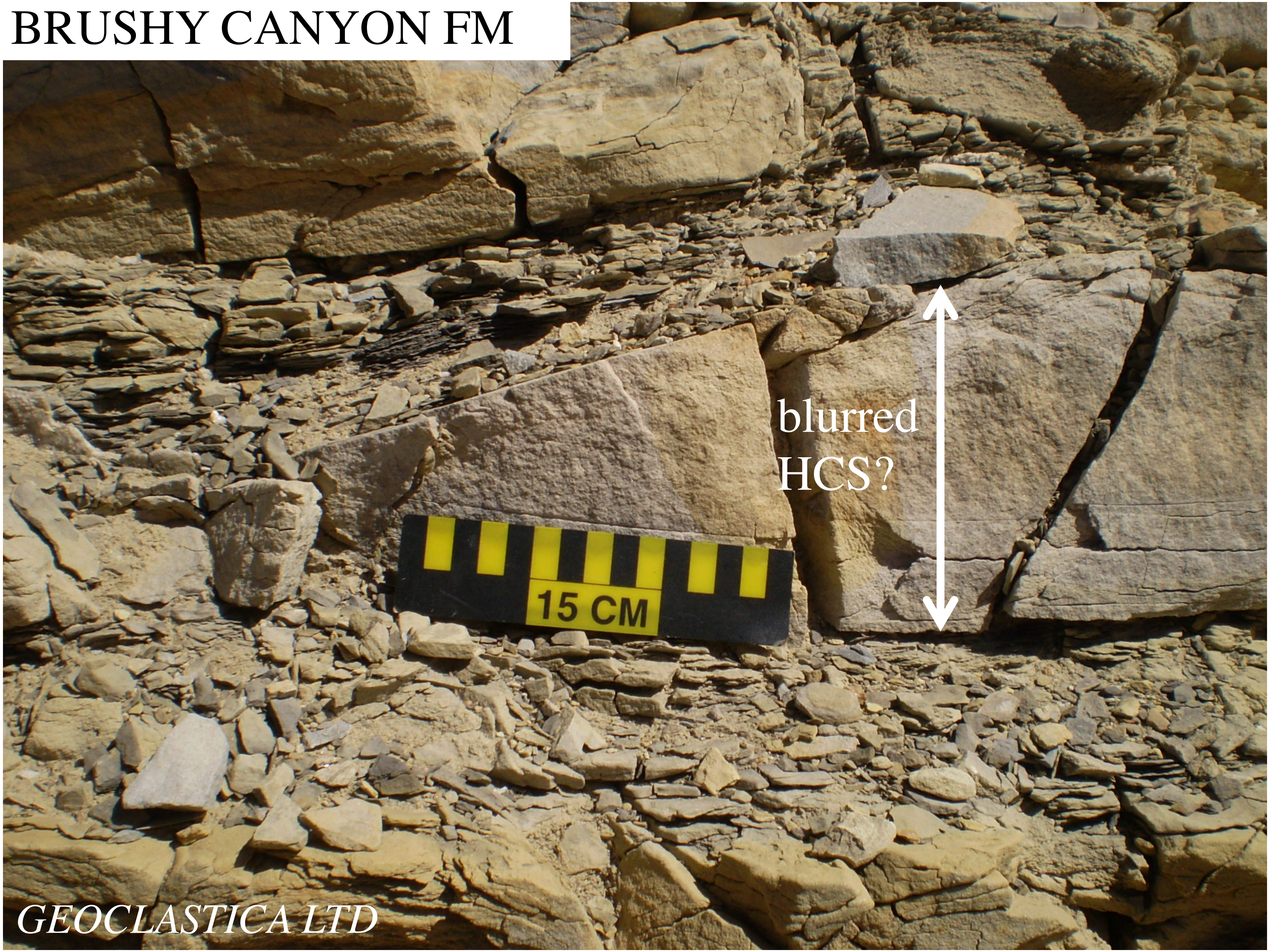
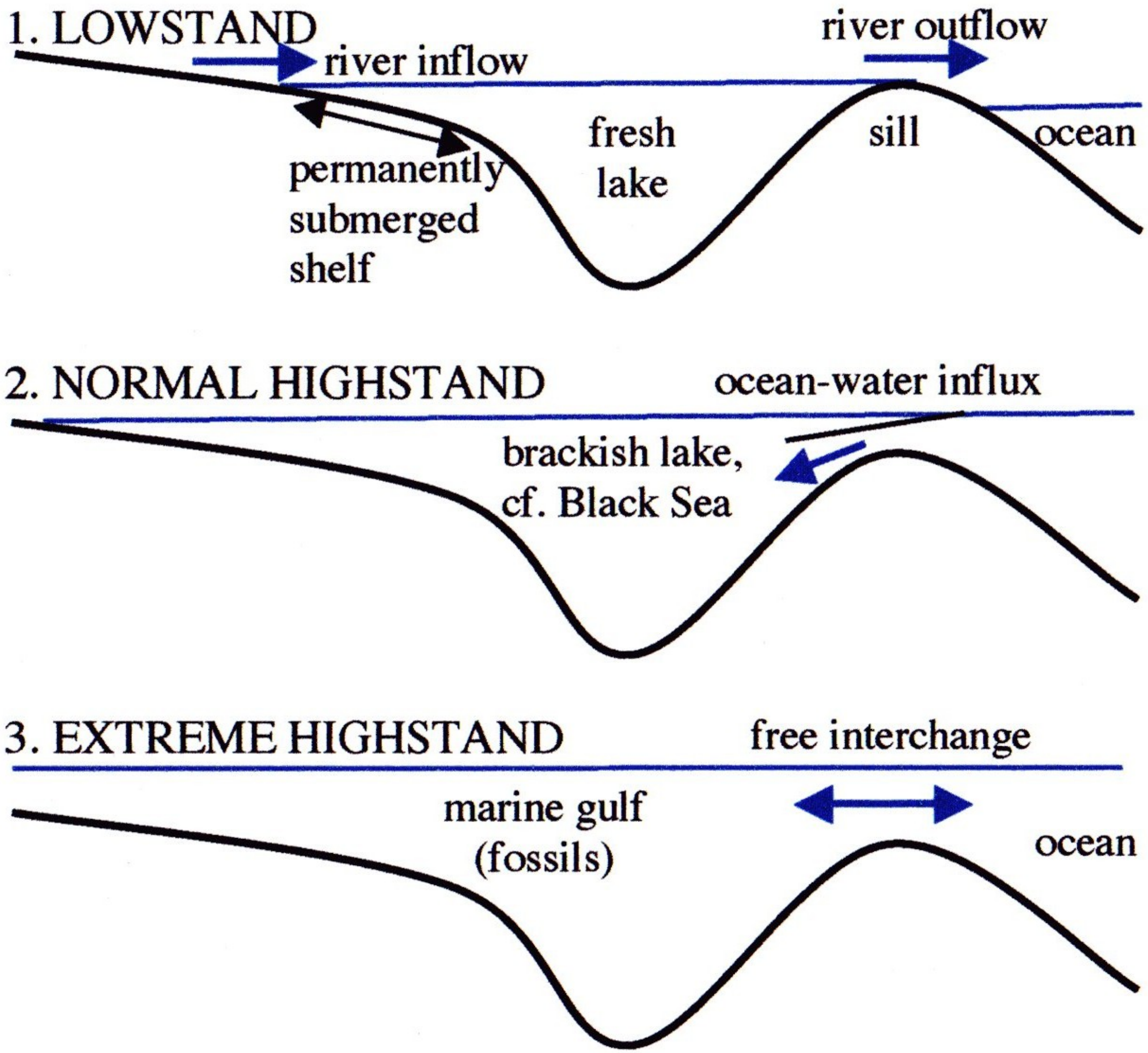
BRUSHY CANYON FM



Interpretation: lake outer shelf deposits

‘Sea-level lake’, fresh to brackish...



Eustatically controlled co-fluctuations in depth and salinity in "sea-level lakes". Thick (100s m) shelf strata can accumulate (e.g. Bude, Brushy Canyon, Ross, Skoorsteenberg, Laingsburg fms), uninterrupted by emergence, because (a) the lake sill limits the lake-level fall ("damped eustasy") & (b) at lowstand, deltas stop prograding as "easy" underflow (lake fresh) delivers river sand directly to the shelf (whose aggradation is limited by storm erosion, governing the equilibrium profile). Contrast marine shelves.

after Higgs 1991

consistent with peri-Pangea setting

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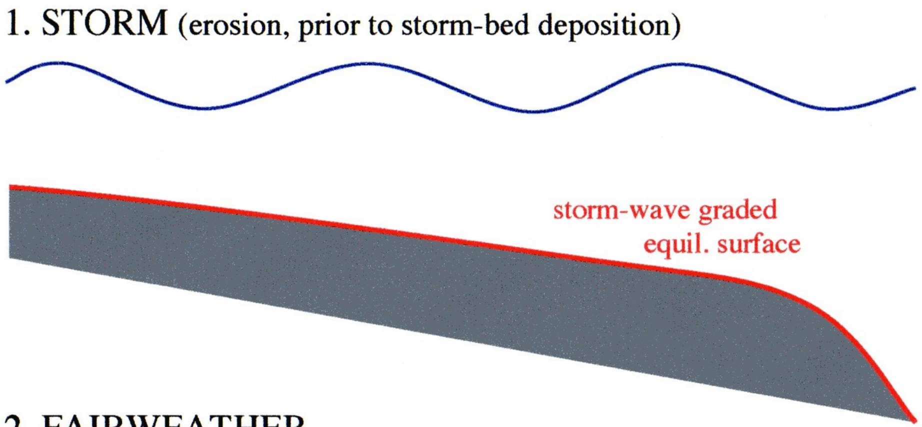
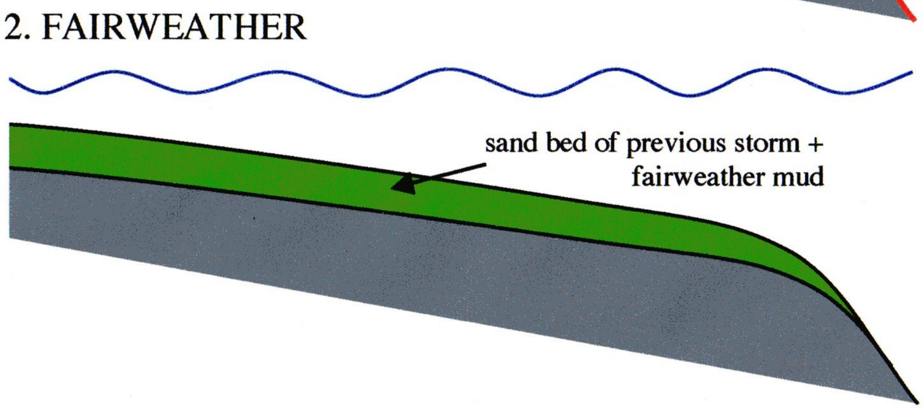
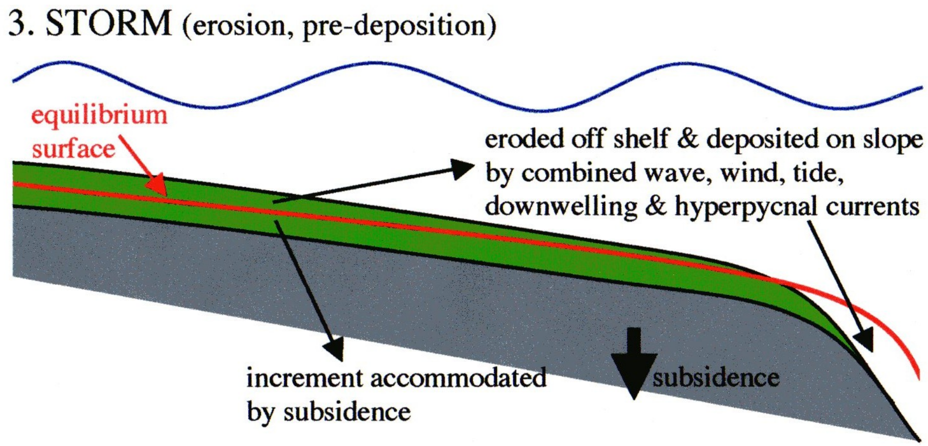
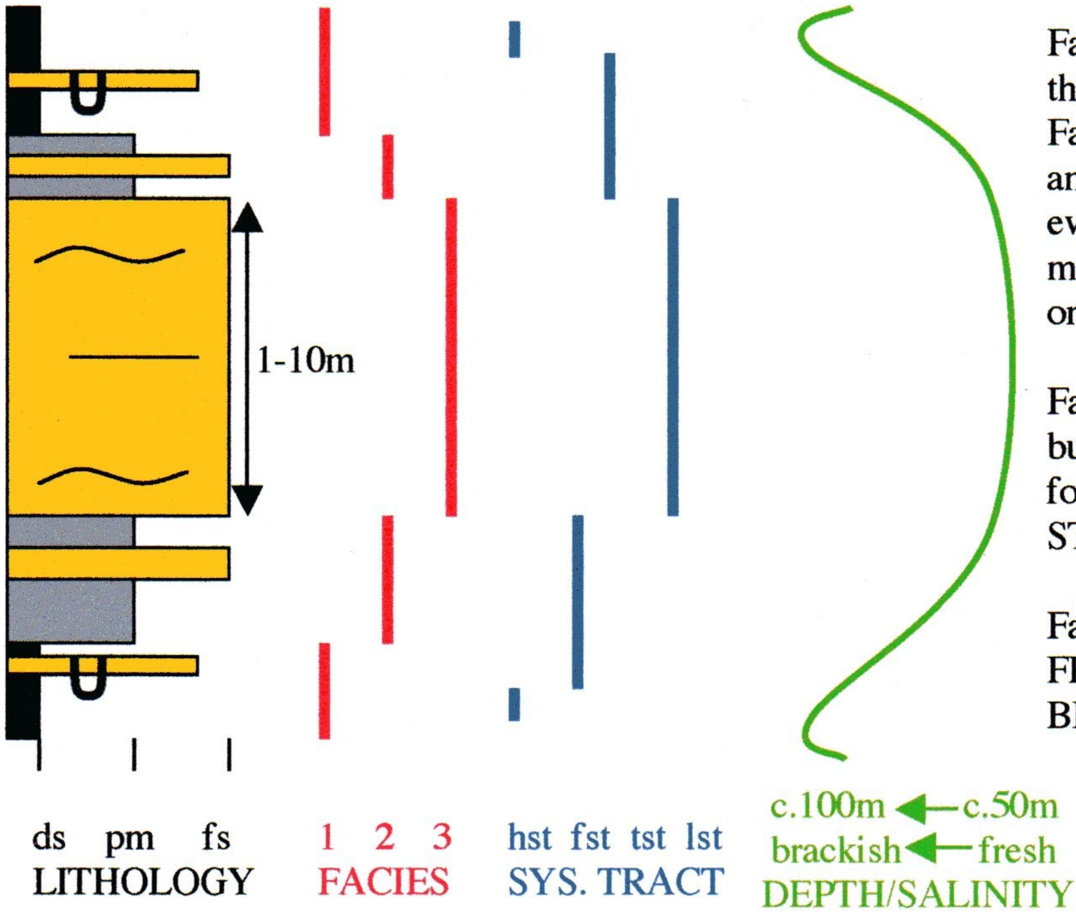






EQUILIBRIUM SHELF PROFILE
(after Seilacher 1982)
Prevents long-term subaerial emergence.
Assumes (A) stillstand & (B) inter-deltaic position.

Bude-type cycles are ‘arrested’ (‘topless’)



Facies 1 & 2: mudst with thin (<30cm) event beds. Facies 3: tabular unit of amalgamated thin (<40cm) event beds; local HCS, mostly blurred, or expressed only as wavy partings.

Facies 1 has post-event burrows but lacks marine fossils/trace fossils - STRONGLY BRACKISH

Facies 2 & 3 lack burrows - FRESH TO WEAKLY BRACKISH

'Bude-type turbidites' ideal cycle. Central sand body interpreted as a sea-level-lake shelf lobe, comprising hyperpycnites & storm-wave-influenced hyperpycnites. Lithologies: ds = dark mudst; pm = pale silty mudst; fs = fine & very fine sandst. Systems tracts: hst highstand; fst falling; tst transgressive; lst lowstand. Many cycles lack Facies 1.

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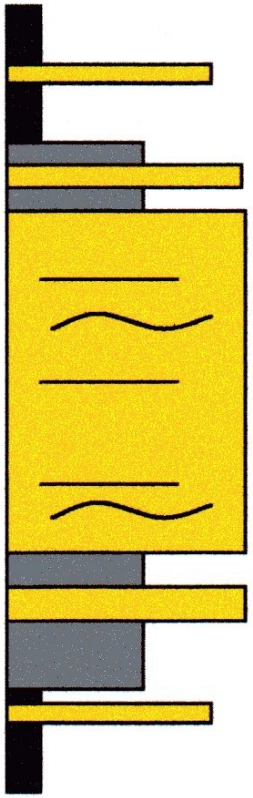
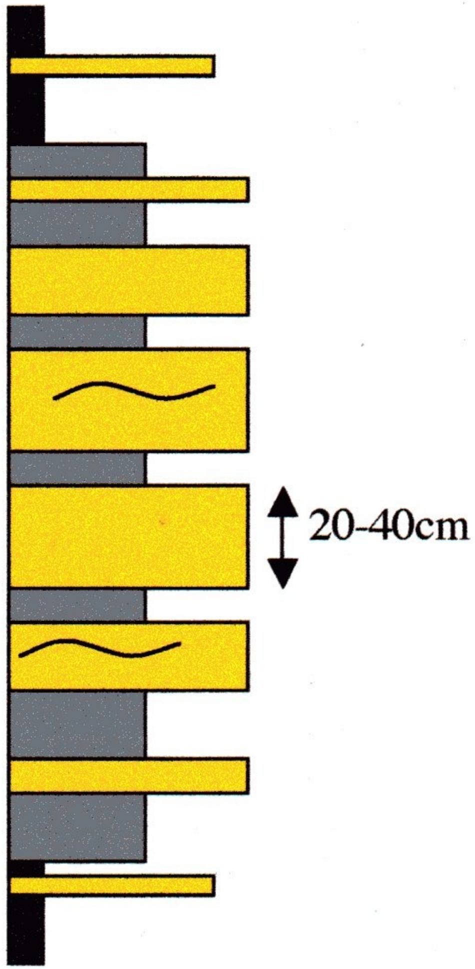
Bude-type cycles are ‘compressed’



Lake outer-shelf "compressed cycle". "Premature amalgamation", due to low cohesion of fresh-water mud (easily resuspended), masks bed-thickness sequences and produces a "blocky" cycle.



"Normal" (i.e. marine) outer-shelf cycle, lacking amalgamation.

after Higgs 1991

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Lake shelf deposits (e.g. Bude, Brushy) are poor analogs for deep-sea turbidite reservoirs because processes differ...

Hyperpycnal flows feeding deep-sea channels & fans are coarser due to (i) higher-velocity feed (lowstand, incised, braided river in flood) & (ii) longer downslope acceleration

Shelf flows (lacustrine or marine) have less acceleration potential

Deep sea lacks 'premature amalgamation' (weakly cohesive, freshwater mud) & storm-wave erosion

Therefore

Deep-sea fan lobes and lake-shelf lobes differ in architecture (amalgamation; wave scours) & grain size

Unlike shelf channels, deep-sea channels are aggradational (leveed), sinuous, thicker (10s-100s m) & occupy canyons

BRUSHY *IS* A VALID OUTCROP ANALOG FOR ...

SHALLOW-LACUSTRINE HYPERPYCNAL RESERVOIRS

e.g. Brushy Canyon oilfields

(N.B. reserves & flow rates are *two* orders of magnitude smaller than 'analogous' deep-sea-turbidite fields)

Are lake-shelf hyperpycnite reservoirs common in rift phase of passive margins? e.g. Brazil sub-salt?

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Bude (my home!) is also a good analog for Brushy reservoirs...

-public land
-easy access, London 4 hrs by road
-4 times thicker (more rock to study)
-3D exposure (cliff & foreshore), partly wave-polished

THANK YOU

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