Pleistocene Shelf-to-Basin Depositional Systems, Offshore East Kalimantan, Indonesia: Insights into Deep-Water Slope Channels and Fans*

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Abstract

3D seismic data show the depositional history of shallow Pleistocene shelf margin, slope and basinal strata in offshore East Kalimantan, Indonesia. Siliciclastic sequences on the shelf are dominated by progradational packages deposited during highstands and falling eustatic sea level. During the last two lowstands of sea level (~18 and ~130 ka), coarse siliciclastics were generally not deposited in deep-water environments because lowstand deltas did not prograde over the underlying shelf margin. During the lowstand of sea level that ended at ~240 ka, deltas prograded over the previous shelf edge, and sand-rich sediments spilled onto the slope.

During the late Pleistocene, siliciclastic sediment supply determined the depositional characteristics of the slope. Channel-levee complexes developed on slopes where deltaic sediment supply was large; in contrast, incised valleys/canyons formed on slopes where siliciclastic input was limited. Pleistocene channel-levee complexes can be traced upslope to lowstand deltas associated with the paleo-Mahakam River. In areas with limited sediment supply, rivers and deltas were generally not present on the outer shelf, including areas upslope from incised slope valleys and canyons. Strata on the basin floor downslope of the slope valleys and canyons are dominated by mass-transport complexes, suggesting that slope valleys and canyons formed by mass failures of the slope, not by erosion associated with turbidite sands derived from rivers or deltas.

In the area with limited sediment supply, one small river was present on the shelf margin during the late Pleistocene, and sediments originating from its lowstand delta filled a pre-existing slope valley/canyon and formed a basin-floor fan. That slope valley/canyon has a lower fill that consists of amalgamated, sinuous channel deposits and an upper fill consisting of a shale-rich, channel-levee complex. The basin-floor fan also has two parts: a lower fan containing broad lobes with relatively continuous reflectors and an upper fan with a shale-rich, sinuous channel-levee complex that prograded over the lower fan and fed sheet-like lobes on the upper, outer fan. These shallow Pleistocene systems serve as analogs for deeper, more poorly imaged reservoir systems.

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Saller, A.H., and I.N.W. Dharmasamadhi, 2012, Controls on the development of valleys, canyons, and unconfined channel-levee complexes on the Pleistocene slope of East Kalimantan, Indonesia: Marine and Petroleum Geology, v. 29, p. 15-34.

Saller, A.H., S.W. Reksalegora, and P. Bassant, 2011, Sequence stratigraphy and growth of shelfal carbonates in a deltaic province, Kutai Basin, Offshore East Kalimantan, Indonesia, *in* W.A. Morgan, A.D. George, P.M. Harris, J.A. Kupecz, and J.F. Sarg, eds., Cenozoic Carbonate Systems of Australasia: Society for Sedimentary Geology Special Publication 96, p. 147-174.

Saller, A.H., I.N. Dharmasamadhi, T. Lilburn, and R. Earley, R., 2010, Seismic geomorphology of submarine slopes: Channel-levee complexes versus slope valleys and canyons, Pleistocene, East Kalimantan, Indonesia, *in* L.J. Wood, T.T. Simo, and N.C. Rosen, eds. Seismic Imaging of Depositional and Geomorphic Systems: Gulf Coast Section SEPM, 30th Annual Conference p. 433-471.

Saller, A.H., K. Werner, F. Sugiaman, A. Cebastiant, R. May, D. Glenn, and C. Barker, 2008, Characteristics of Pleistocene deep-water fan lobes and their application to an Upper Miocene reservoir model, offshore East Kalimantan, Indonesia: AAPG Bulletin, v. 92, p. 919-949.

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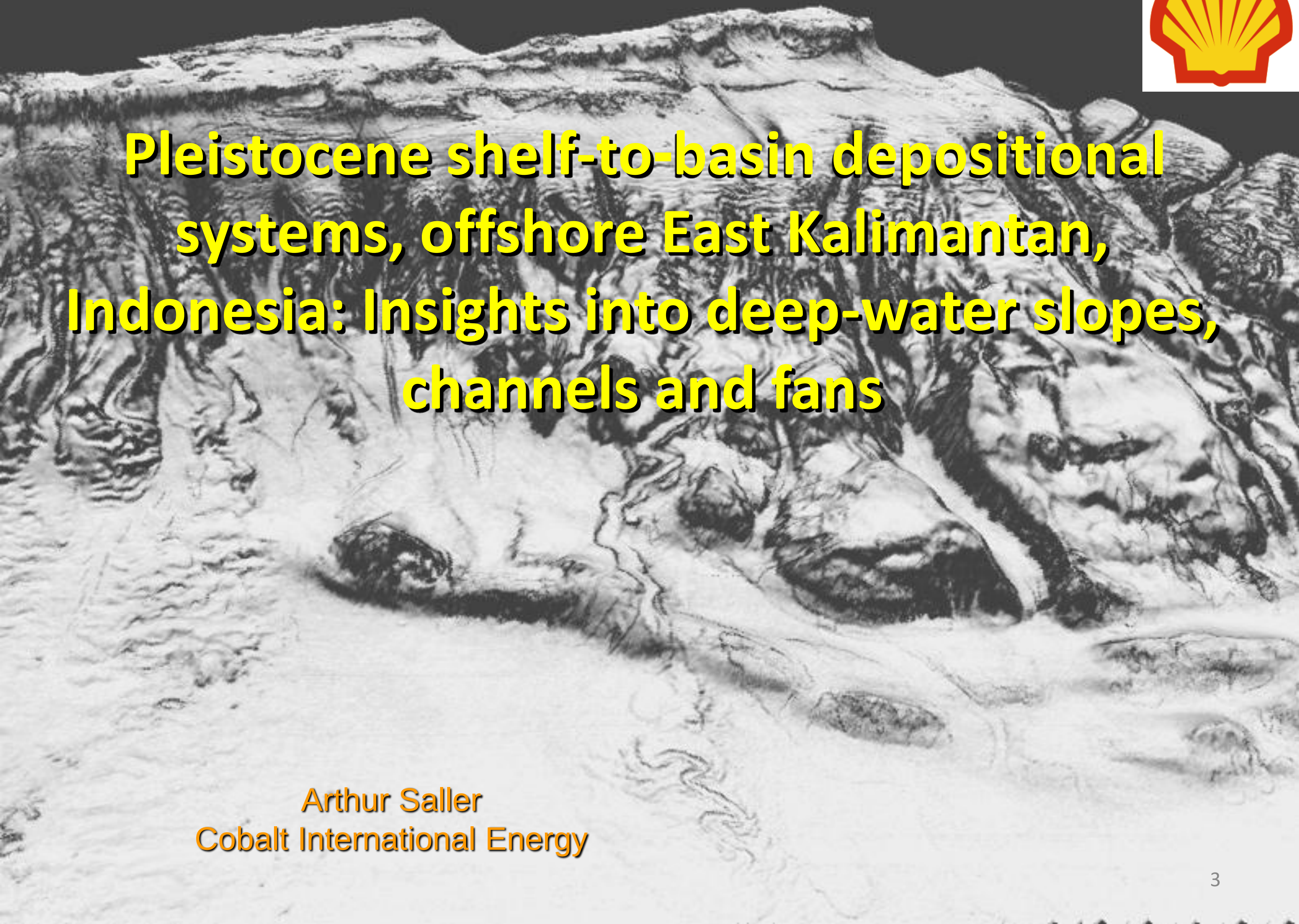

Pleistocene shelf-to-basin depositional systems, offshore East Kalimantan, Indonesia: Insights into deep-water slopes, channels and fans

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Presentation includes material from:

- Saller, A.H., and I.N.W. Dharmasamadhi, 2012, Controls on the development of valleys, canyons, and unconfined channel-levee complexes on the Pleistocene slope of East Kalimantan, Indonesia: Marine and Petroleum Geology, v. 29, p. 15-34.
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Pleistocene shelf-to-basin depositional systems, offshore East Kalimantan, Indonesia: Insights into deep-water slope channels & fans- **Summary**

- Shallow 3D seismic data from shelf margin to basin floor show contrasting depositional patterns in Pleistocene deep-water **slopes** of offshore East Kalimantan, Indonesia
- Central slope
  - Abundant sediment supply from the paleo-Mahakam Delta
  - Dominated by unconfined channel-levee complexes
- Northern slope
  - Little siliciclastic sediment
  - Dominated by valleys and canyons, most unfilled
- Except for one slope valley & basin-floor fan complex, **northern** slope & basin floor show no evidence of sand-rich channels or fans, but contain widespread mass-transport complexes
- In general, slope valleys & canyons form by slumps and mass flows
- One area in the north contains an isolated lowstand delta that provided sediment to fill a slope valley and create a basin-floor fan

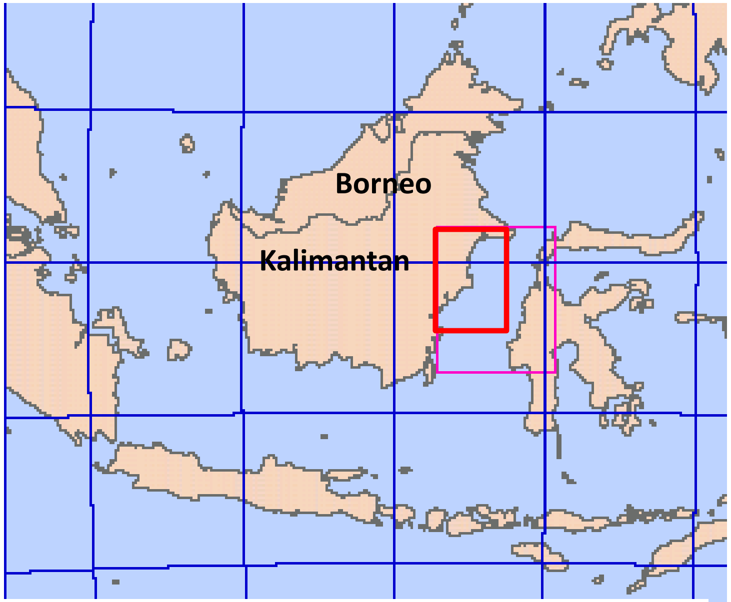

PHILIPPINES
MALAYSIA
Study Area
INDONESIA

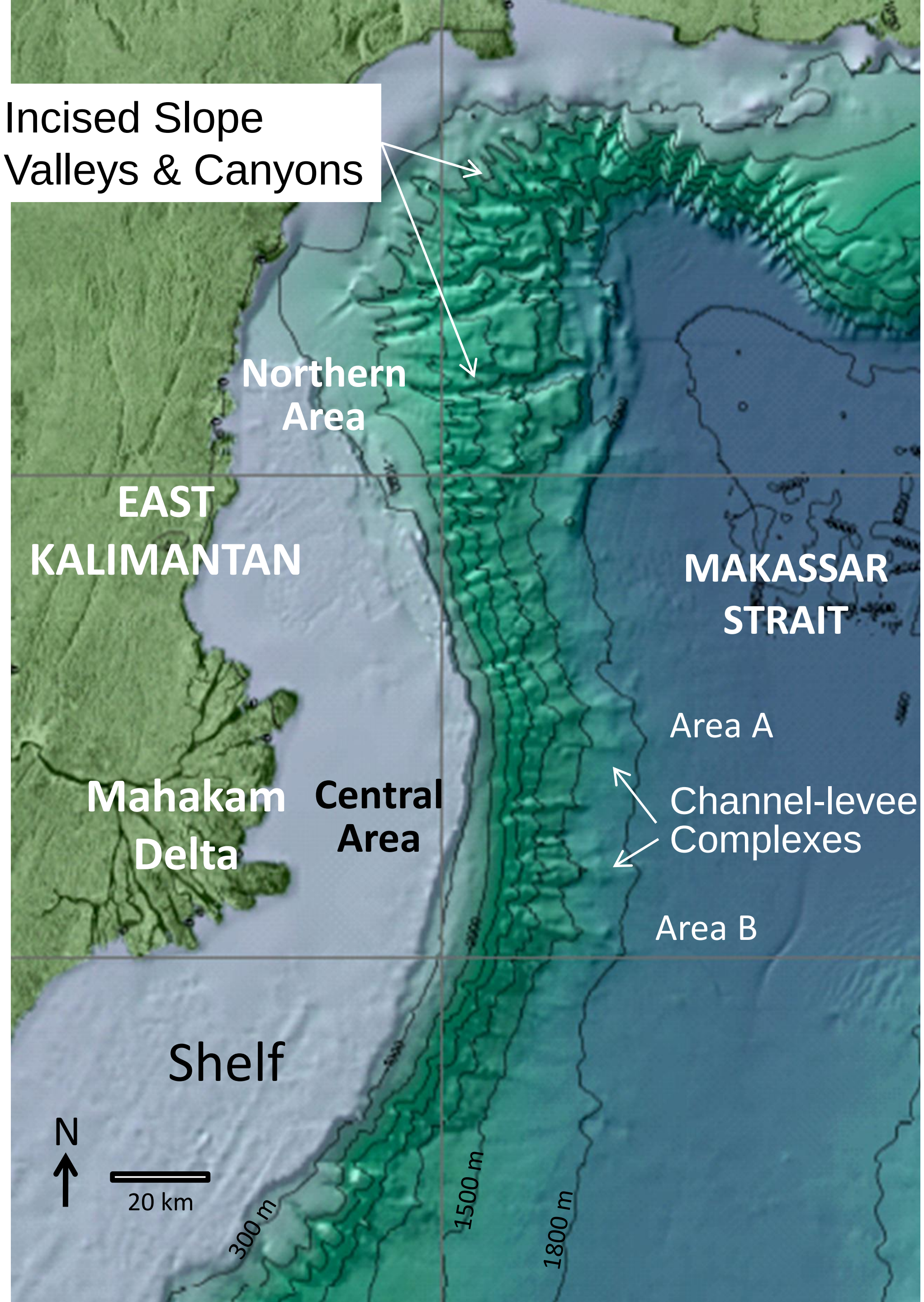
Indonesia

Location Maps

The Pleistocene slope of East Kalimantan contains

1. Well developed channel-levee complexes immediately basinward of the Mahakam Delta
2. Well developed slope valleys & canyons in the north where siliciclastic input is minimal

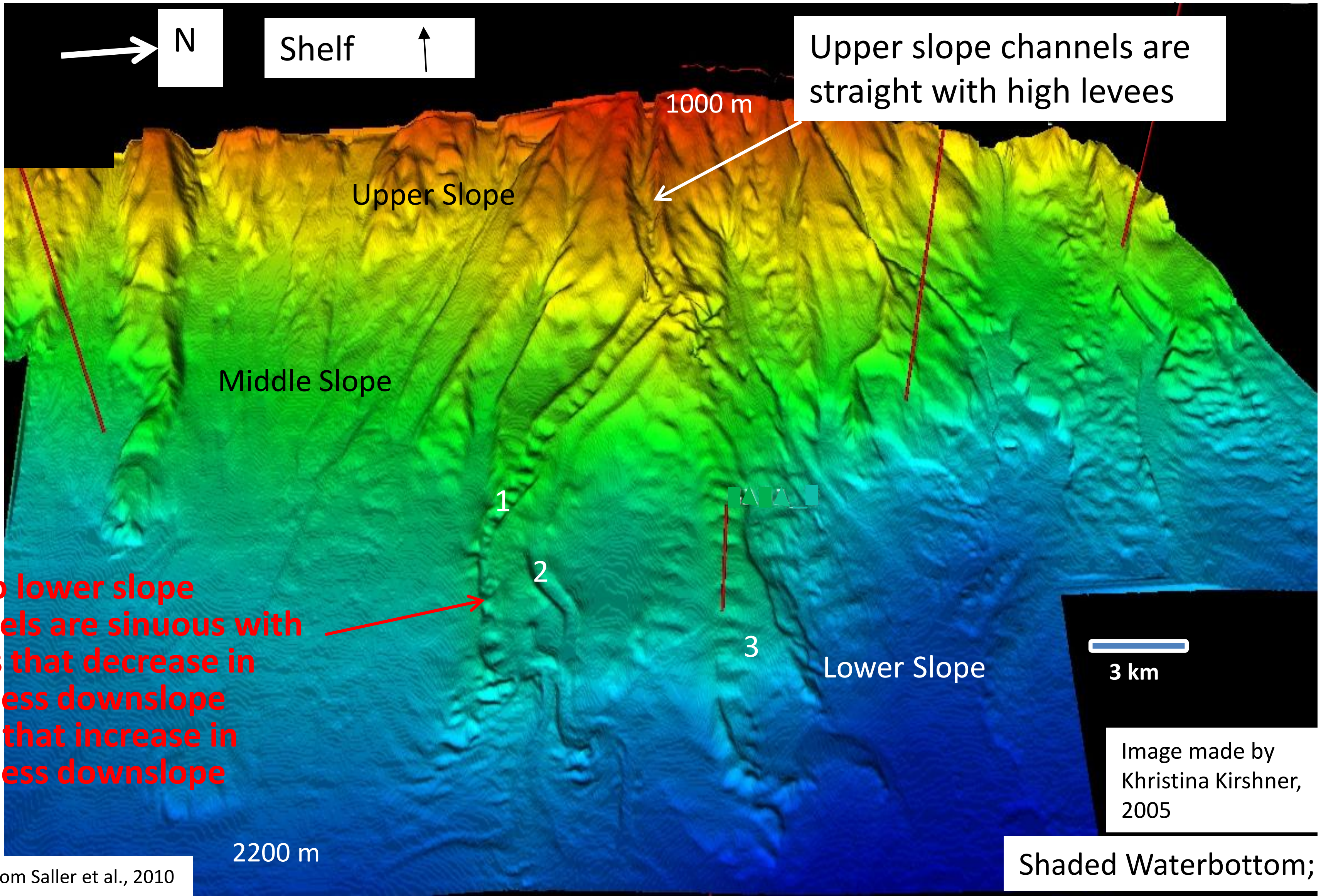




Images made by Phil Teas & John Decker

Modified from Saller et al., 2010

Central Area (A) east of the Mahakam: Slope with Channel-Levee Complexes

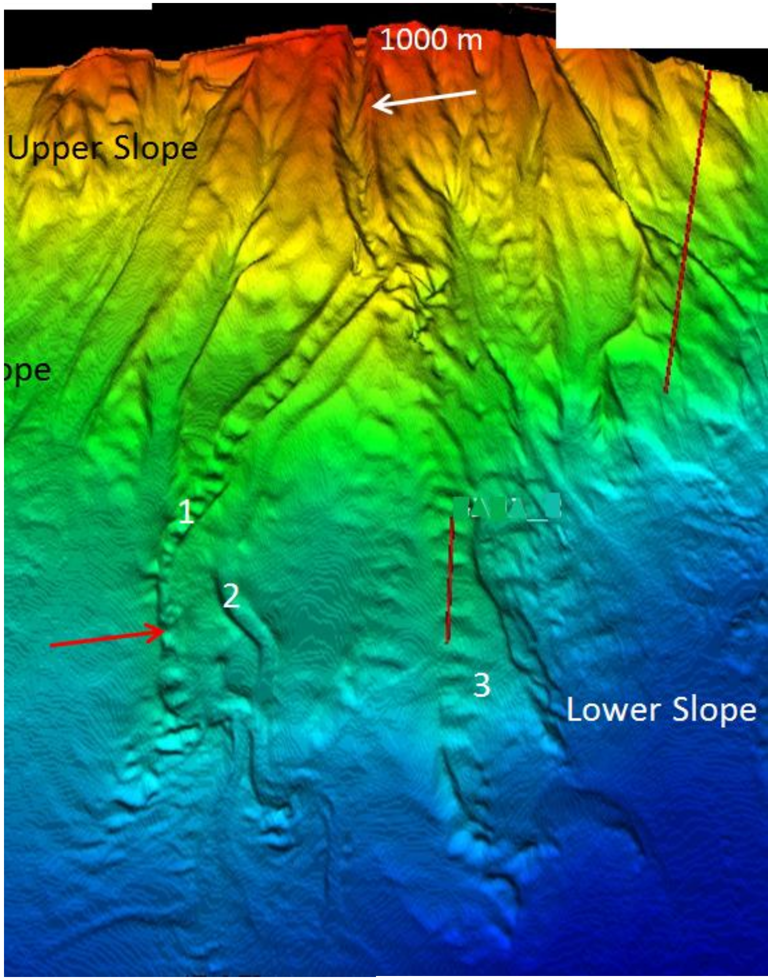


Mid to lower slope channels are sinuous with levees that decrease in thickness downslope & fills that increase in thickness downslope

Modified from Saller et al., 2010

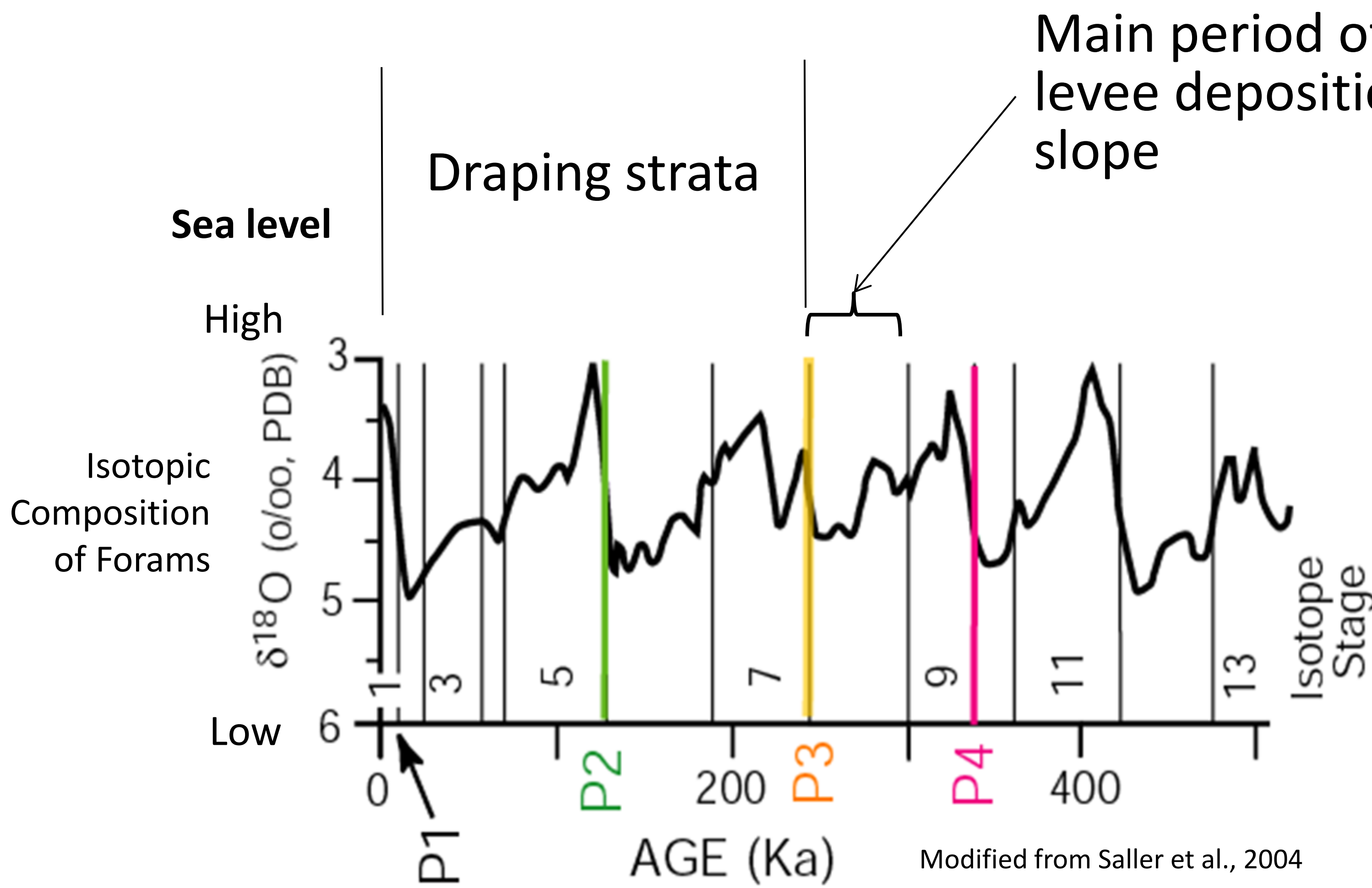
Central Slope: Unconfined Channel-Levee Complexes

- Upper Slope Channels
  - Straight, deep & aggradational
  - Traced upslope to shelf margin associated with the paleo-Mahakam deltas
  - Levees are 200 ms (170 m) thick
  - Channel - levee relief is ~100 ms (~85 m)
- Middle-Lower Slope Channel-Levee Complexes
  - Sinuous
  - Lateral channel migration followed by aggradation
  - Avulsion with younger complexes avoiding bathymetric highs created by previous channel-levee complexes
  - Lower slope levees are 80 ms (70 m) thick
  - Lower slope channel - levee relief is ~20 ms (~17 m)



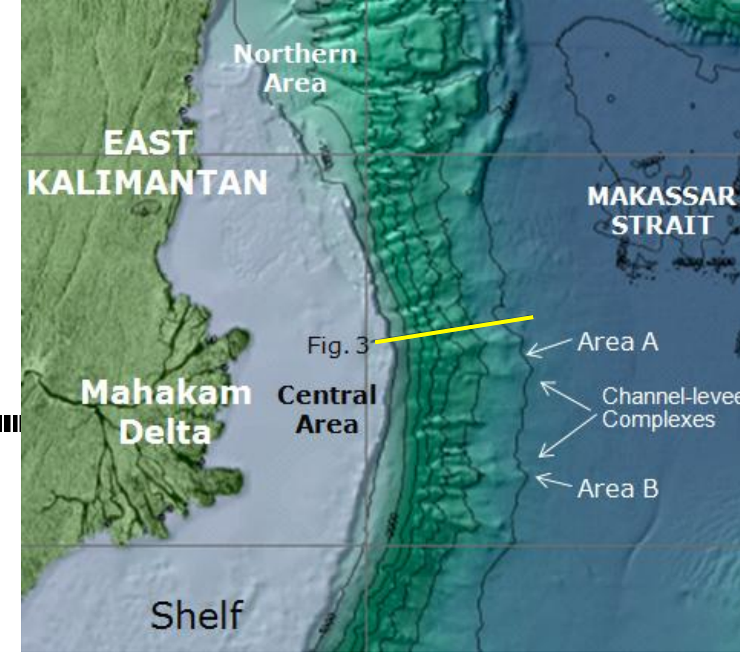
Modified from Saller et al., 2010

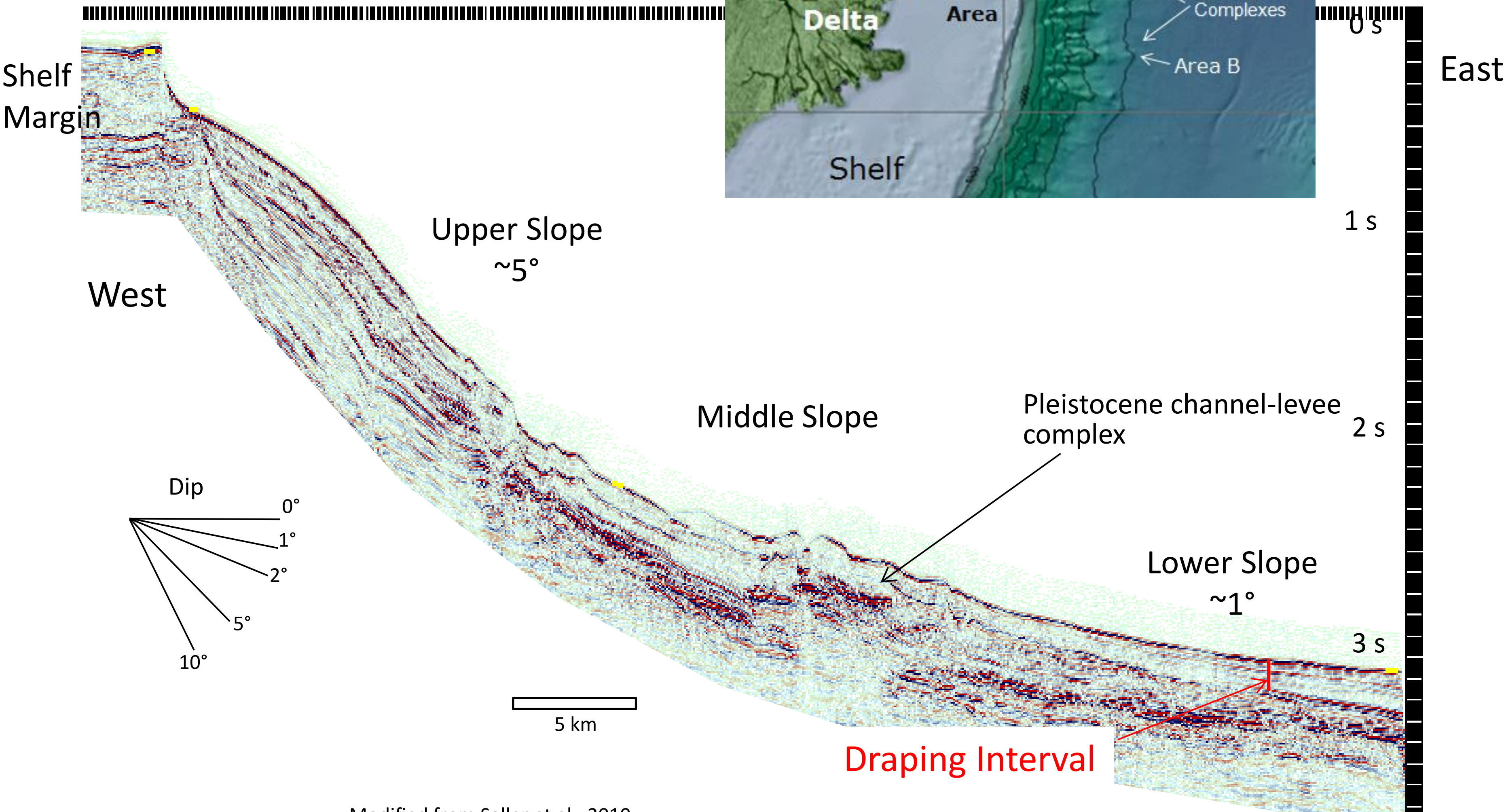
Deposition of Channel-Levee Complexes on the Slope occurred mainly during the Lowstand of Sea Level that Ended at ~240 ka



Modified from Saller et al., 2004

Central Area: Dip profile intersecting Channel-Levee Complexes
Slope angle decreases basinward





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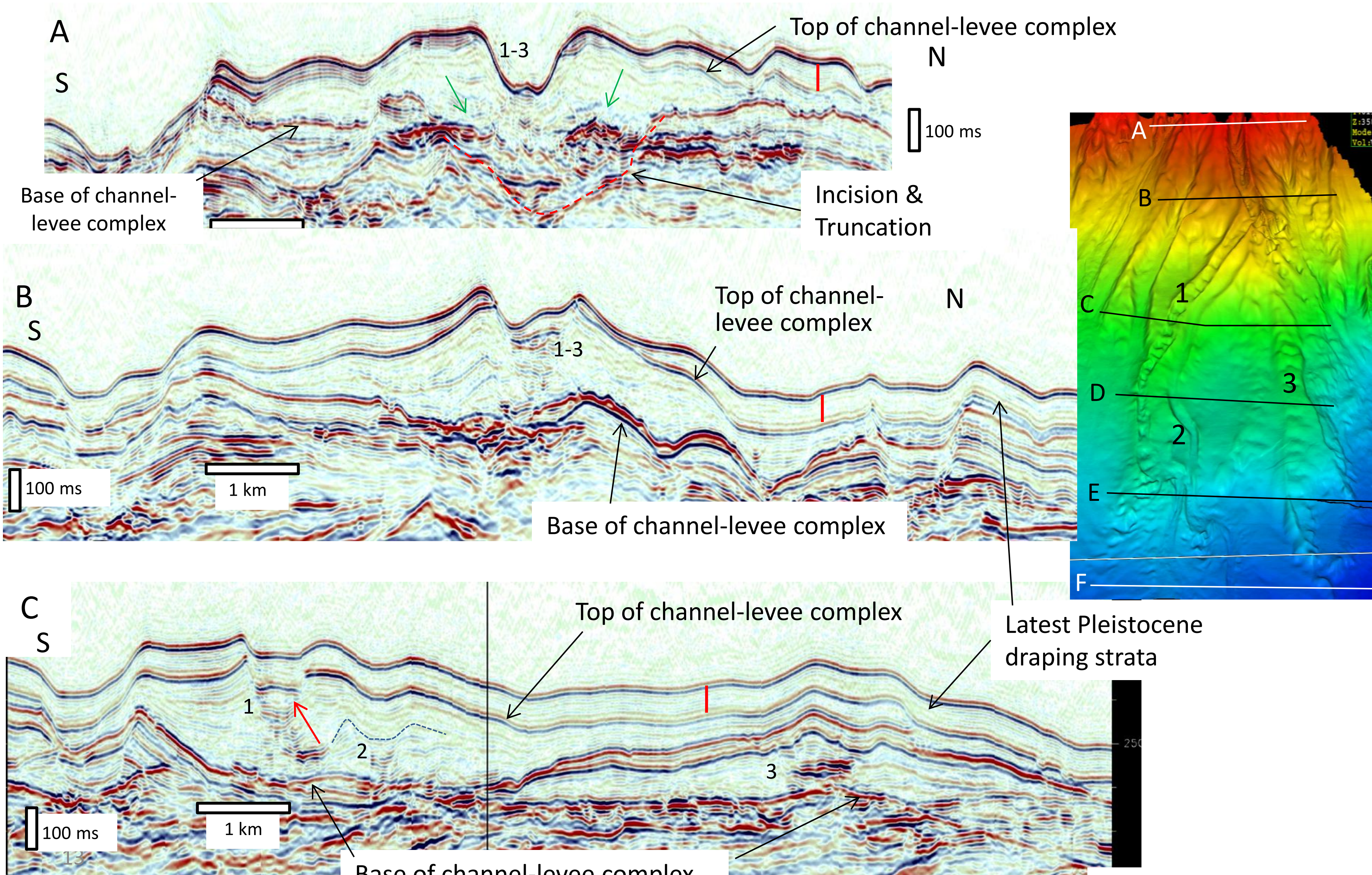
Area A: Strike Profiles of the Upper & Middle Slope with Deep Channels & Thick Levees



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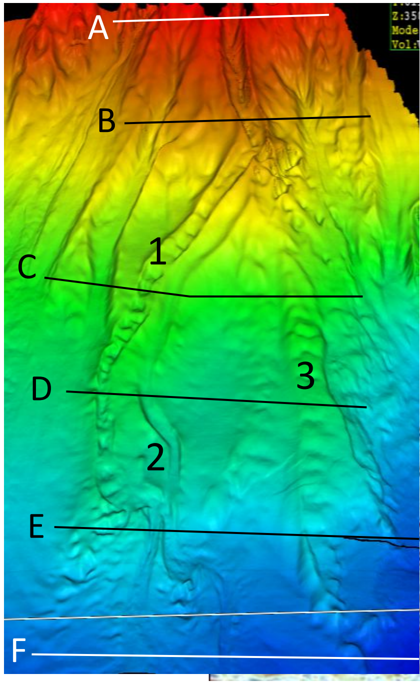
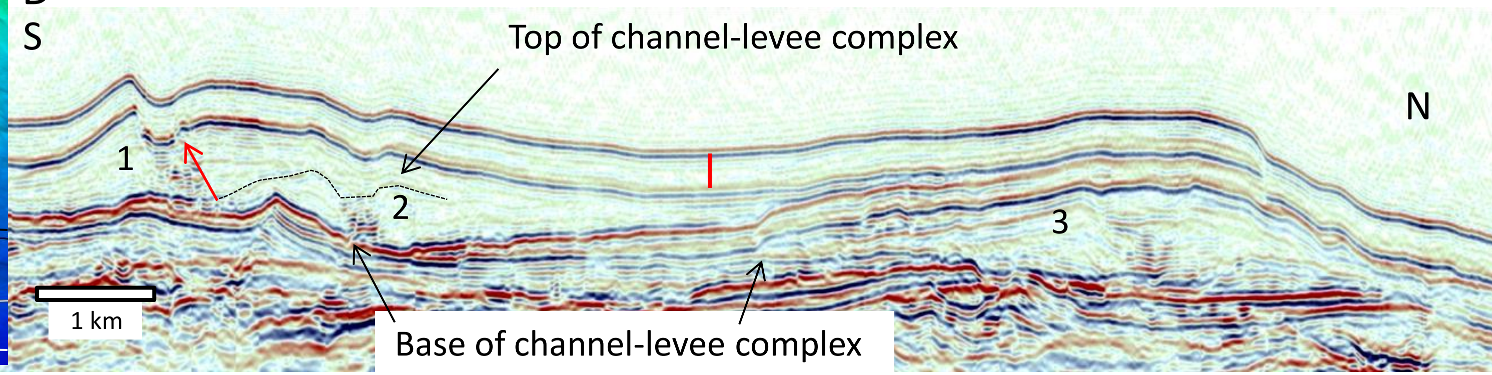
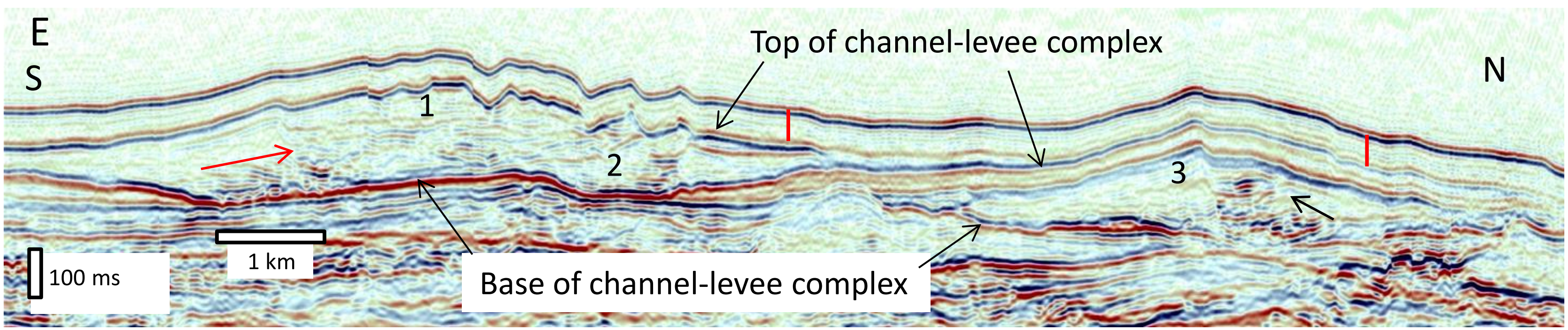
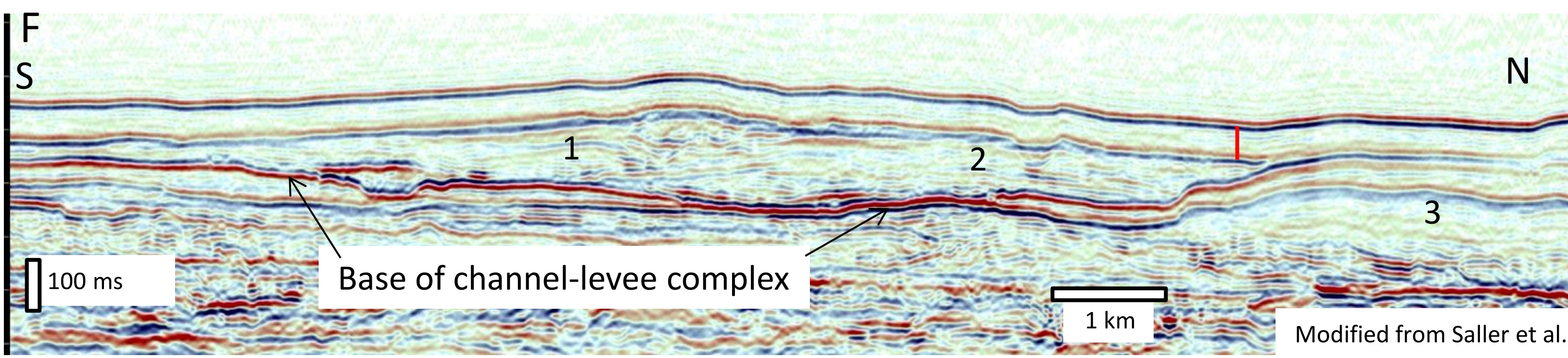
Middle & Lower Slope Strike Profiles: Channels become more sinuous, more filled downslope, & show compensational stacking



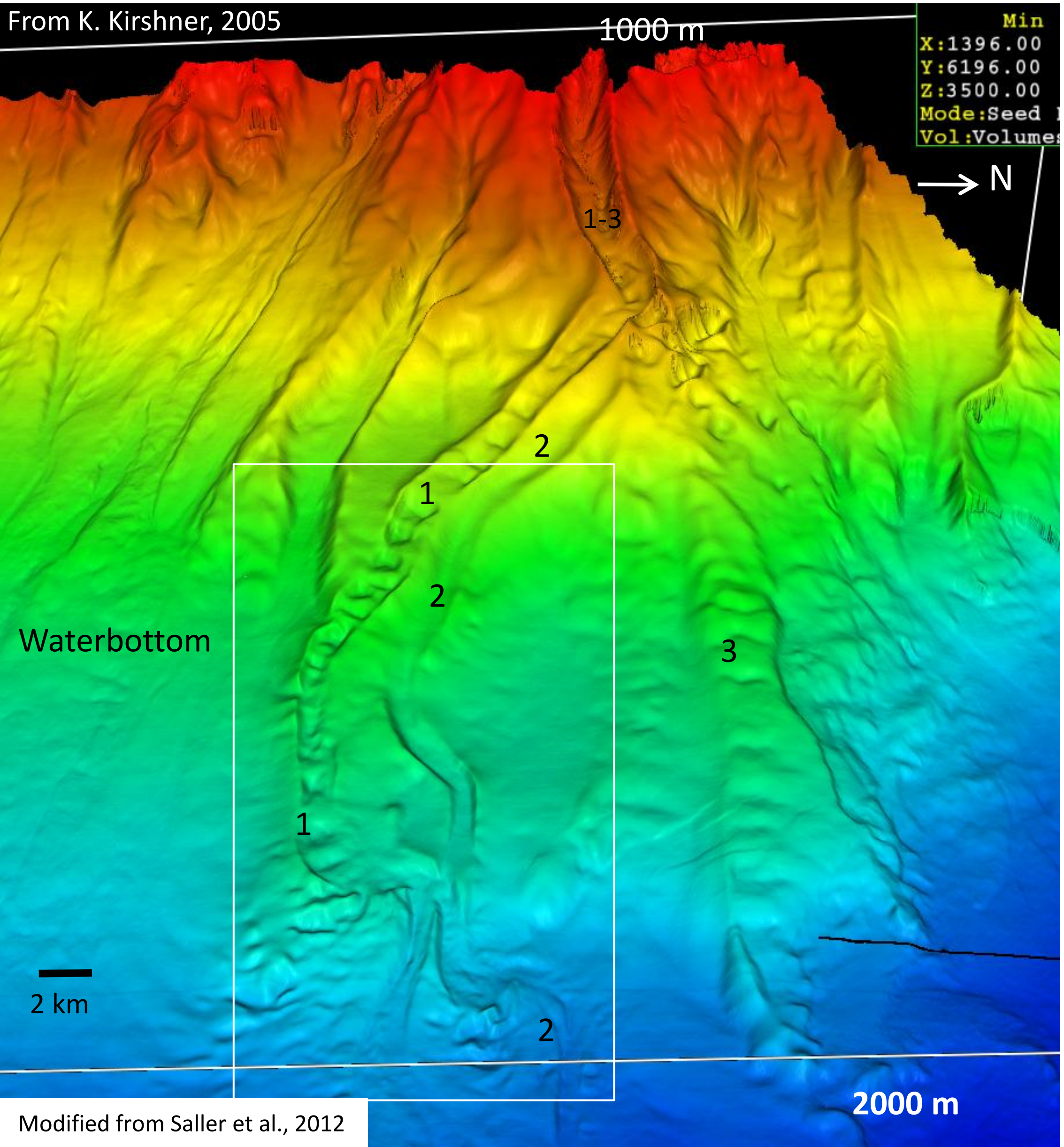




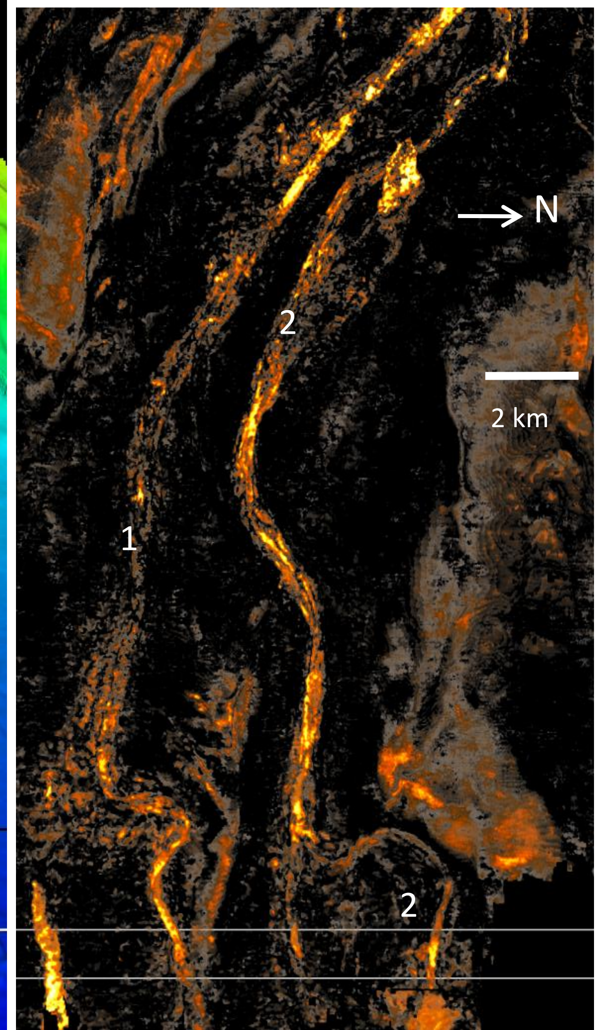


Modified from Saller et al., 2010

Area A: Pleistocene Channel-Levee Complexes: Sinuosity and fill increase downslope

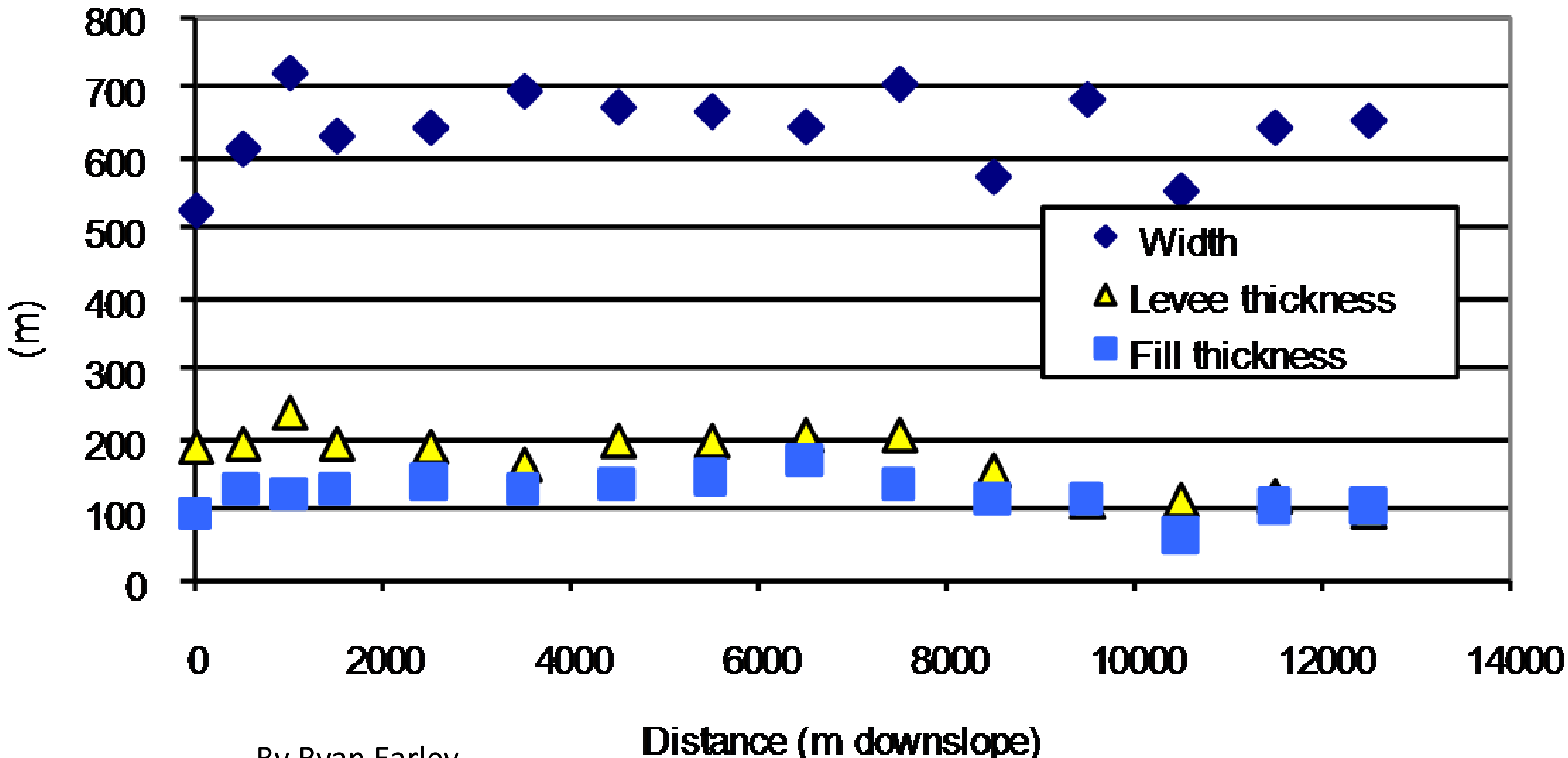


Optical Amplitude stack apparently showing ~100 m wide sand-rich channel fills



Area A, Channel-Levee Complex 1:
Downslope Trends

(1) Channel width remains relatively constant
(2) Levee thickness decreases
(3) Fill thickness approaches levee thickness indicating channels are largely filled

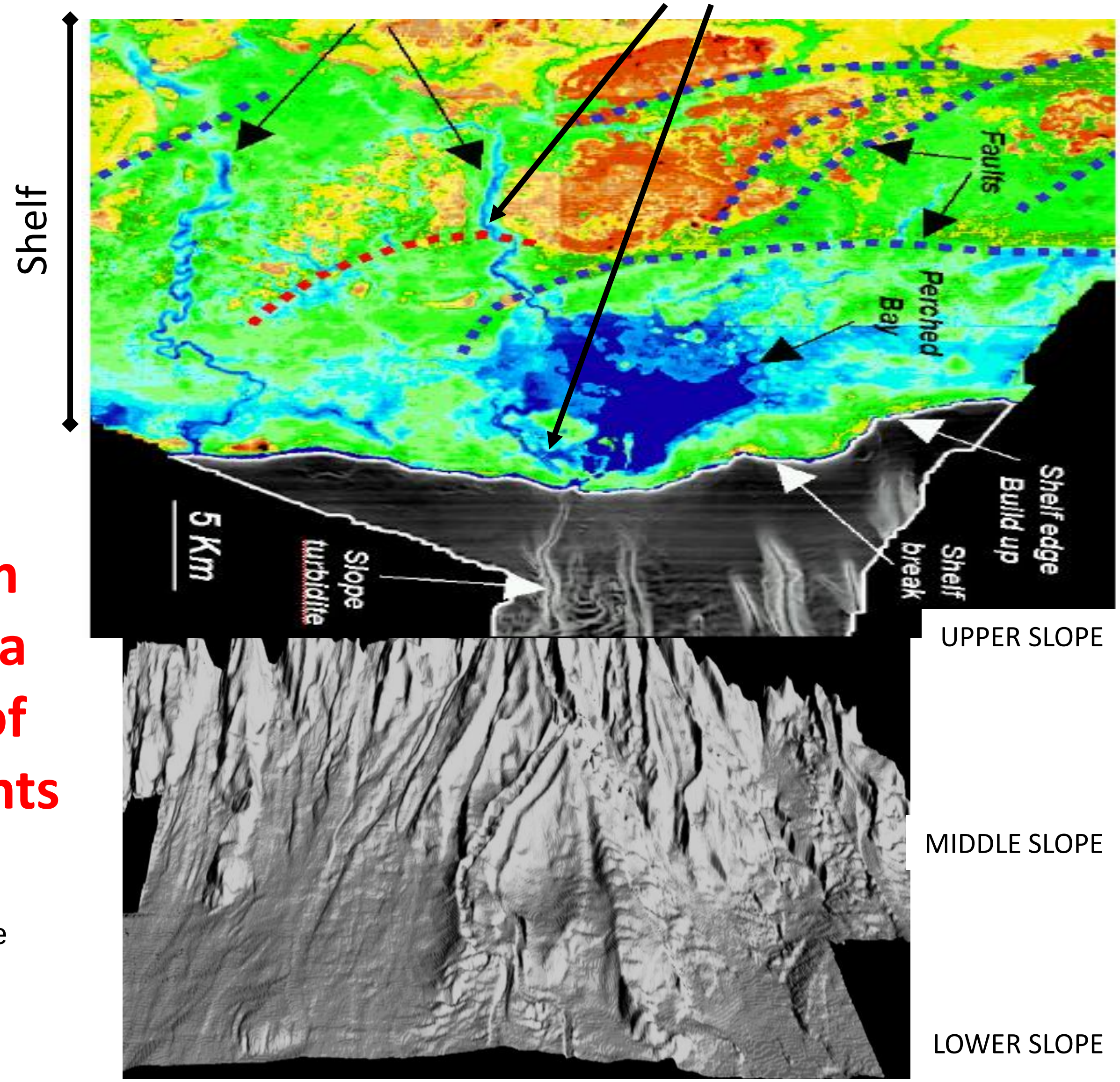


By Ryan Earley

Modified from Saller et al., 2010

Slope Channels can be traced up to the Shelf Margin

Note incised valley on shelf leading to the only active slope valley



Shelf image from Crumeyrolle and Renaud (2003), used with permission

UPPER SLOPE

MIDDLE SLOPE

LOWER SLOPE

Channel-levee complexes form on slopes with a robust supply of deltaic sediments

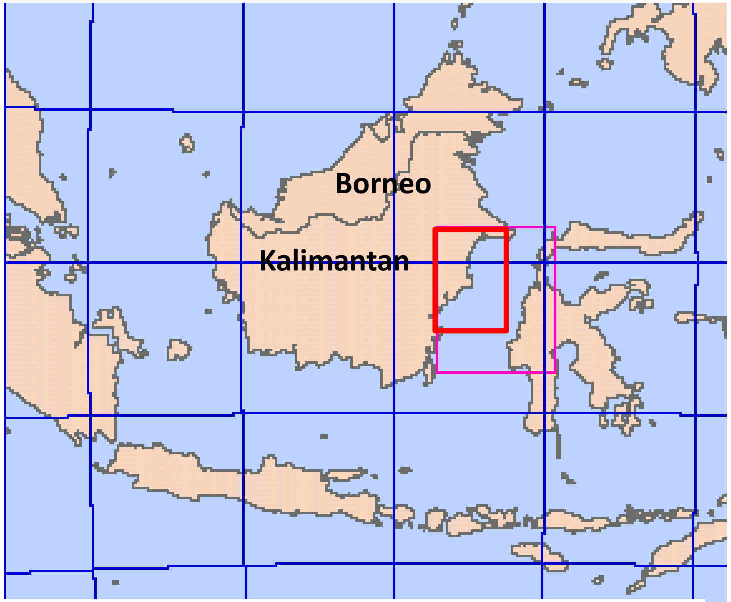
Khristina Kirschner made the gray shaded upper to lower slope image

Modified from Saller et al., 2010

Location Maps

The Pleistocene slope of East Kalimantan contains

1. Well developed channel-levee complexes immediately basinward of the Mahakam Delta
2. Well developed slope valleys & canyons in the north where siliciclastic input is minimal



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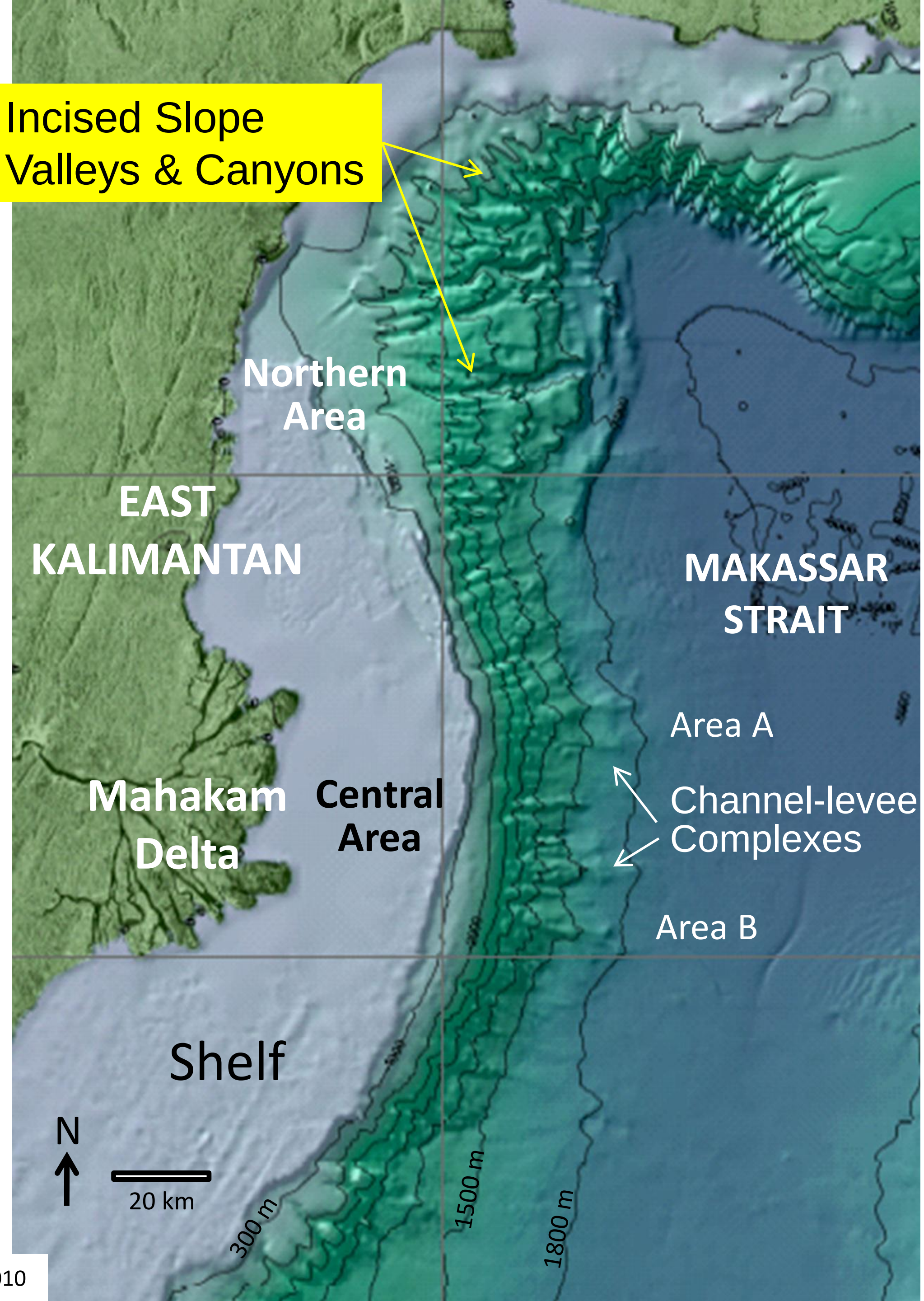
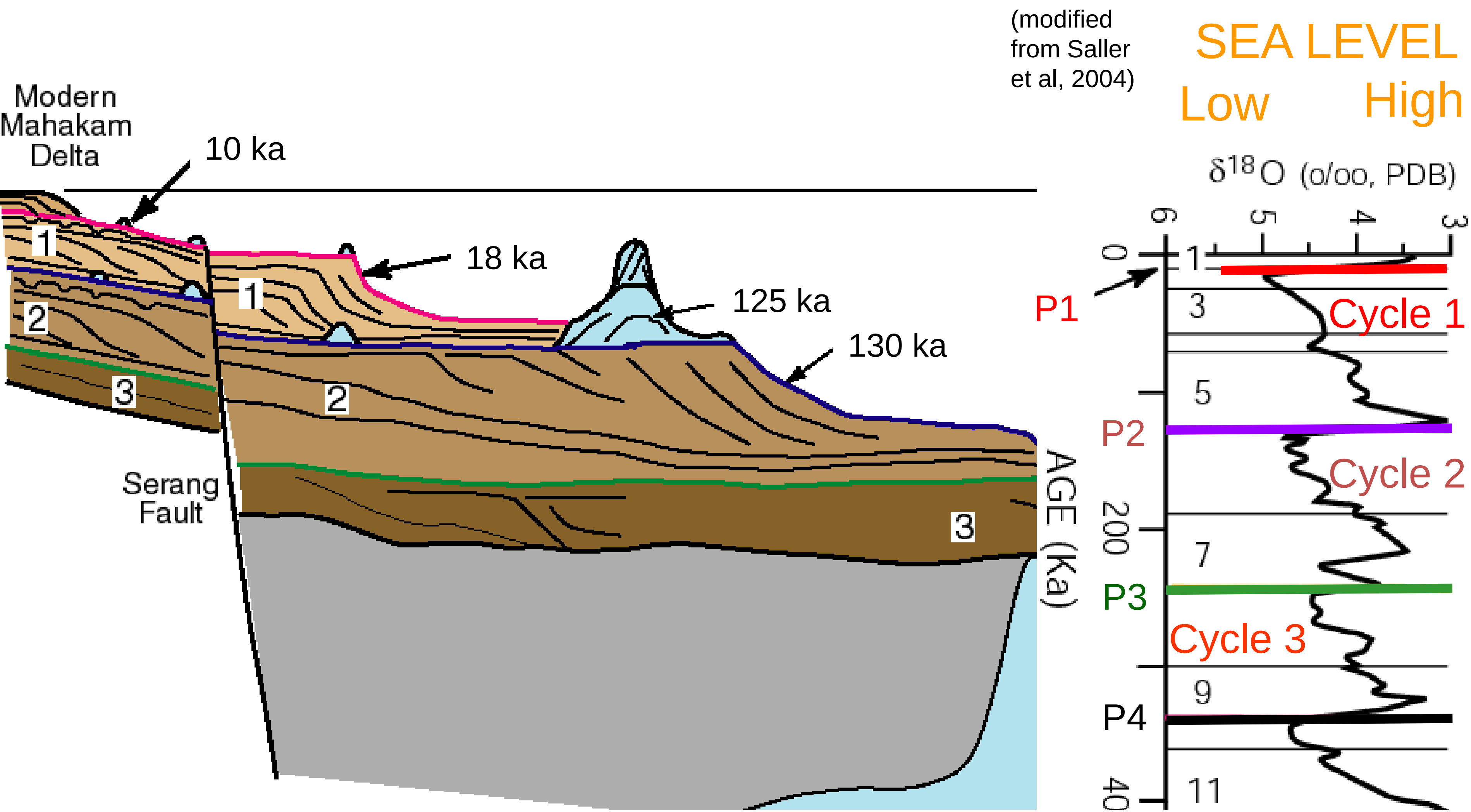


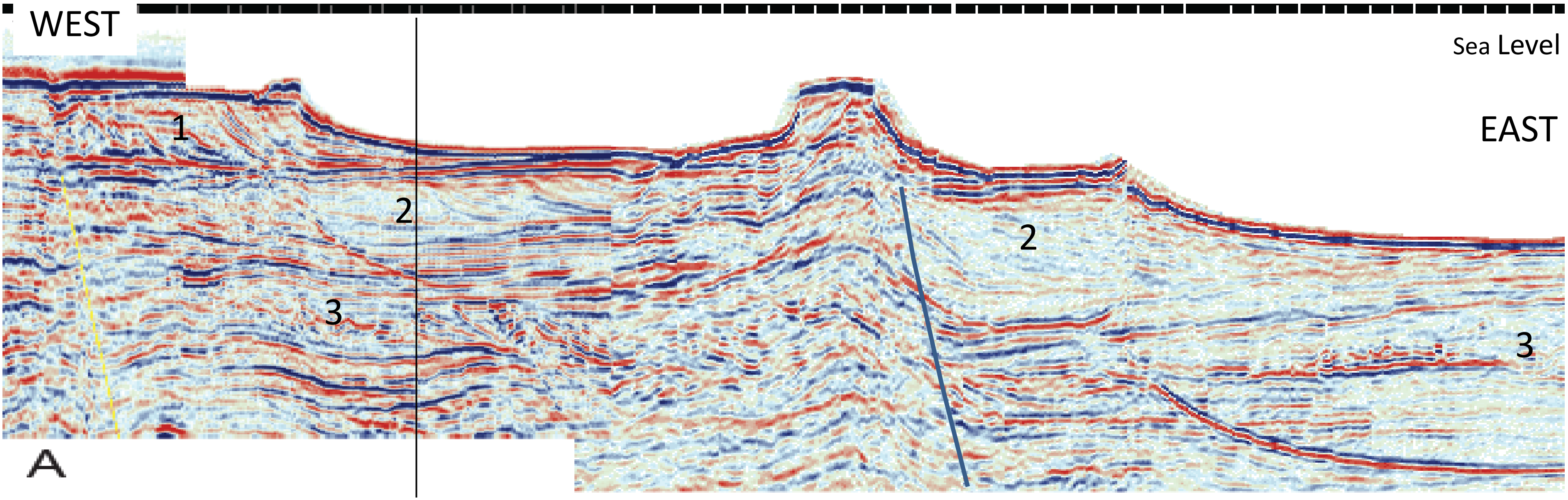
Modified from Saller et al., 2010

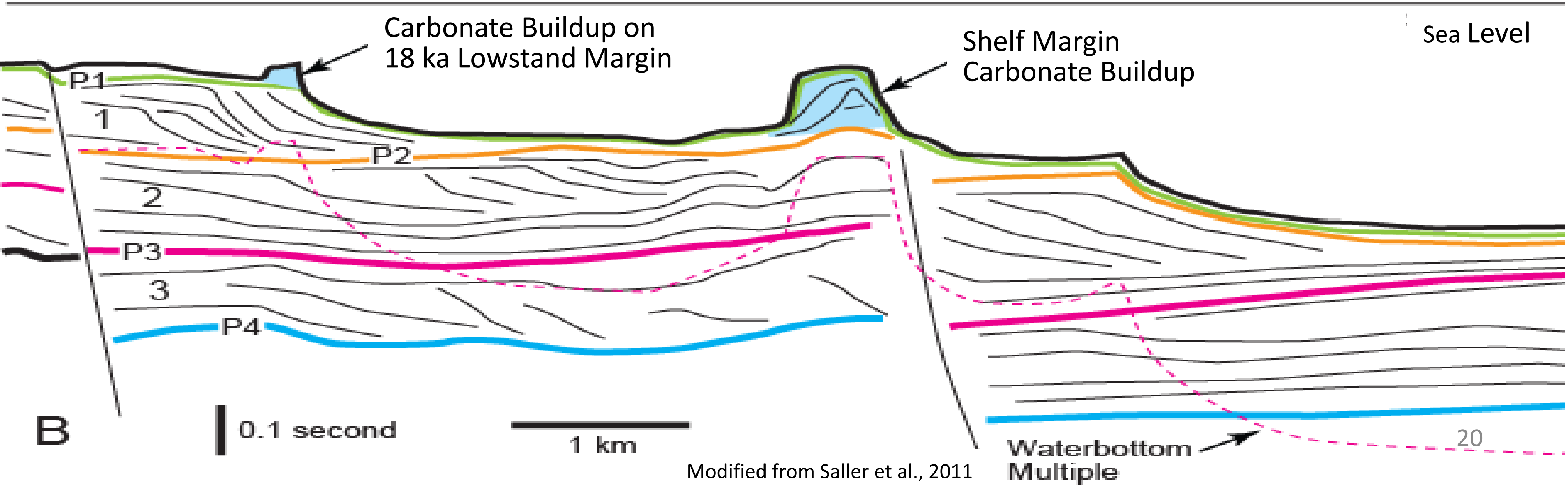
LATE CENOZOIC STRATIGRAPHY - NORTHERN KUTEI BASIN



1. Three Progradational Packages on the Shelf are Correlated to Pleistocene Eustatic Sea-Level Fluctuations
2. Terminal Shelf Margins Generally Stepback Landward
3. Only Progradation 3 Spills over Underlying Shelf Margin

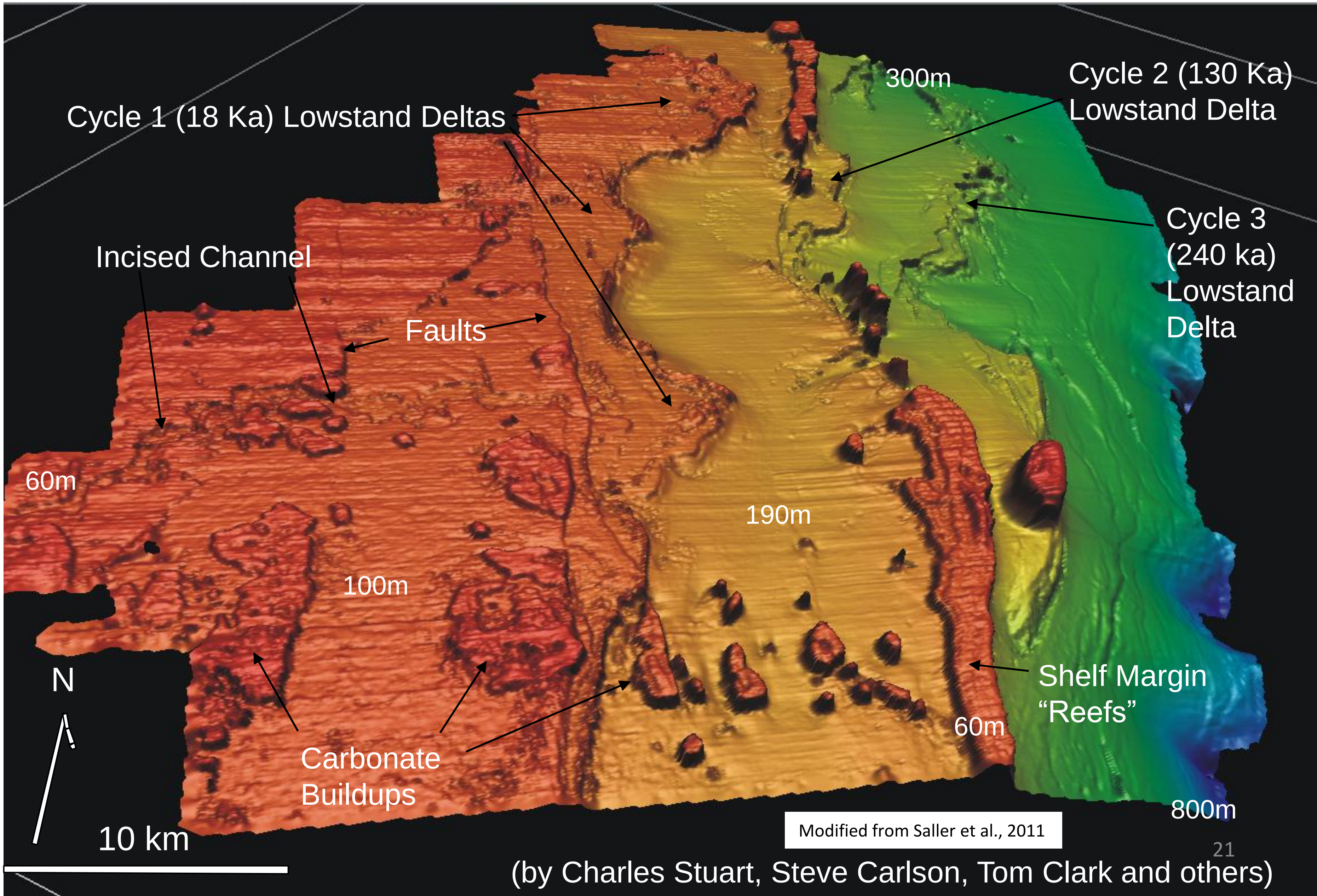
3 Prograding Sequences on the Shelf, with Margins that are generally Backstepping





Modified from Saller et al., 2011

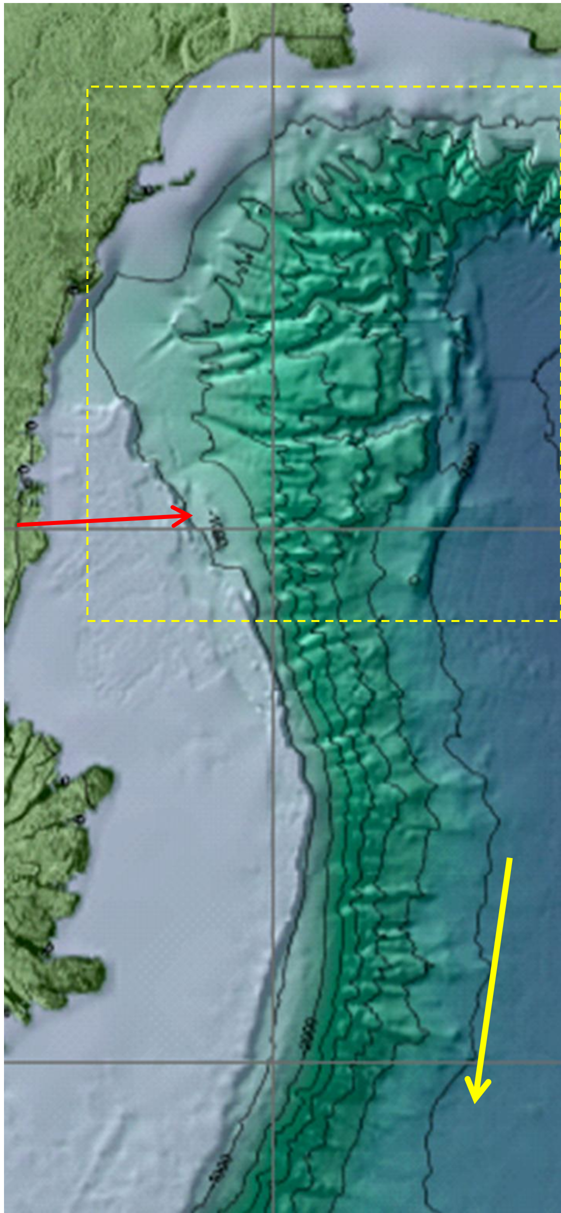
MIDDLE-OUTER SHELF BATHYMETRY SHOWING LOWSTAND & TRANSGRESSIVE ENVIRONMENTS NORTH OF MAHAKAM DELTA



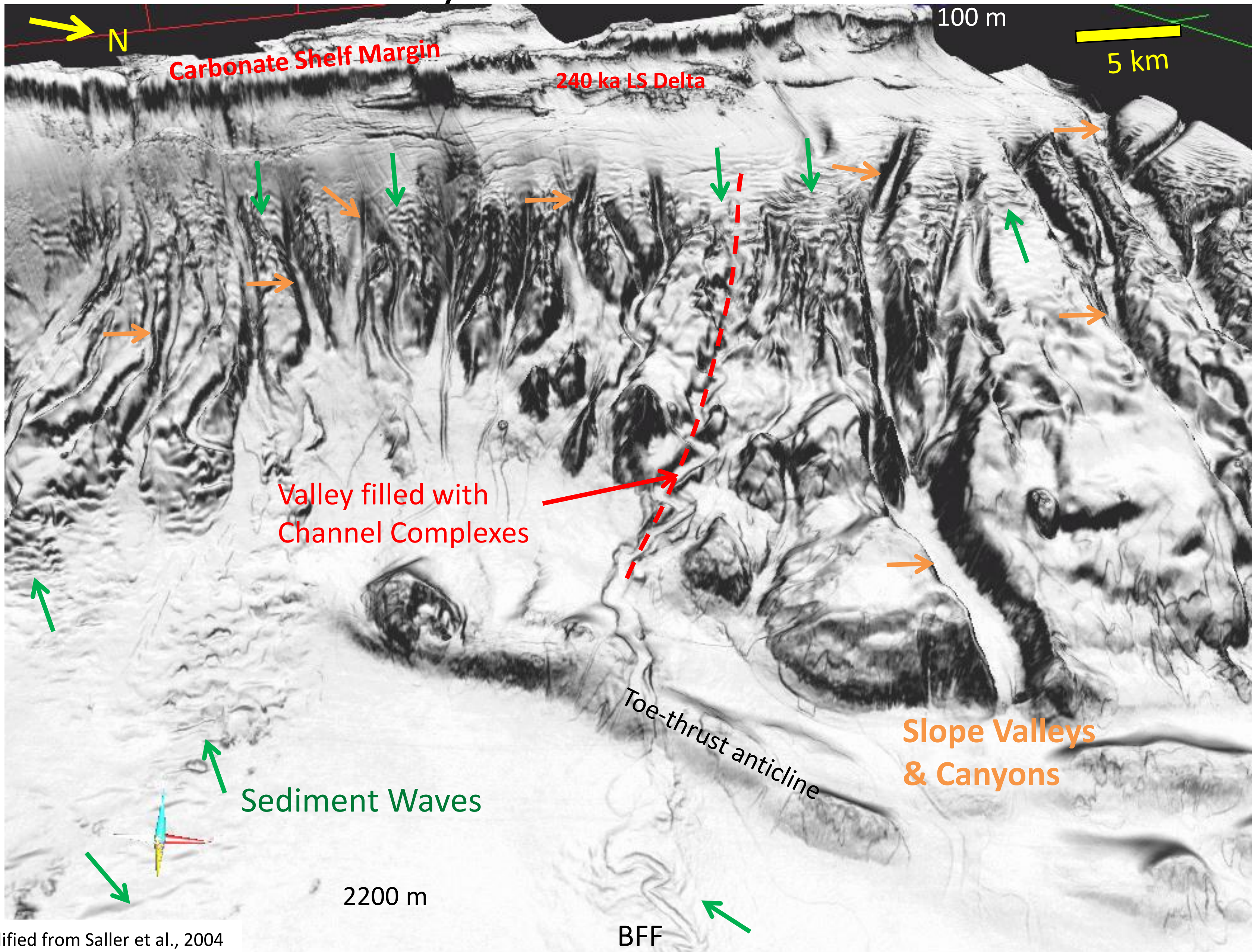
(by Charles Stuart, Steve Carlson, Tom Clark and others)

Northern Slope is dominated by valleys & canyons

- North of the Mahakam Delta, supply of siliciclastic sediment during the Pleistocene was small, due to prevailing southward current
- Late Pleistocene rivers and deltas were generally not present on the northern outer shelf, including upslope from slope valleys
- Only one distinct lowstand delta was present on the northern shelf margin during the late Pleistocene, and sediments from that lowstand delta filled a pre-existing slope valley complex & formed a basin floor fan
- Except for that basin-floor fan, strata on the northern basin floor have no sand-rich channels or fans, but contain broad areas of chaotic reflectors interpreted as mass-transport complexes
- This suggests that slope valleys and canyons formed by mass failures, not by erosion associated with turbidite sands from rivers or deltas

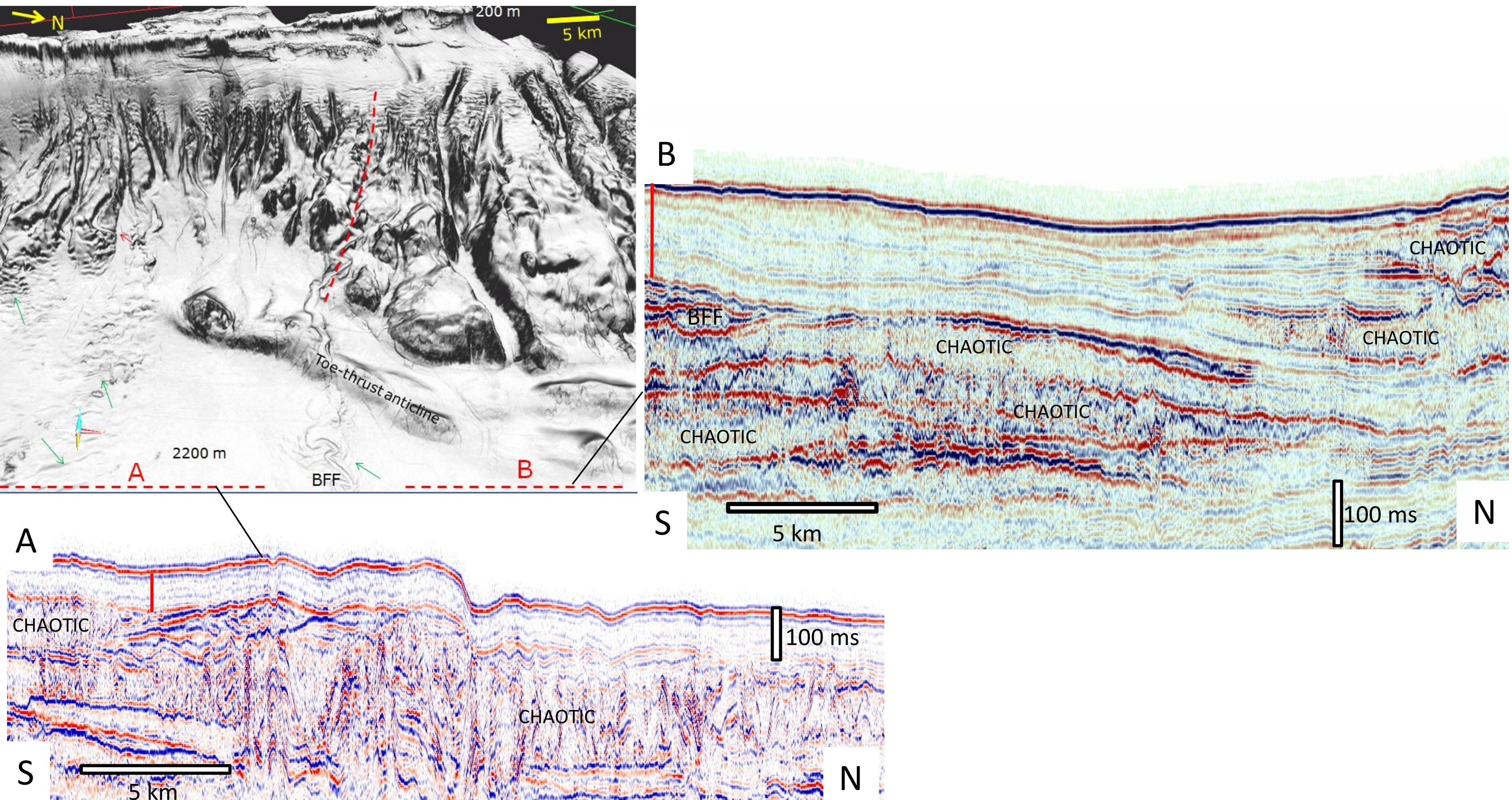


Northern Slope Dominated by Slope Valleys, Canyons & Sediment Waves



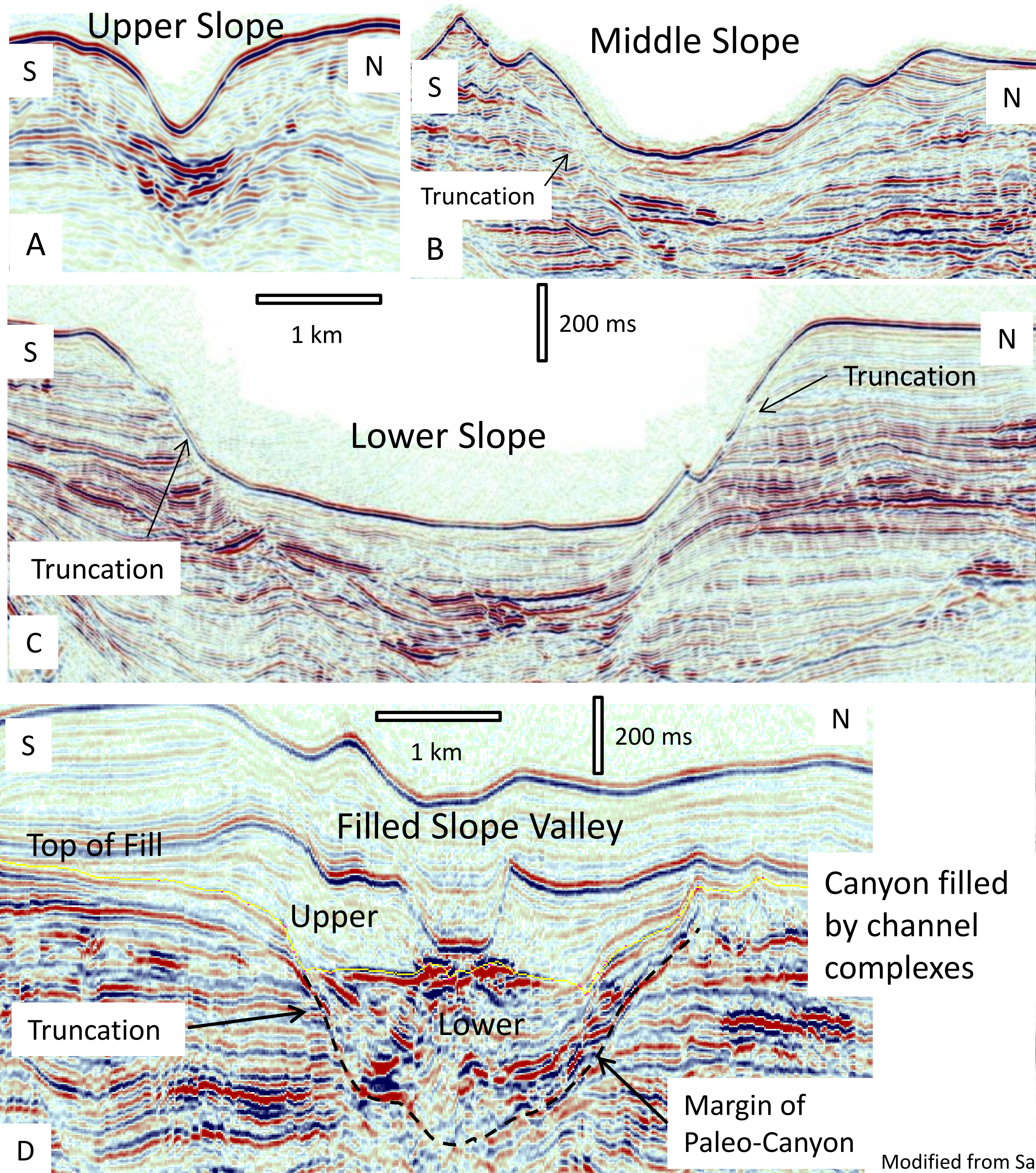
Modified from Saller et al., 2004

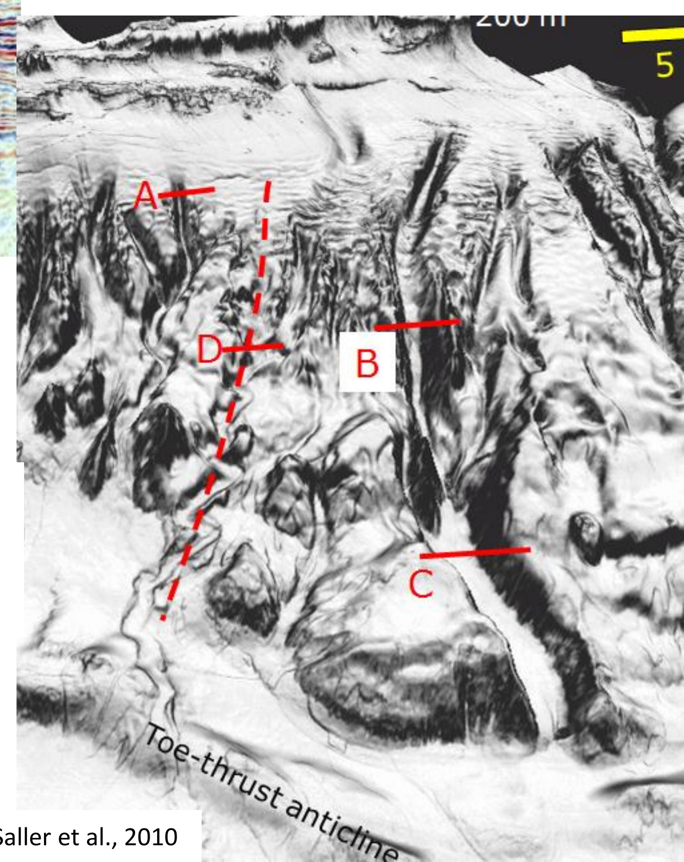
Chaotic intervals are common on the basin floor adjacent to the slope & are interpreted as mass transport complexes (MTC). MTC's probably formed by slope failure & that slope failure probably created valleys & canyons observed on the slope



Modified from Saller et al., 2010

Slope valleys & canyons form by erosion & levee accretion. They become deeper & wider downslope





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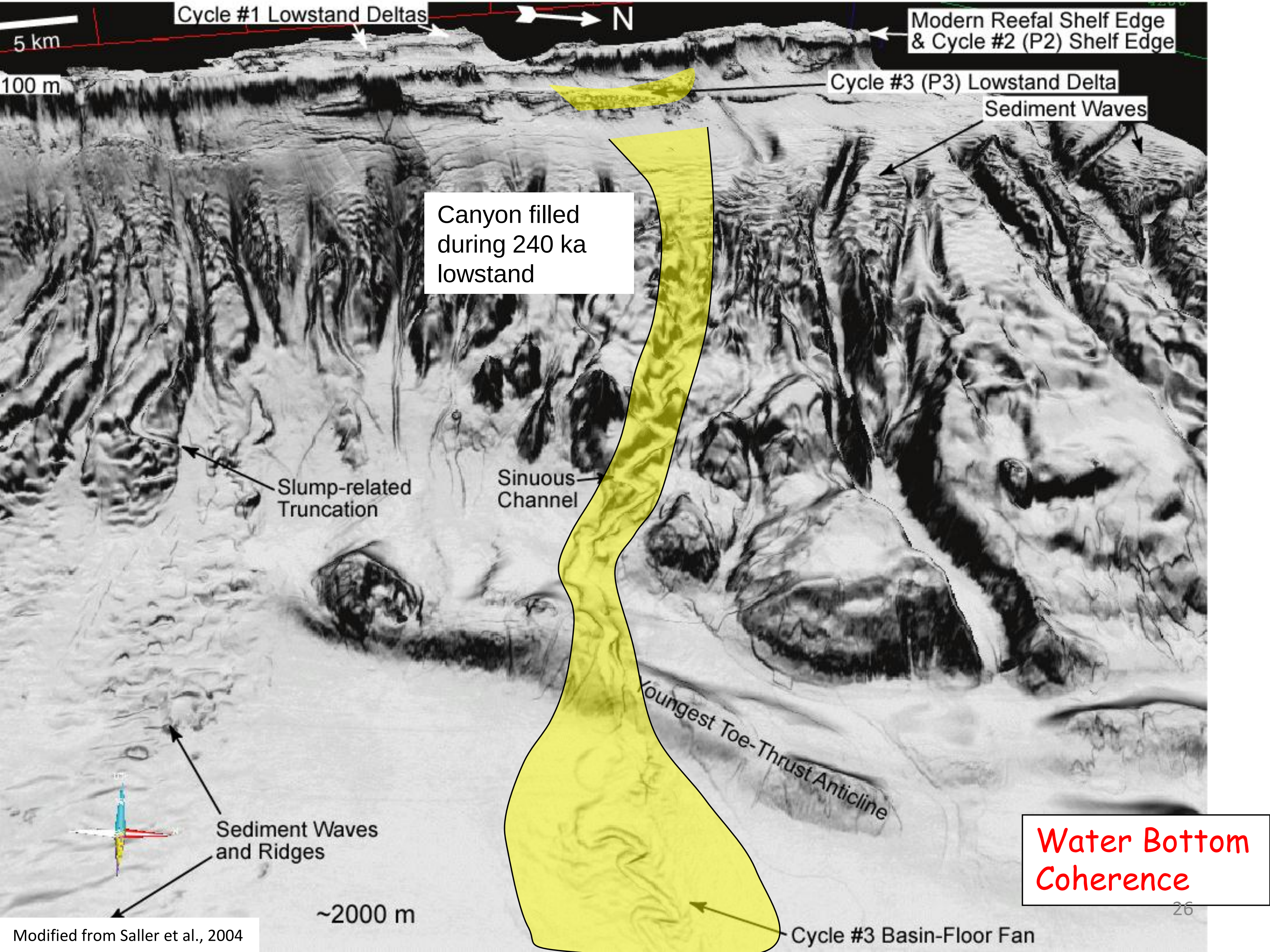

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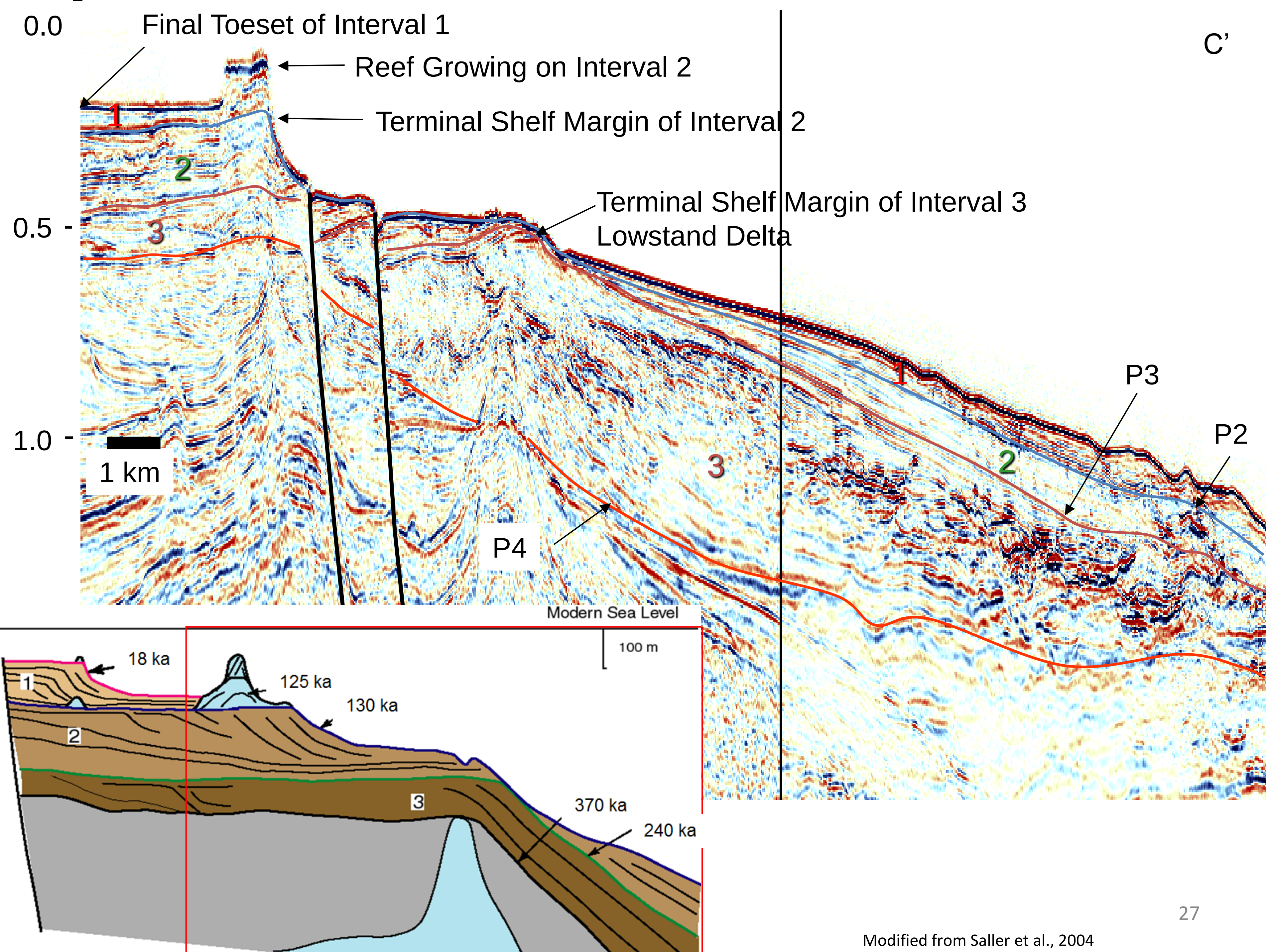

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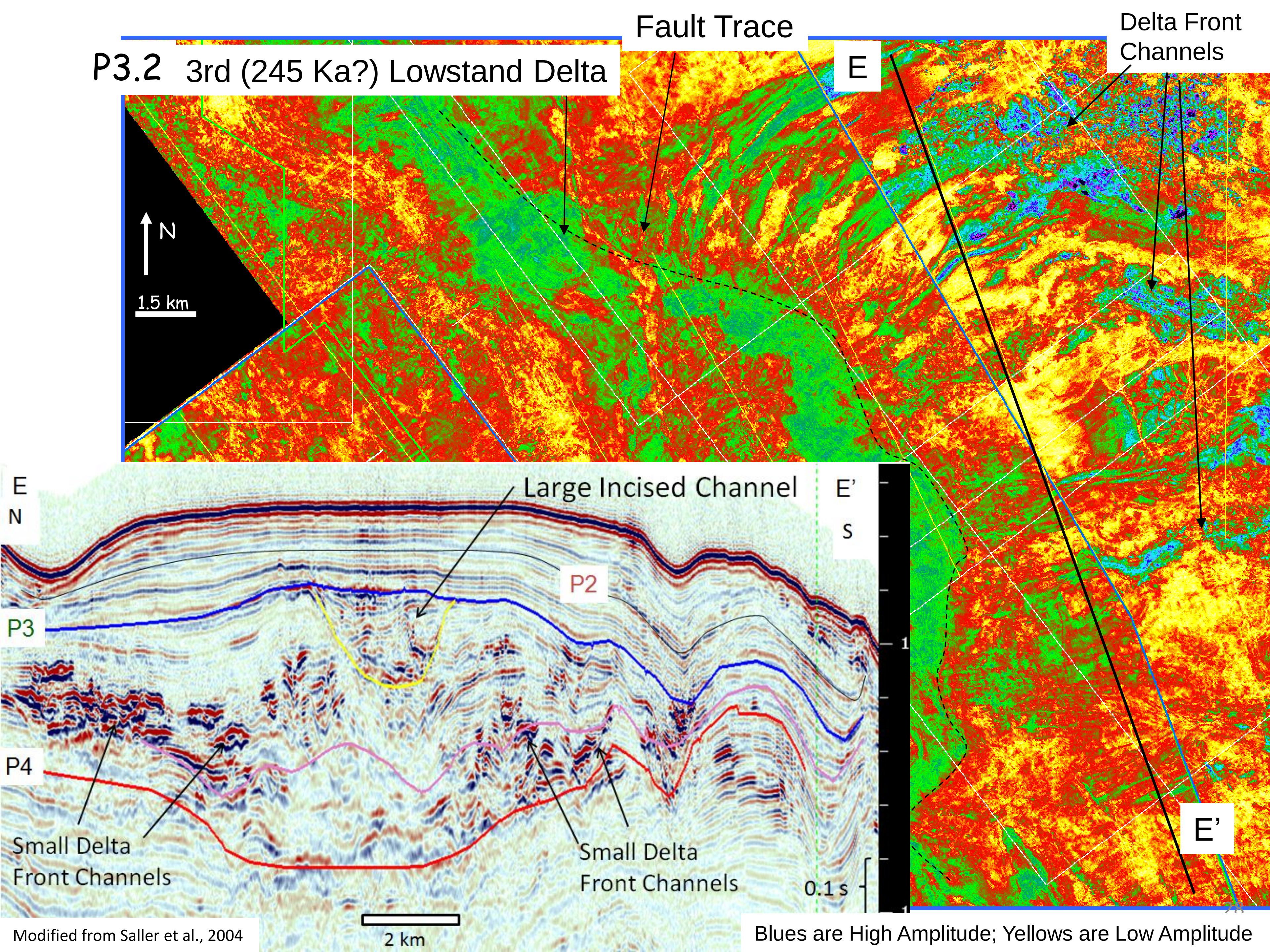
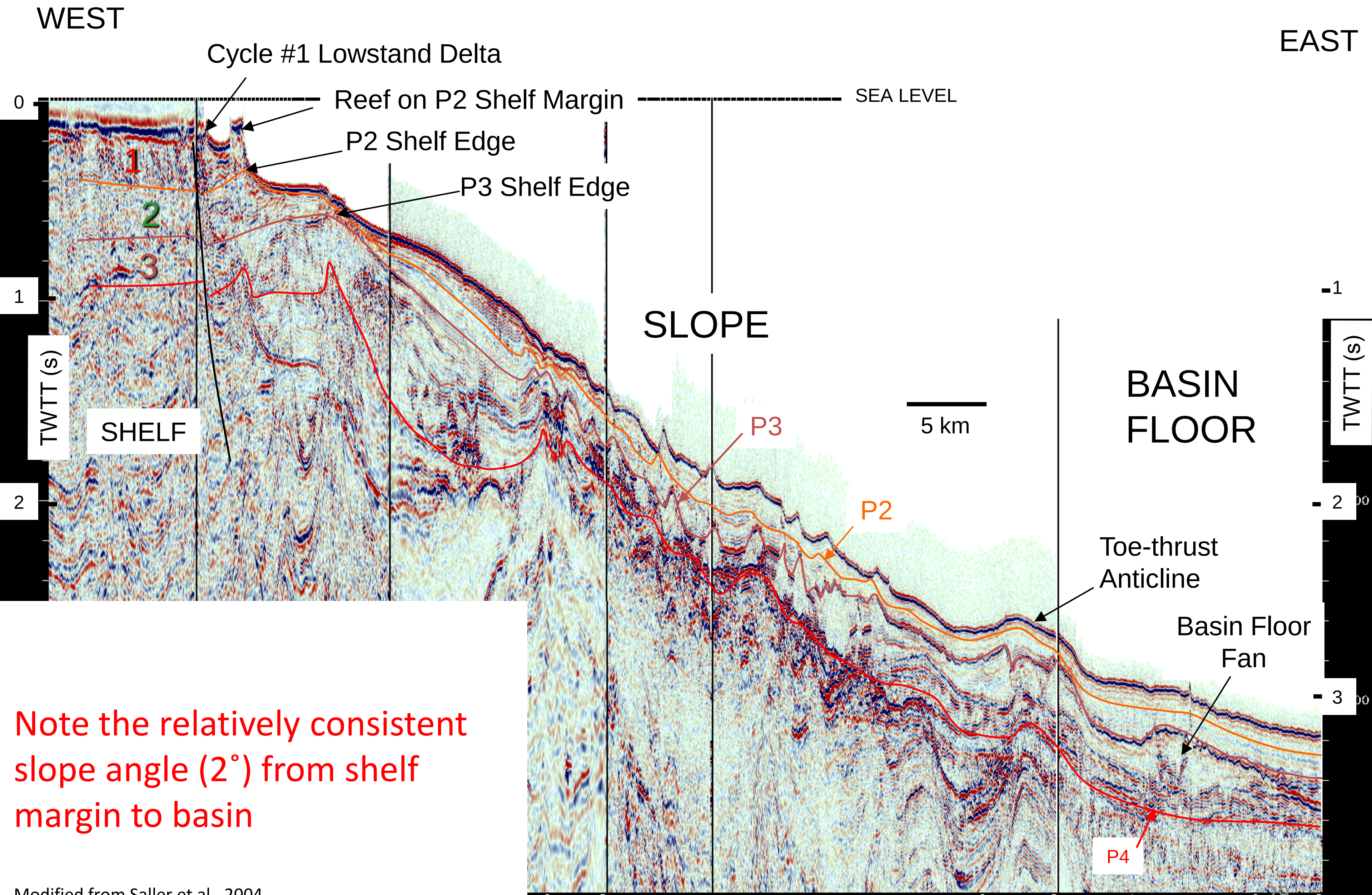

P3.2
3rd (245 Ka?) Lowstand Delta
Fault Trace
E
Delta Front Channels
N
1.5 km
E
N
Large Incised Channel
E'
S
P2
P3
1
P4
Small Delta Front Channels
Small Delta Front Channels
0.1 s
E'
2 km
Modified from Saller et al., 2004
Blues are High Amplitude; Yellows are Low Amplitude

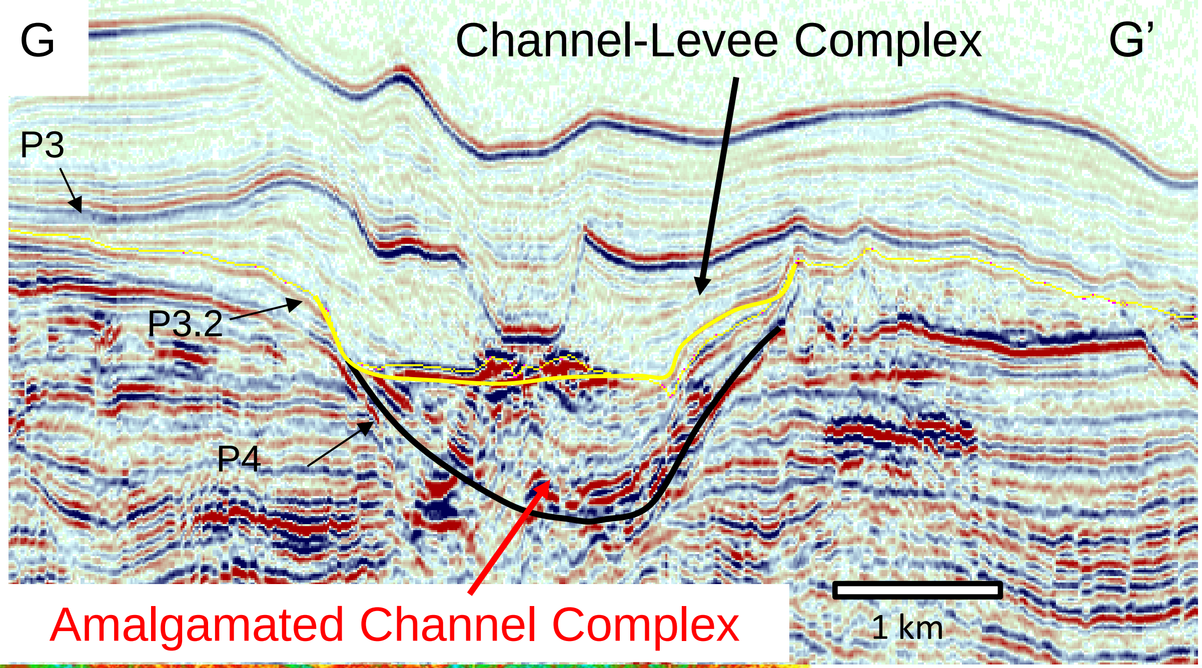
Shelf to Basin Profile



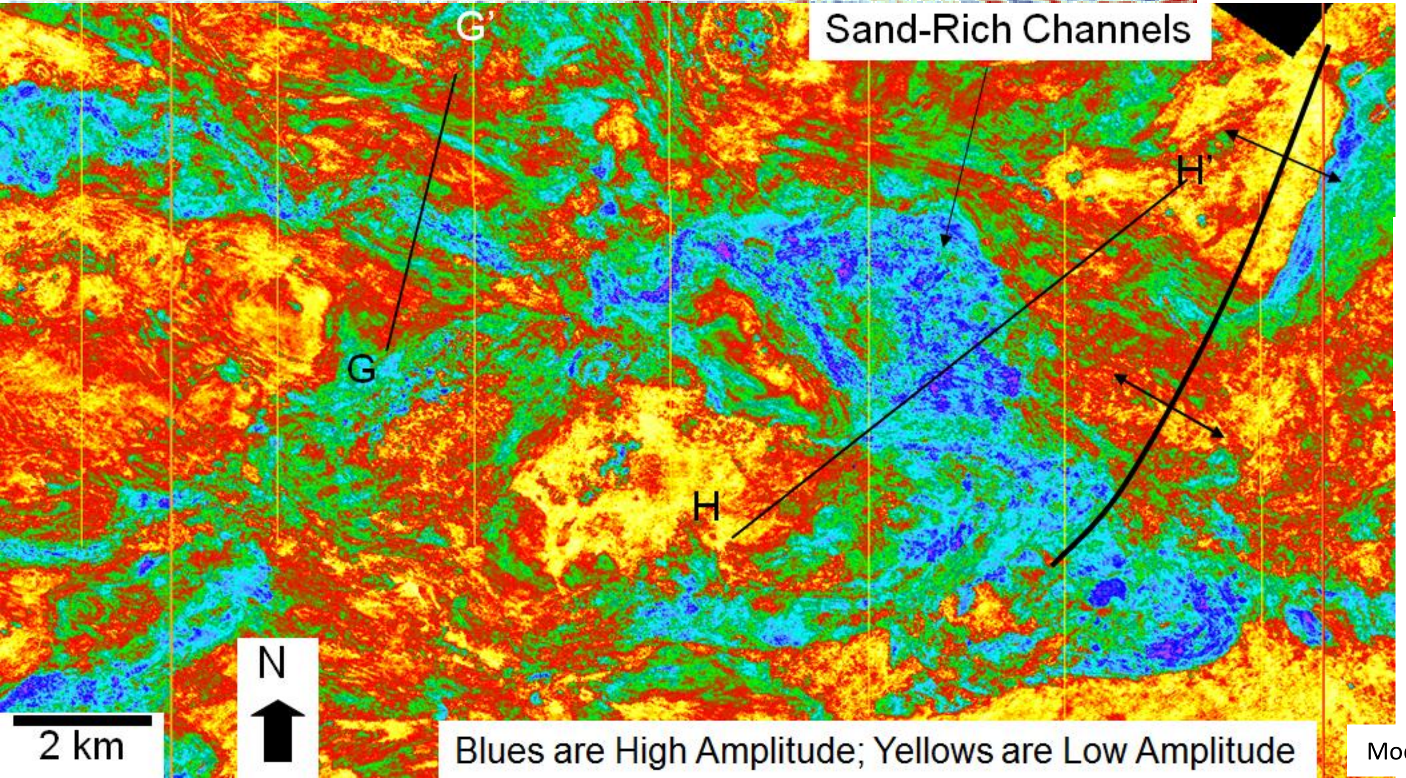
Note the relatively consistent slope angle (2˚) from shelf margin to basin

Modified from Saller et al., 2004

240-250 ka Slope Valley Fill on the Middle Slope has 2 parts



- Lower: High Amplitude Fill, Onlapping, Flat Top (Amalgamated Channel Complex)
- Upper: Low Amplitude, Channel-Levee

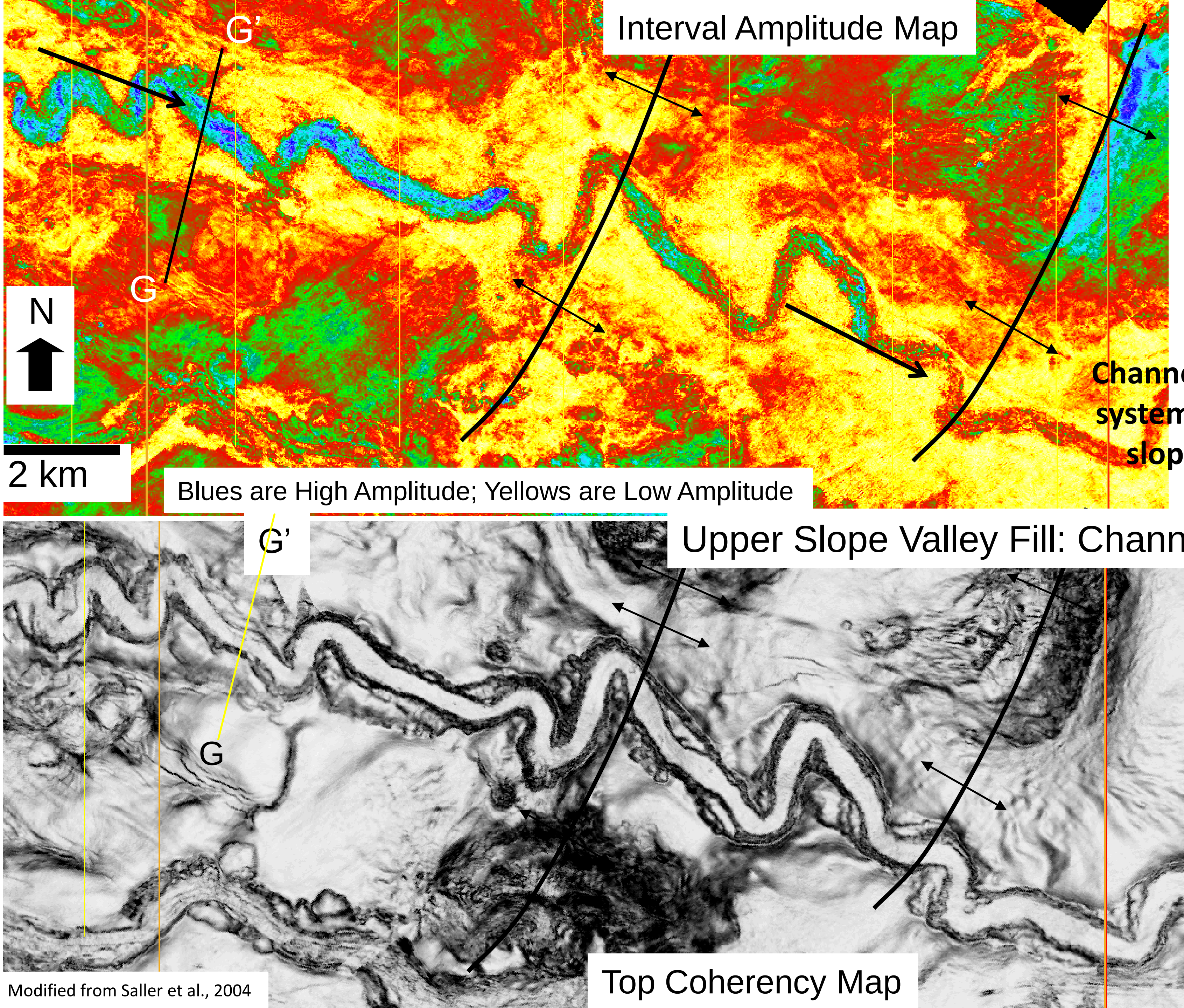


Slope- P4 to P3.2: Early 240 ka Lowstand Amplitude Map

East Basinward

Modified from Saller et al., 2004

Upper Slope Valley Fill: Channel-levee



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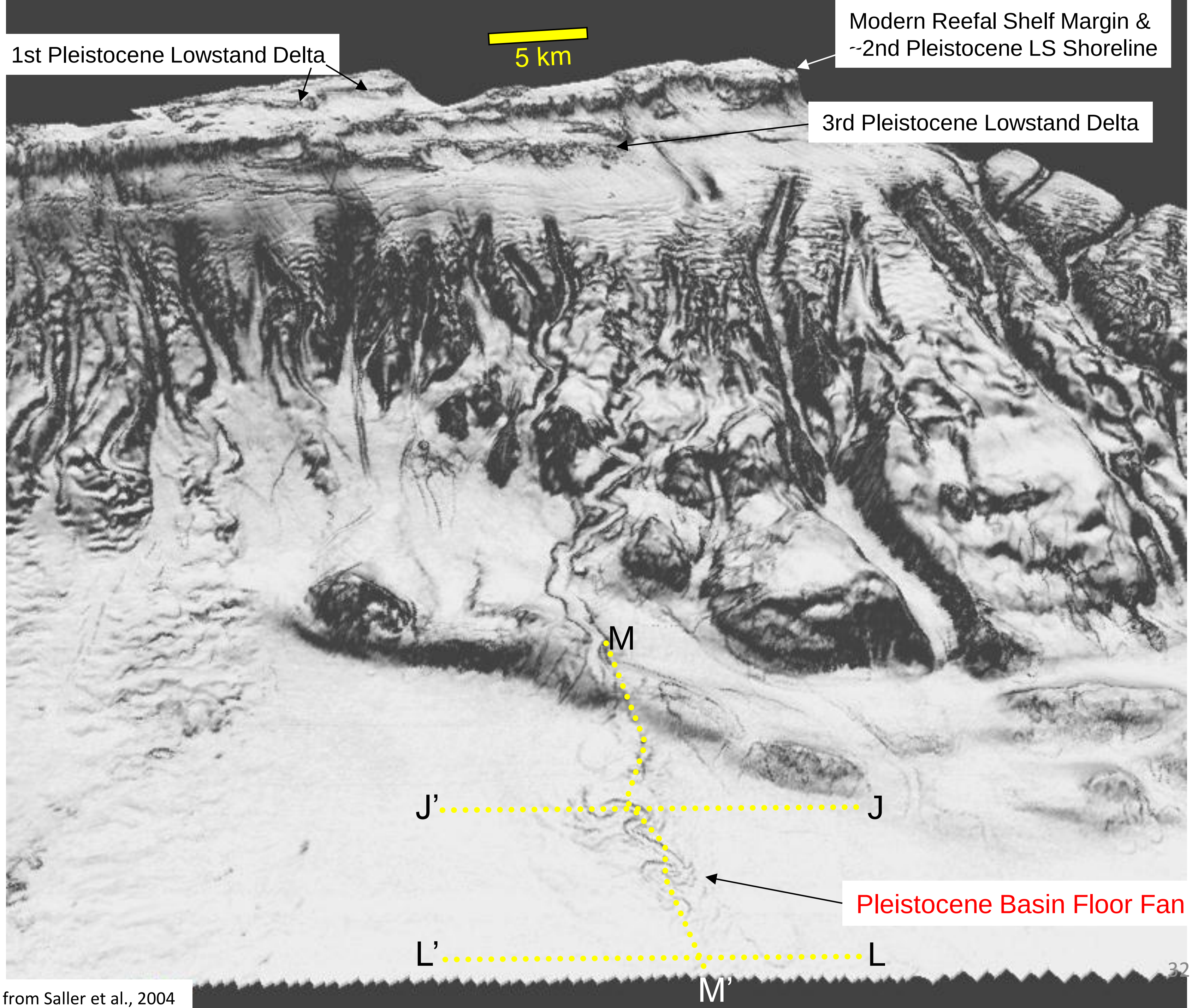
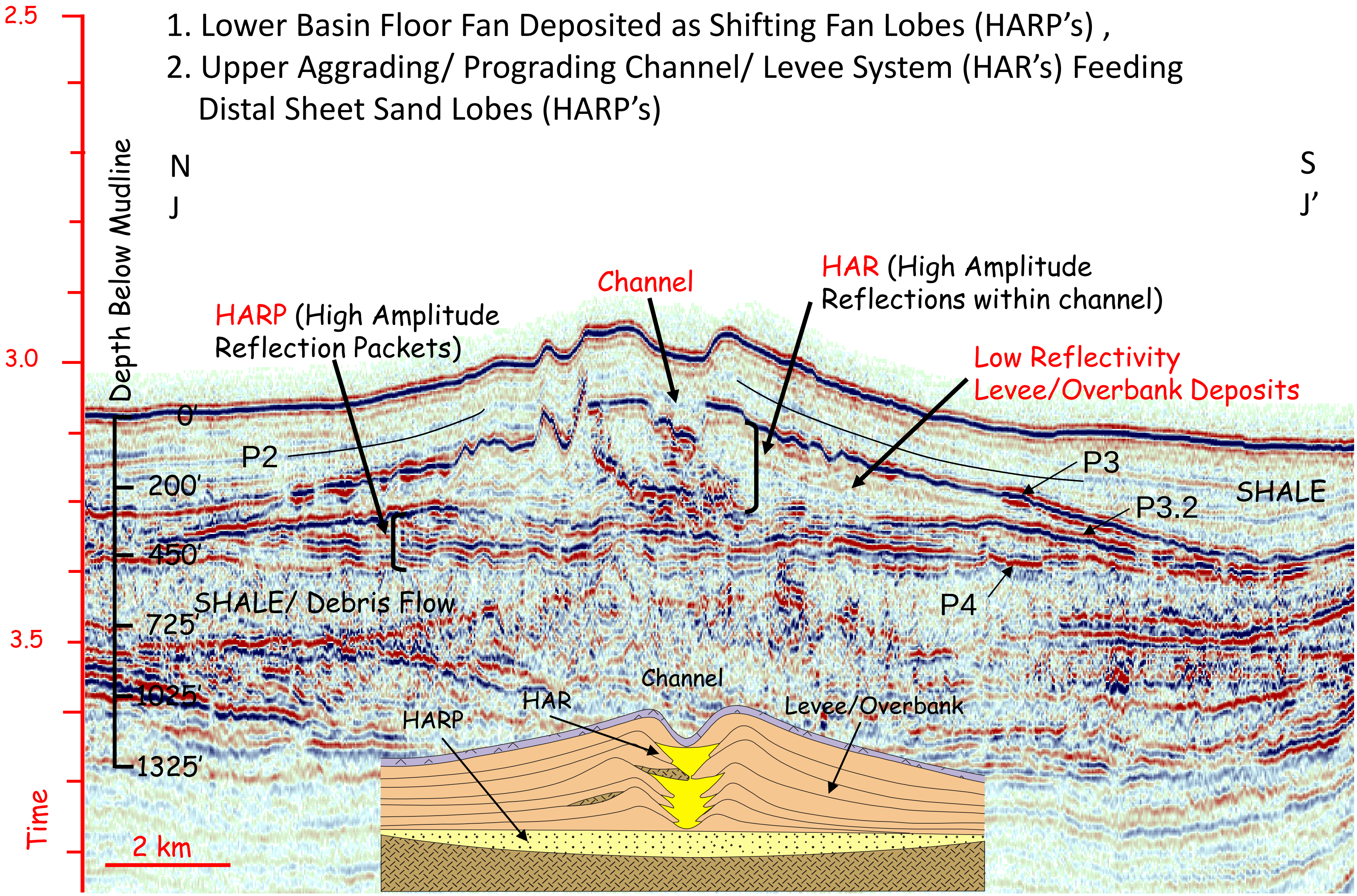


Modified from Saller et al., 2004

Strike Line showing 2 Main Parts of the Pleistocene Kutei Fan

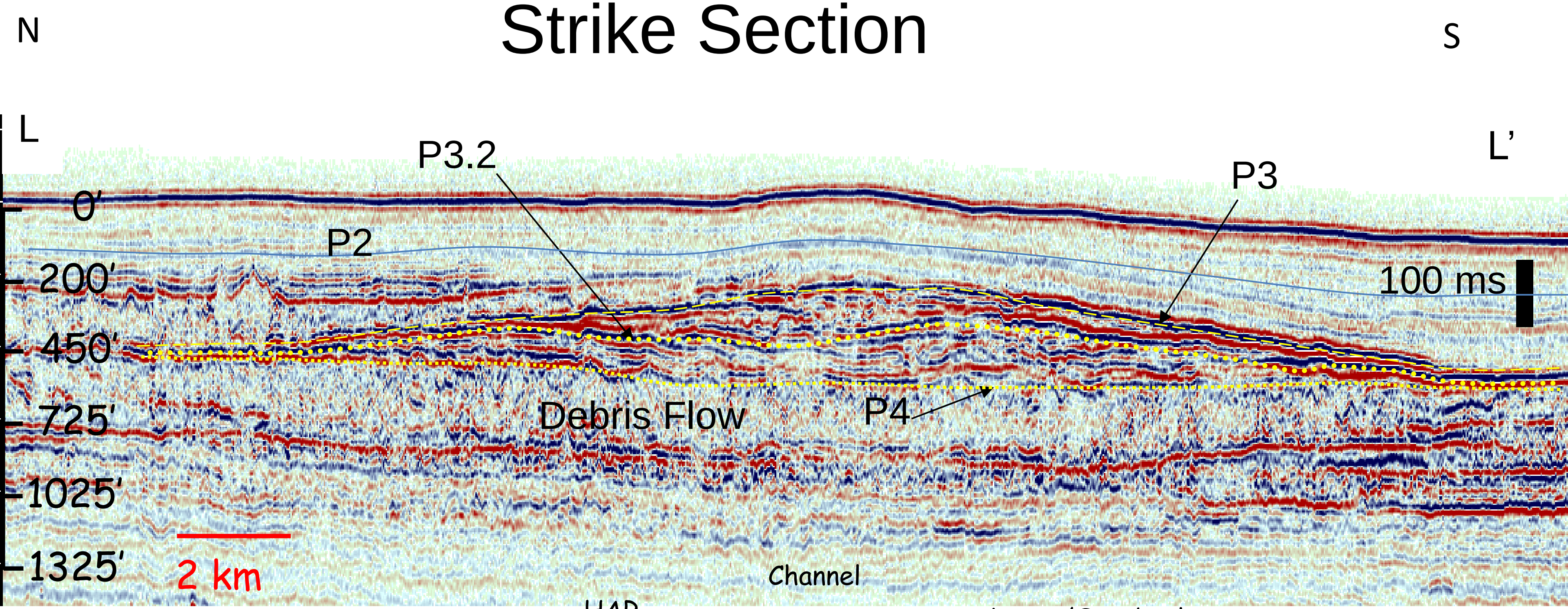
1. Lower Basin Floor Fan Deposited as Shifting Fan Lobes (HARP's) ,
2. Upper Aggrading/ Prograding Channel/ Levee System (HAR's) Feeding Distal Sheet Sand Lobes (HARP's)

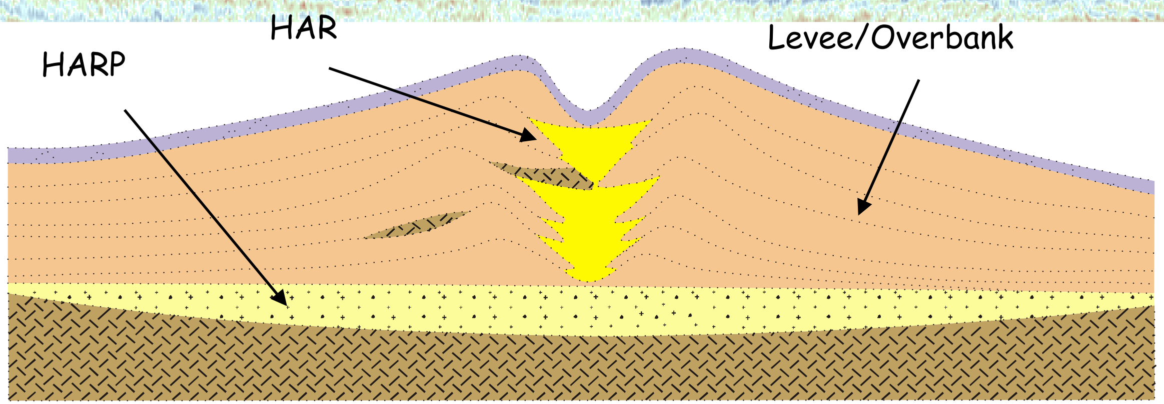


Modified from Saller et al., 2004

DISTAL/ OUTER BASIN FLOOR FAN

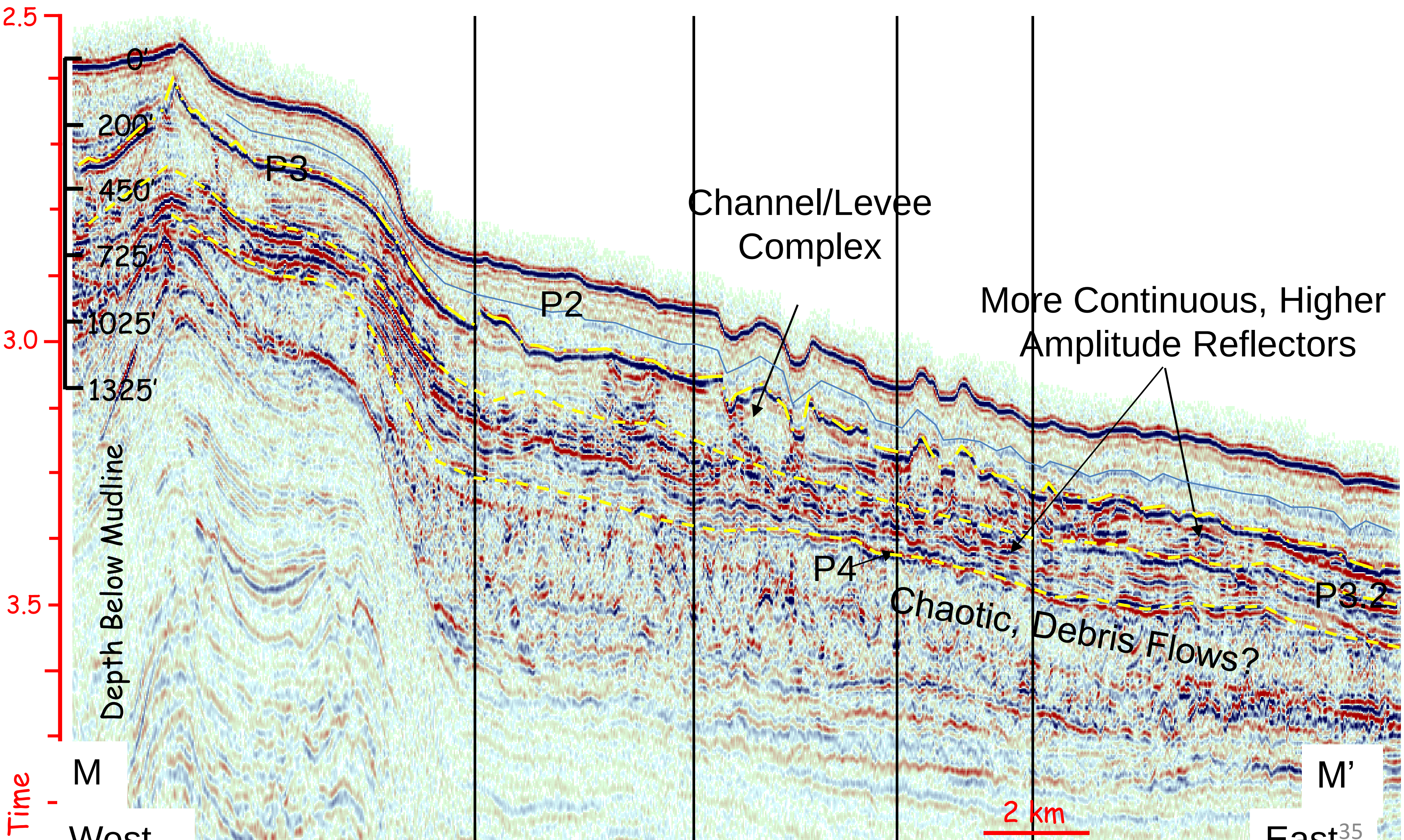
Strike Section





Modified from Saller et al., 2004

Upper Aggrading/Prograding Channel/ Levee System Feeding Distal High Amplitude Lobes on the Outermost Fan

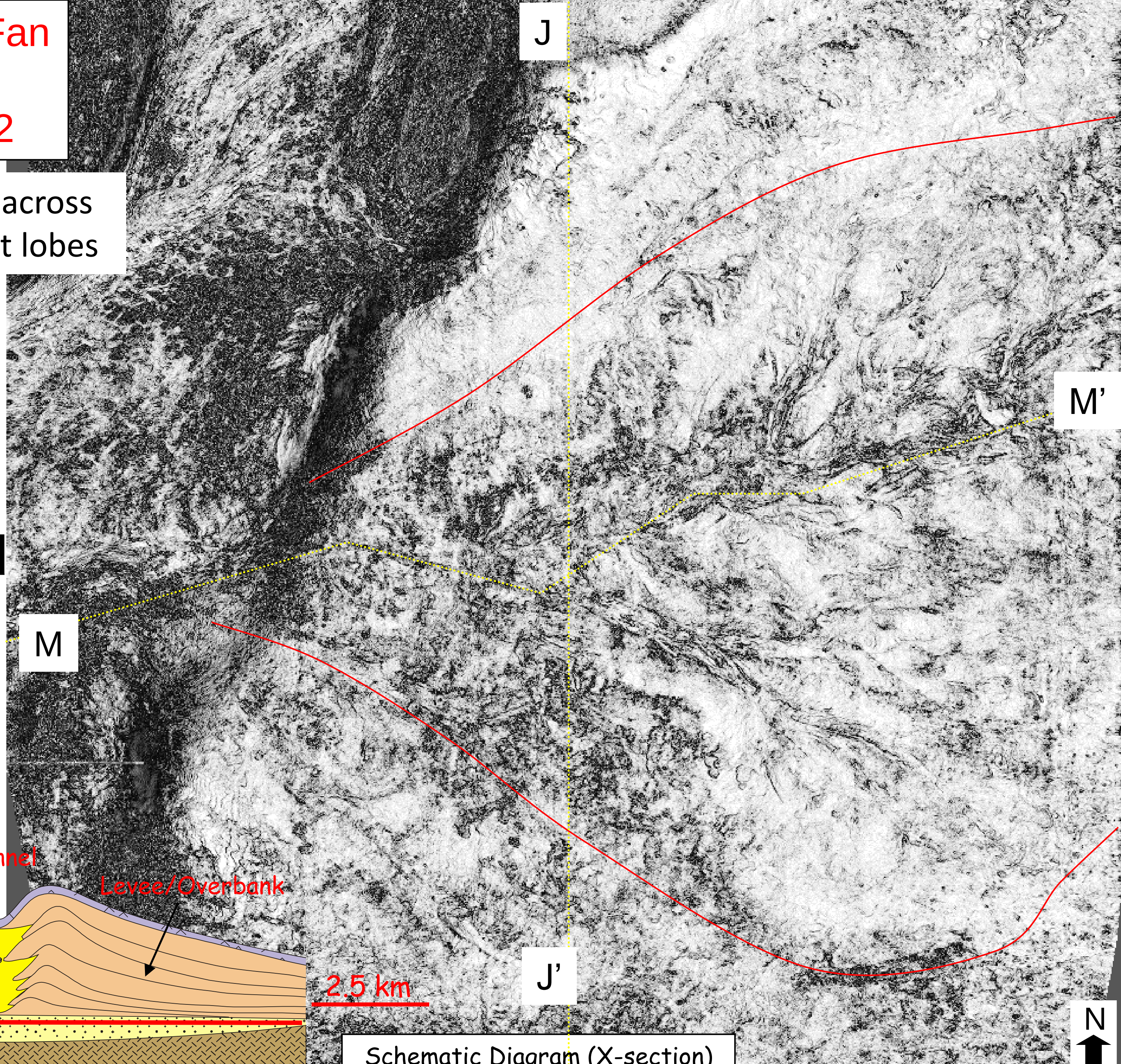


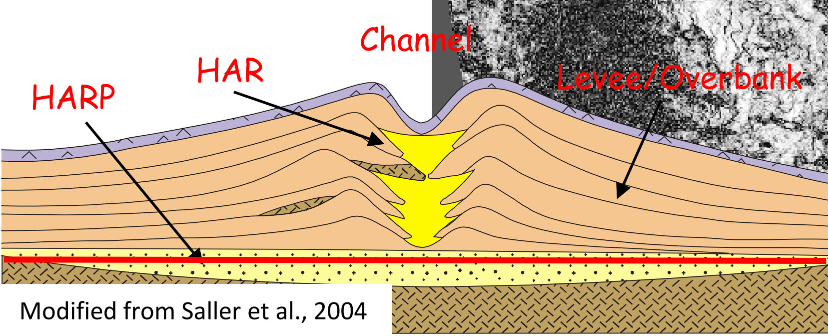
Modified from Saller et al., 2004

Early Lowstand Fan Coherence Slice 16 ms below P3.2

Lower Fan is ~20 km across & contains 14 distinct lobes

Lower Unconfined to Slightly Channelized Basin-Floor Fan



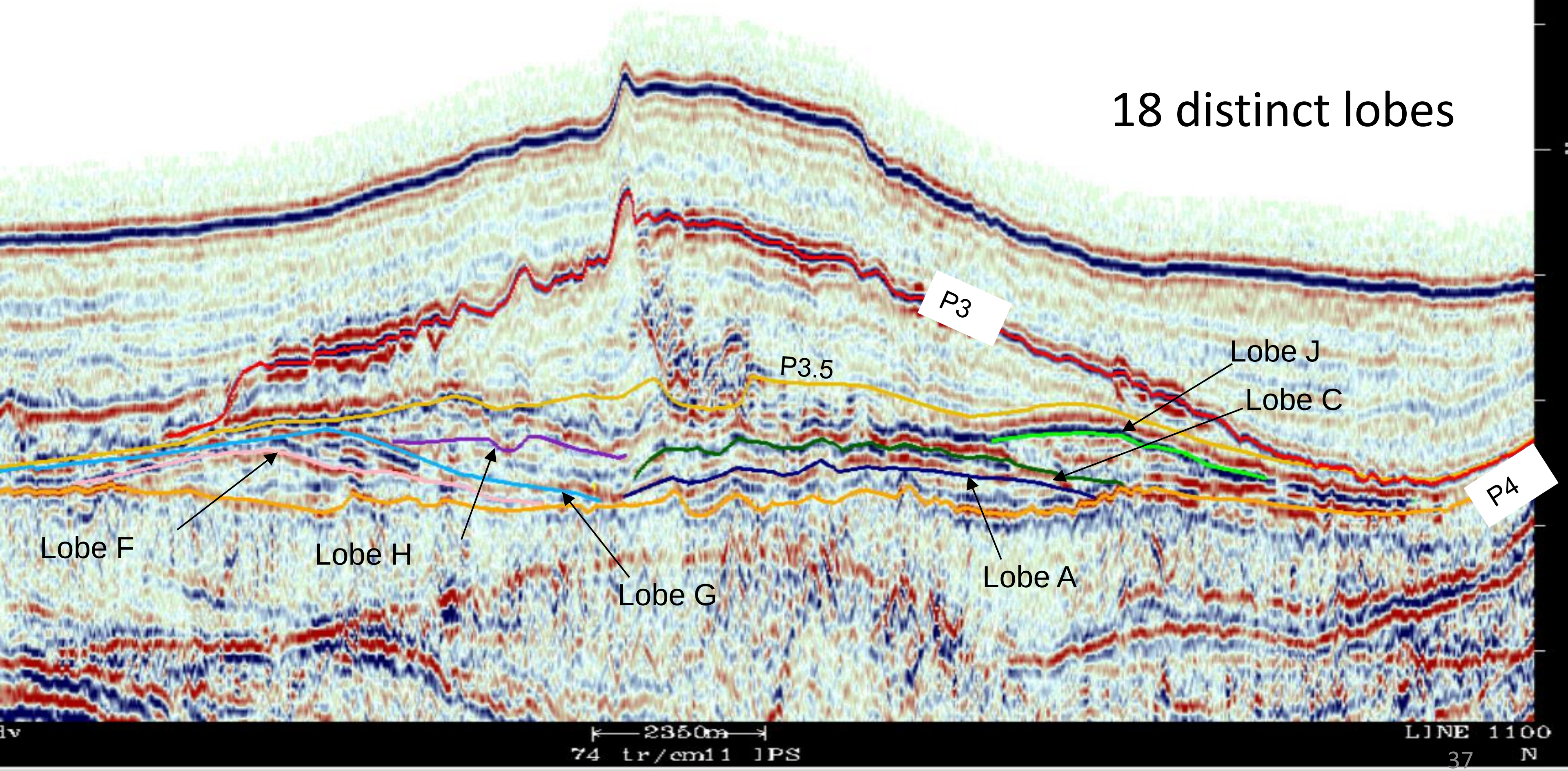


Modified from Saller et al., 2004

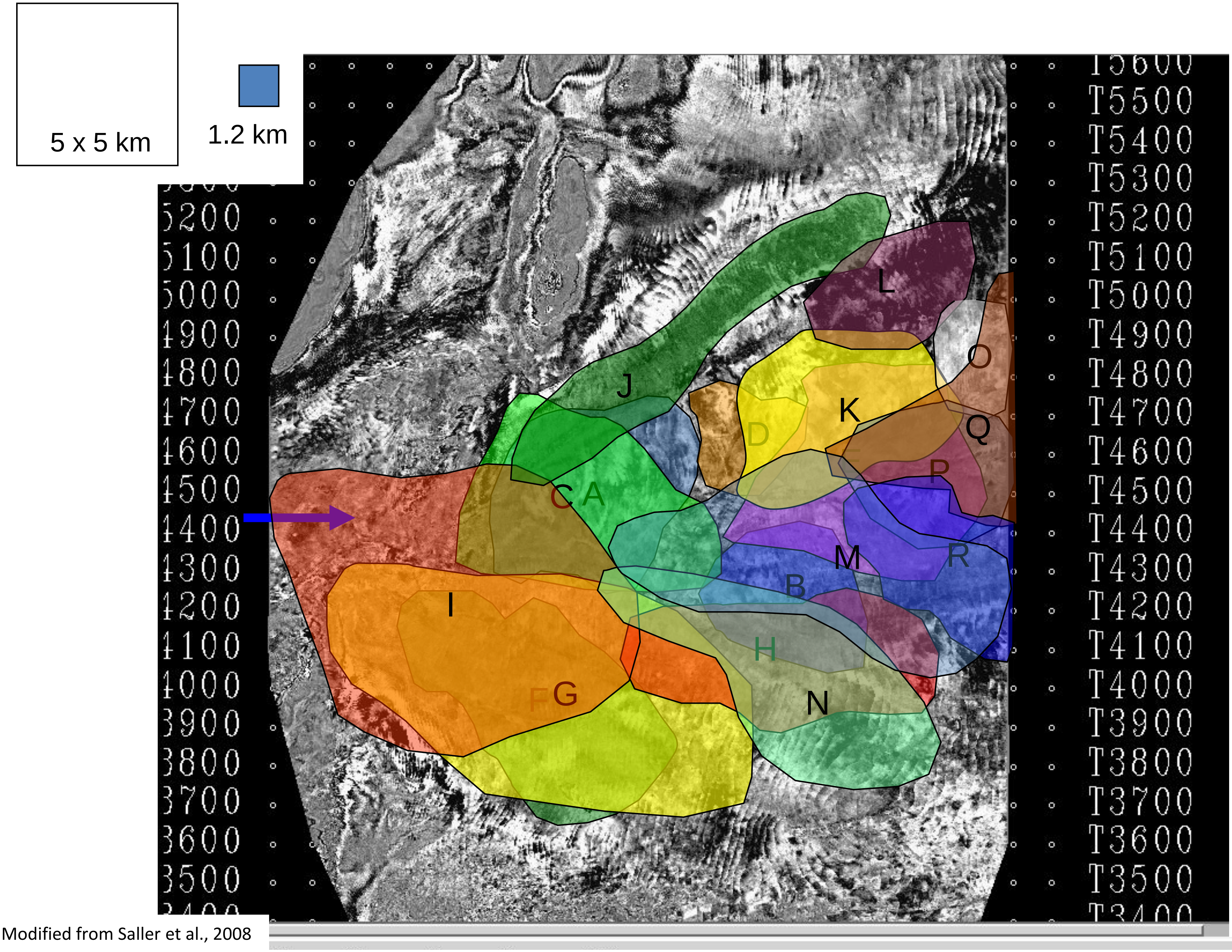
Schematic Diagram (X-section)

WESTERN (UPSLOPE) STRIKE LINE

P3 = Top of Channel-Levee Complex
P3.5 = Top of the Lower Fan Complex
P4 = Base of Fan, Top of Chaotic Debris Flow, Slump Interval



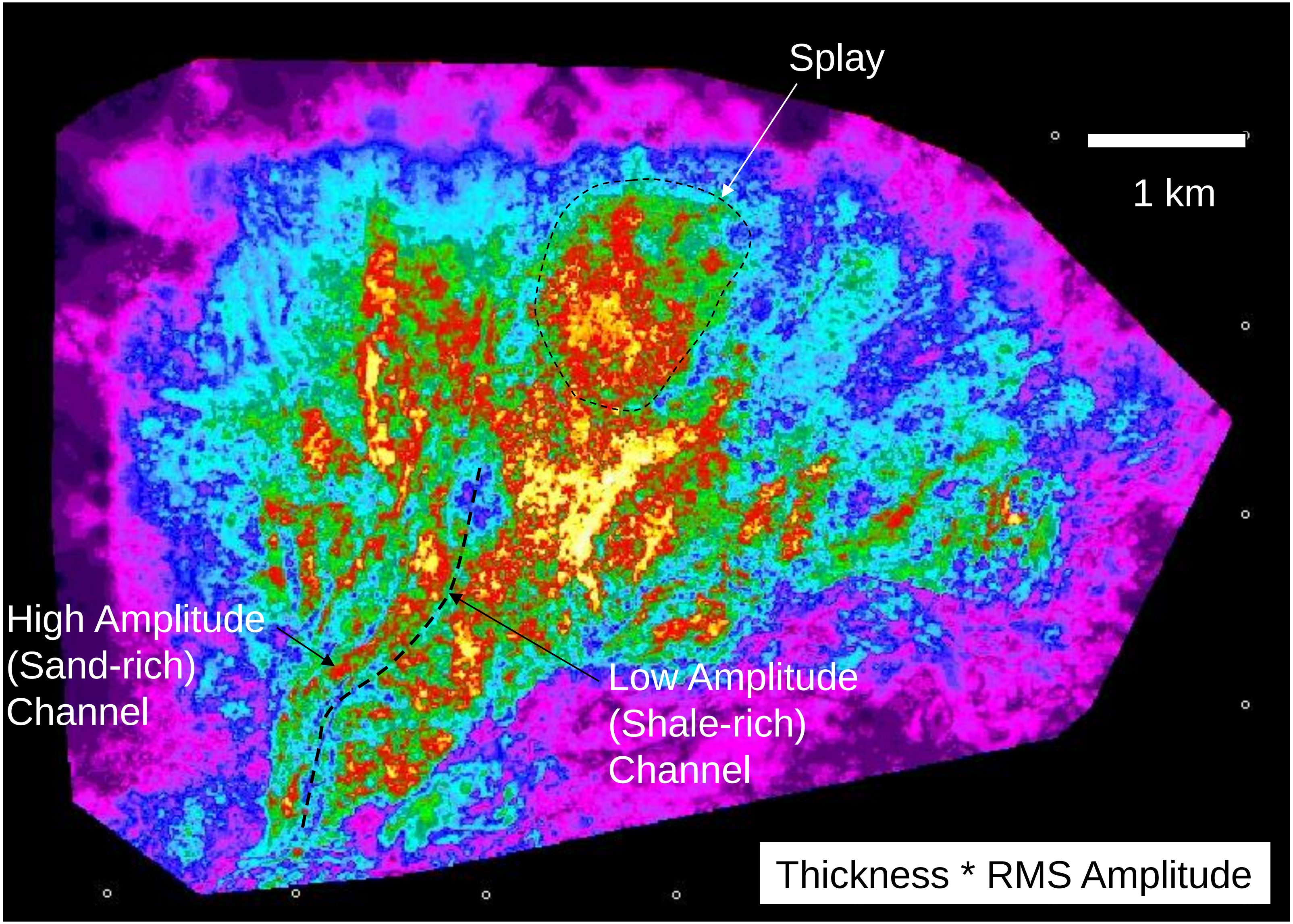
Modified from Saller et al., 2008



Modified from Saller et al., 2008

Amplitude Extraction from halfway from between P3.5 and P4 Horizons

Each Lobe is Unique with Feeder Channels & Broad Splays

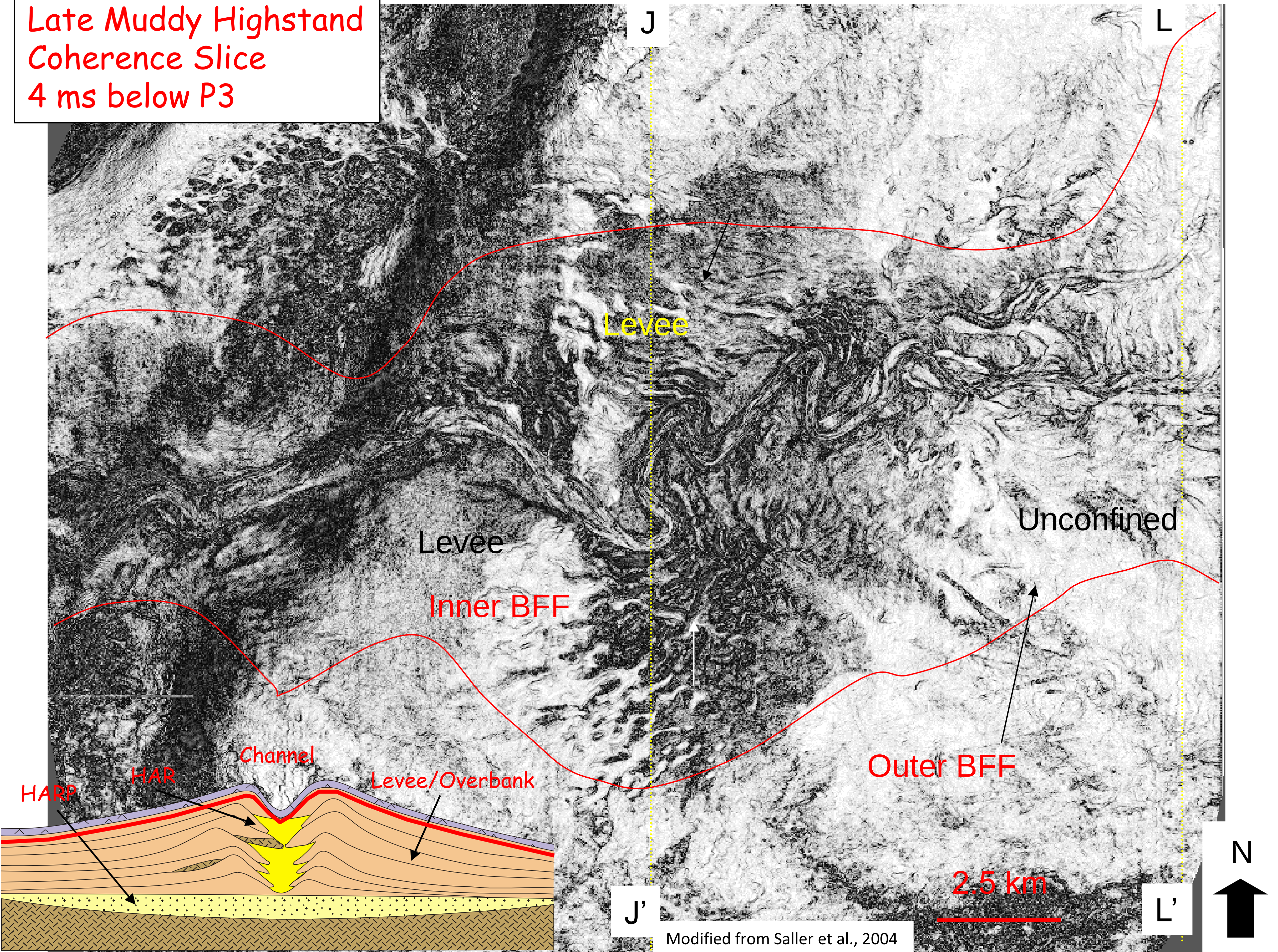


Yellow is thick & high amplitude

LOBE K (10)

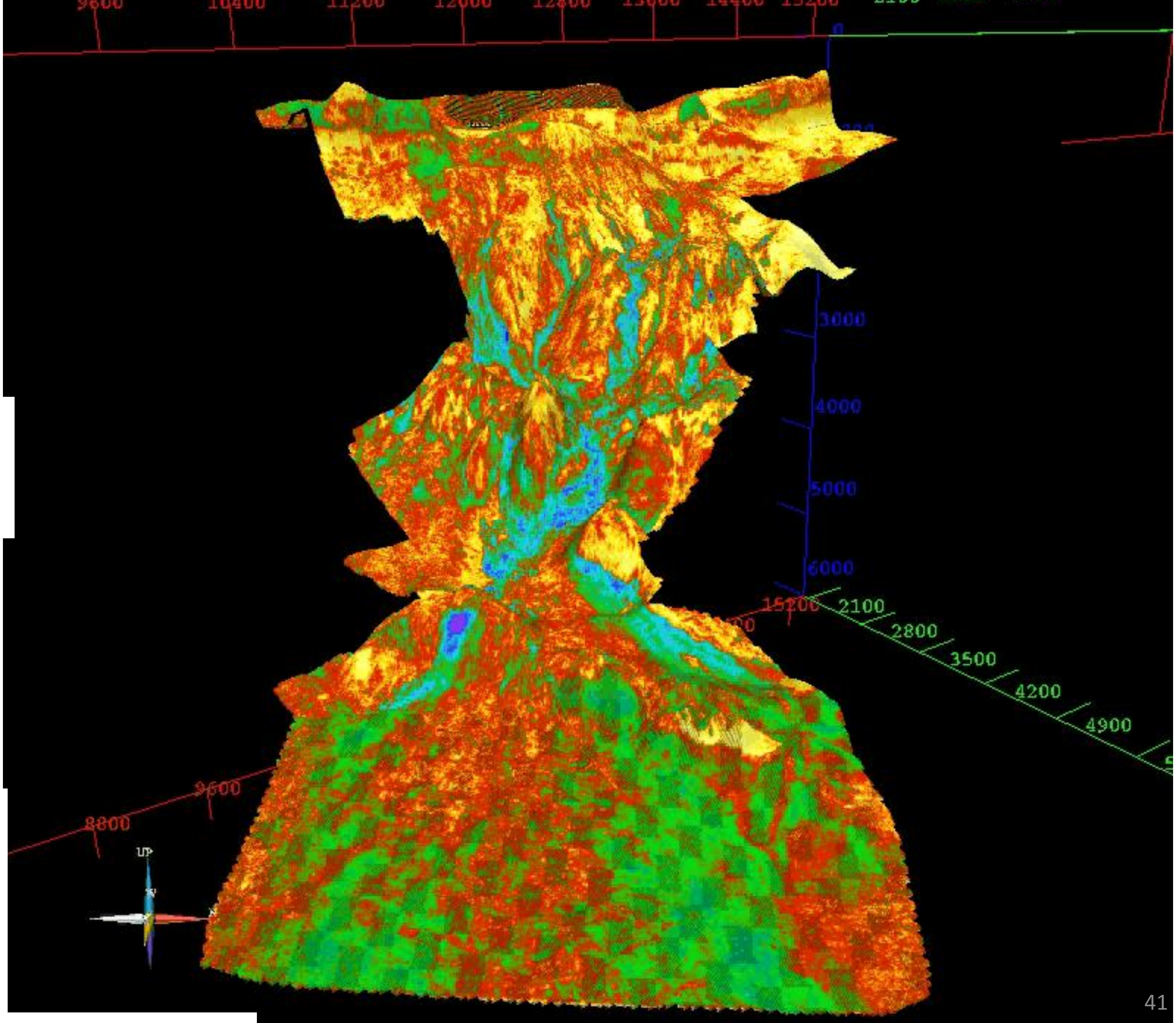
Modified from Saller et al., 2008

Late Muddy Highstand Coherence Slice 4 ms below P3



Modified from Saller et al., 2004

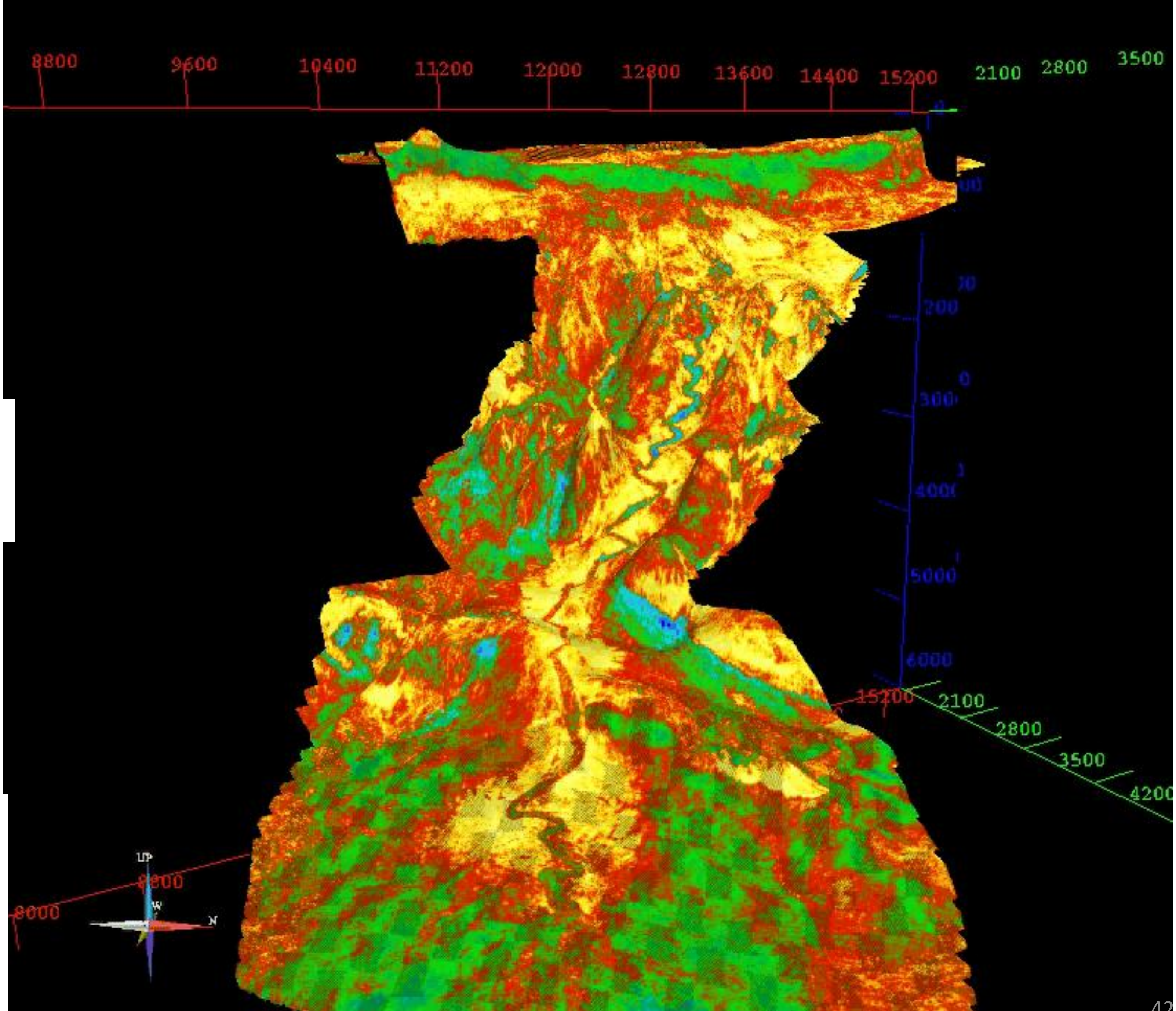
Early Sand-rich Lowstand



Blue - High Amplitude, Sandy;

Yellow - Low Amplitude, Shaly

Modified from Saller et al., 2004



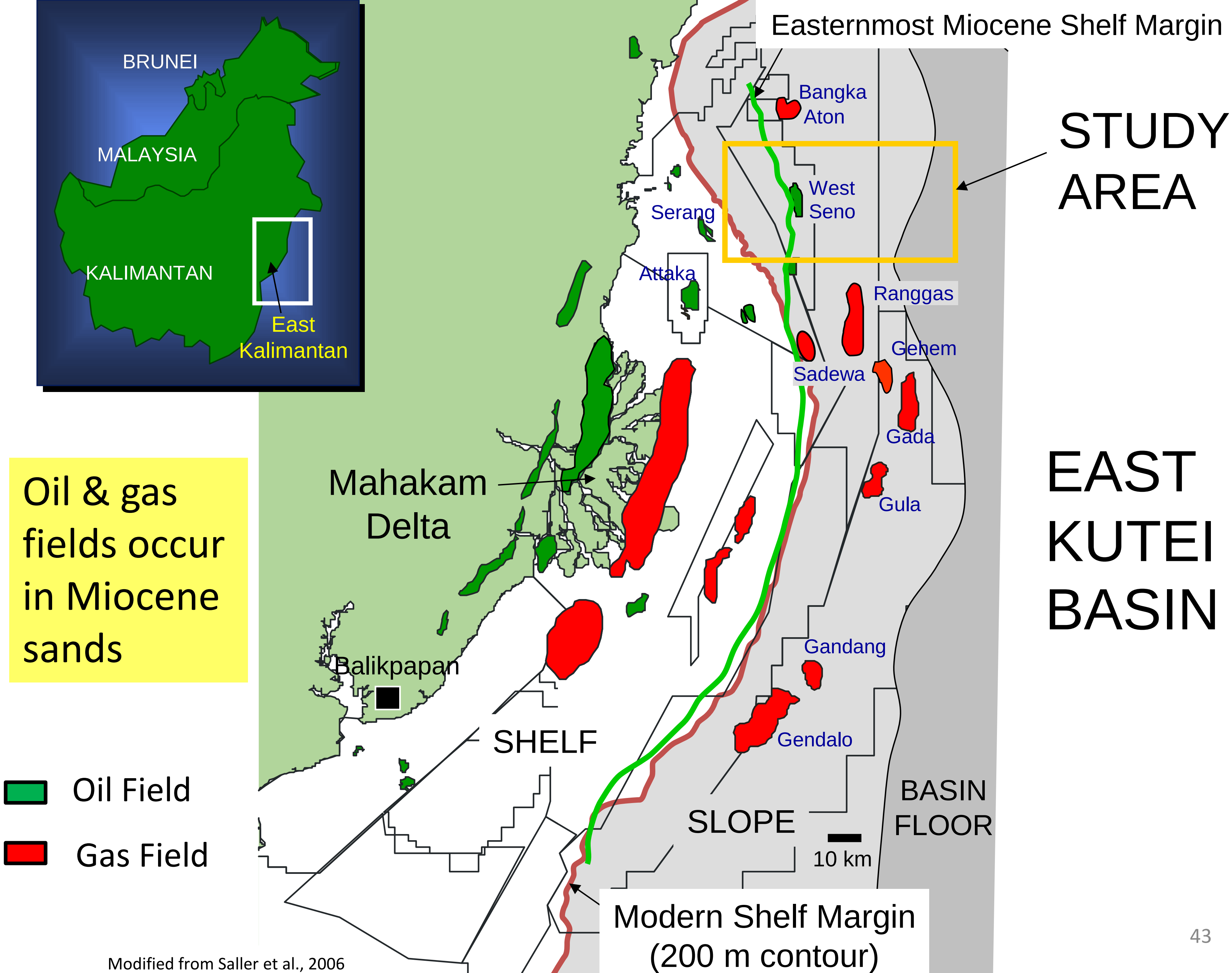
Late
Mud-rich
Lowstand

Blue - High Amplitude, Sandy;

Yellow - Low Amplitude, Shaly

Modified from Saller et al., 2004

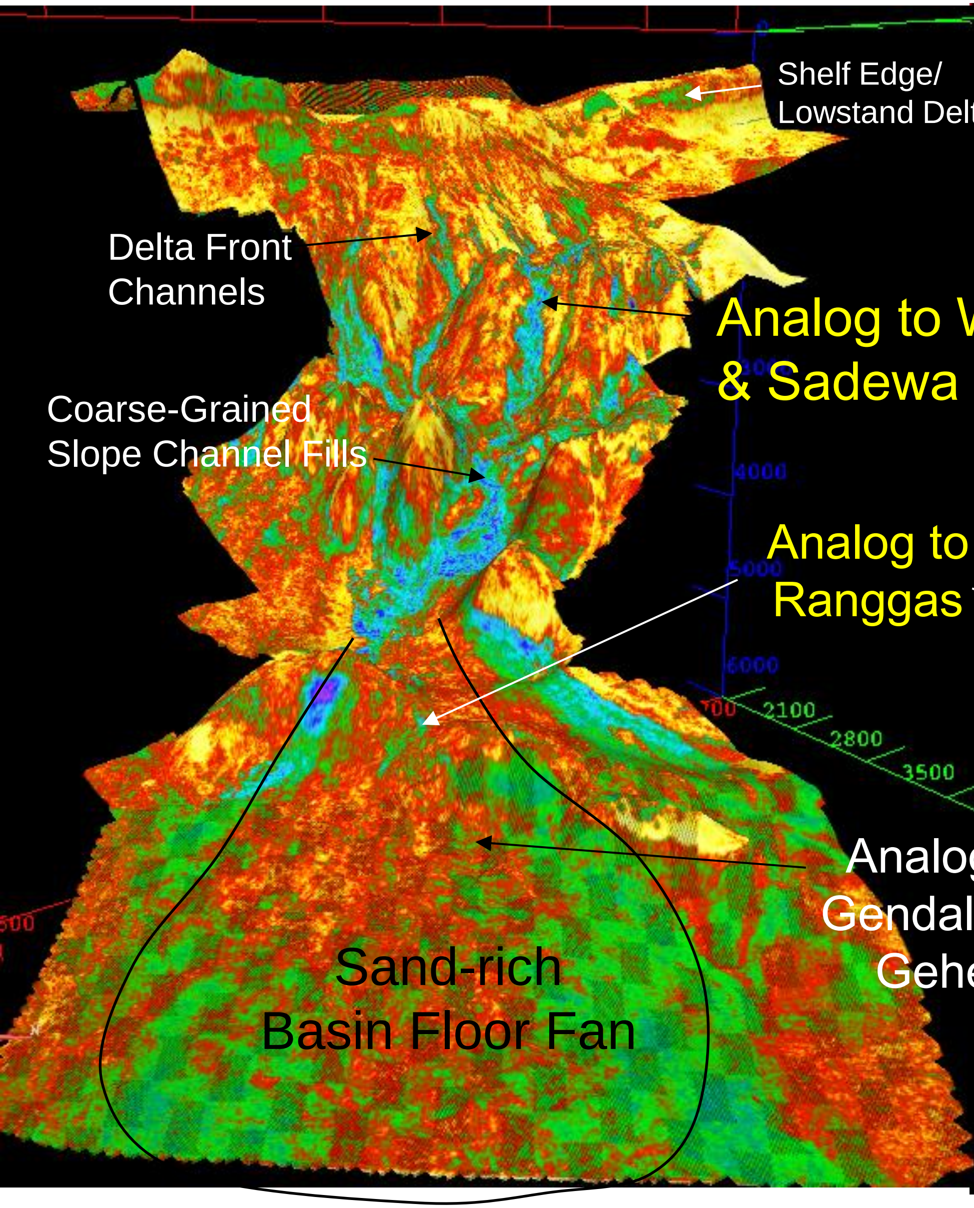
Oil & gas fields occur in Miocene sands

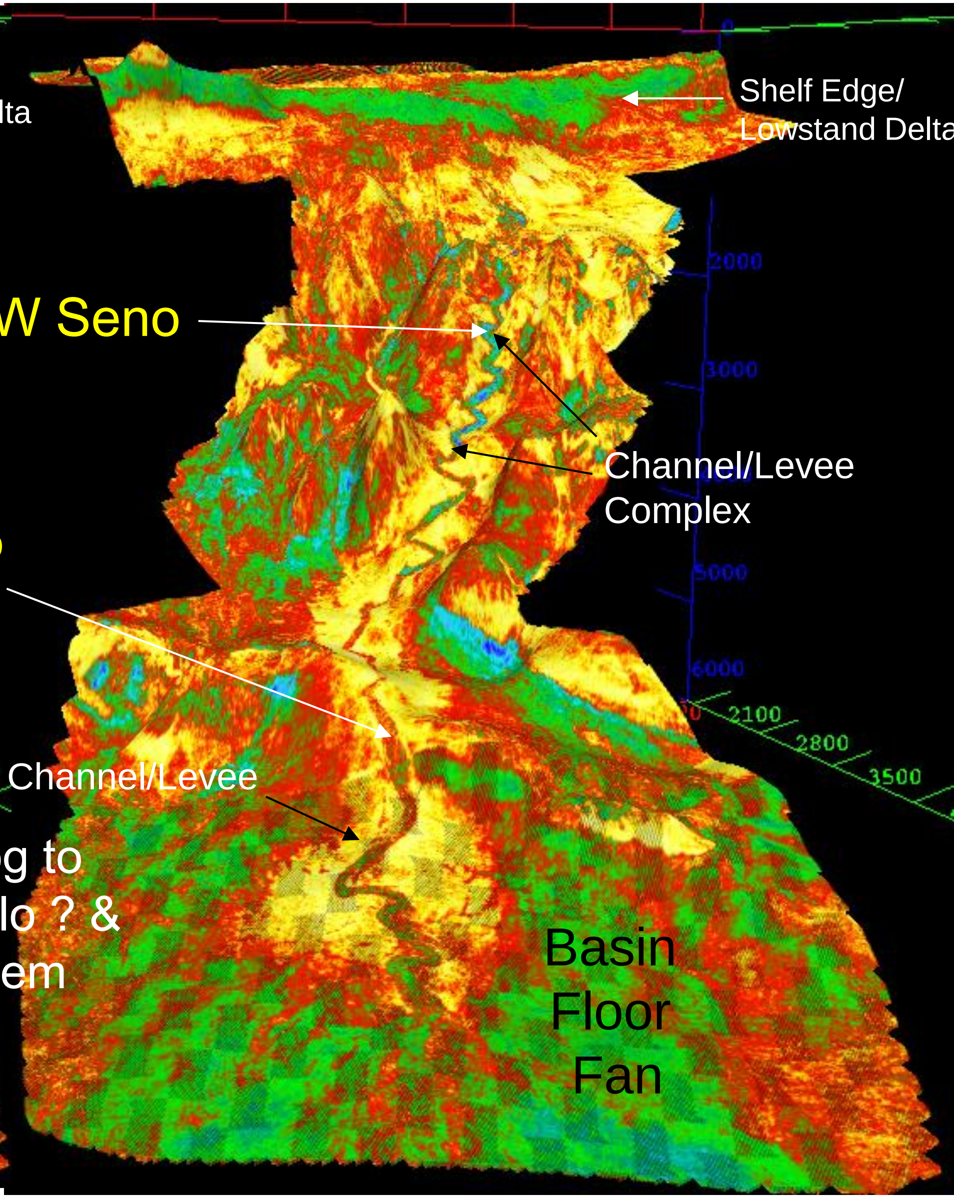


Modified from Saller et al., 2006

Early Lowstand: Sand-rich

Late Lowstand: Mud-rich





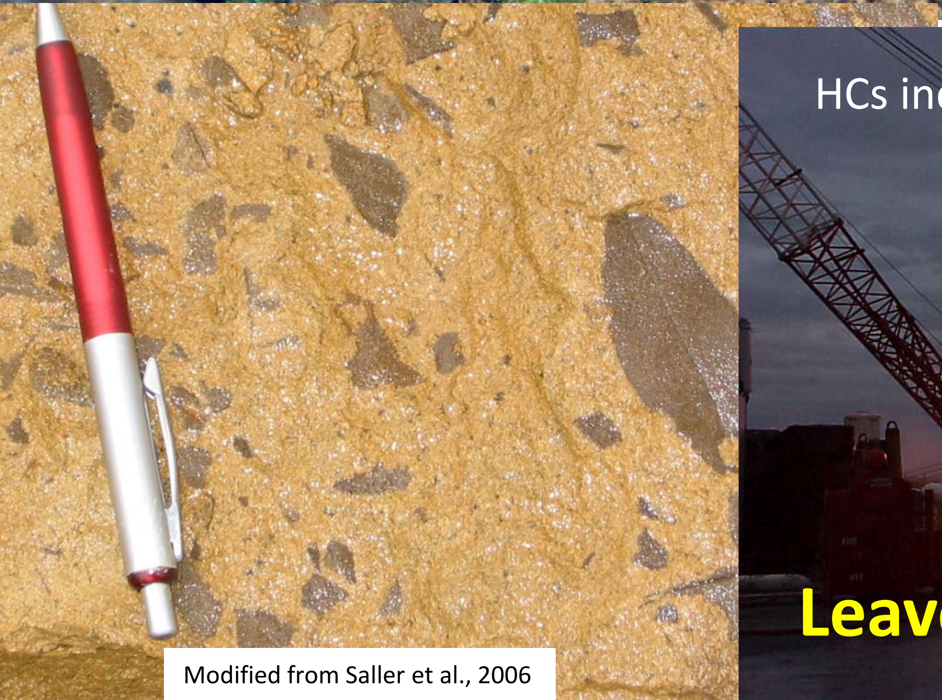
Blue - High Amplitude, Sandy;
Yellow - Low Amplitude, Shaly

RMS amplitude on Structure

Modified from Saller et al., 2004

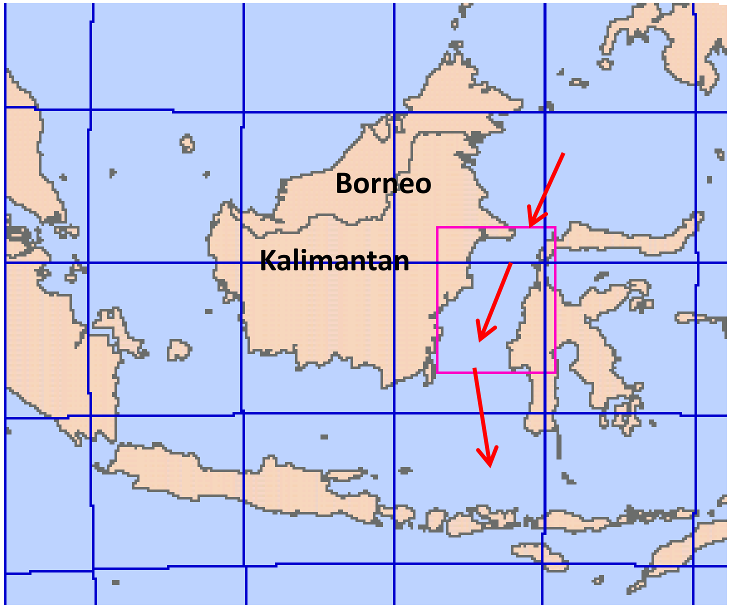
MAJOR OIL & GAS FIELDS OCCUR IN THE MAKASSAR STRAIT

What is the source rock?



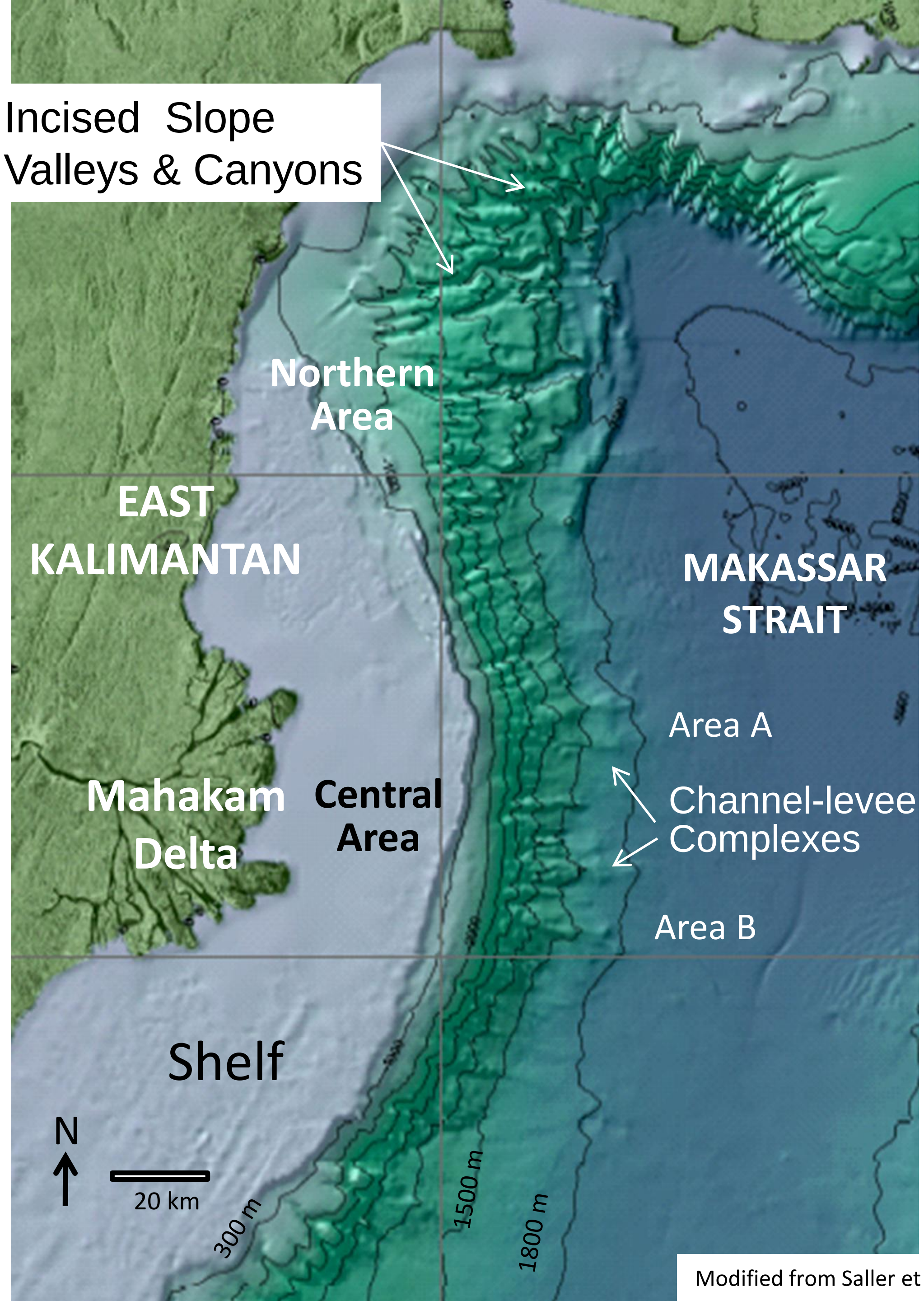
Modified from Saller et al., 2006

Location Maps



Oxidizing Bottom Currents Degraded Most Marine Algal Matter Falling into the Deep Makassar

Wax on Leaves & Tree Resins are the Main Source of Liquid HCs

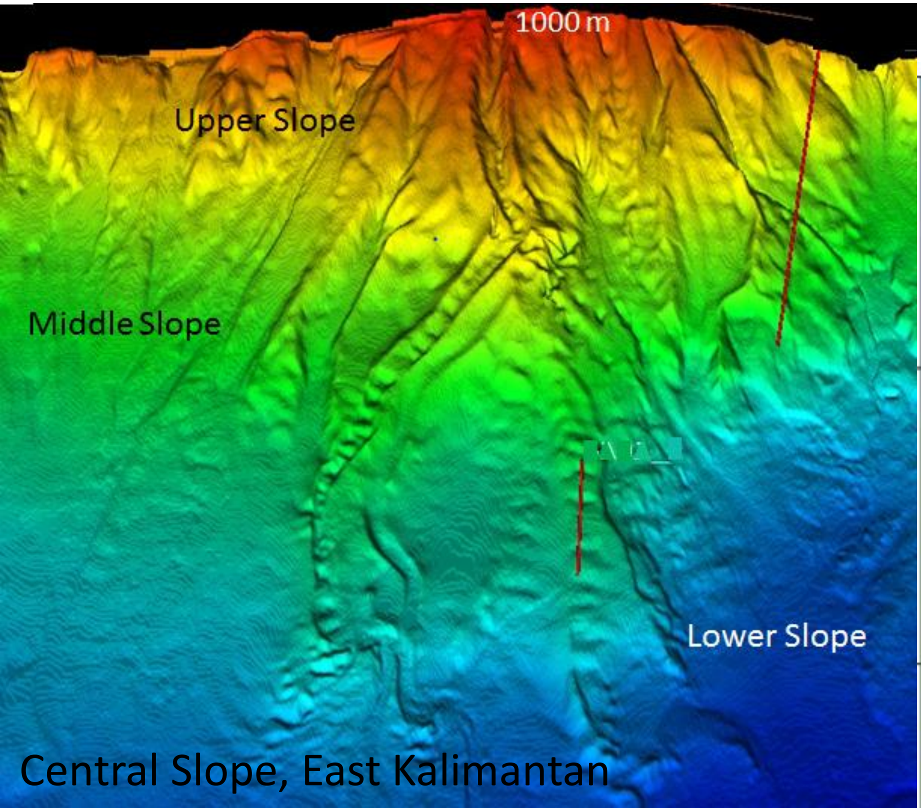


Modified from Saller et al., 2010

Images made by Phil Teas & John Decker

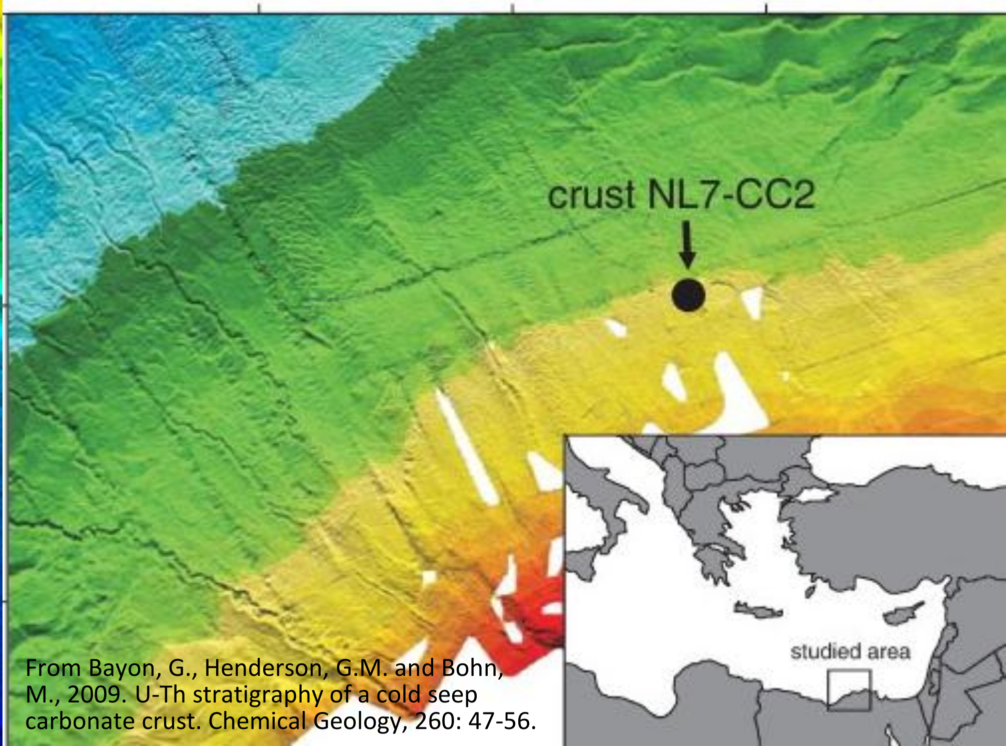
Summary & Implications (So what?)

- Turbidite sands are common reservoirs in deepwater slope settings and can be divided into 2 broad geometries
  - Unconfined channels +/- levees
  - Slope valleys/ canyons
- Abundant, consistent supply of sediment to the slope keeps deep slope valleys and canyons from forming, resulting in slopes dominated by channel-levee complexes
  - Central E. Kalimantan, Mississippi River, Niger Delta, Amazon Fan, Bengal Fan, Nile



Central Slope, East Kalimantan

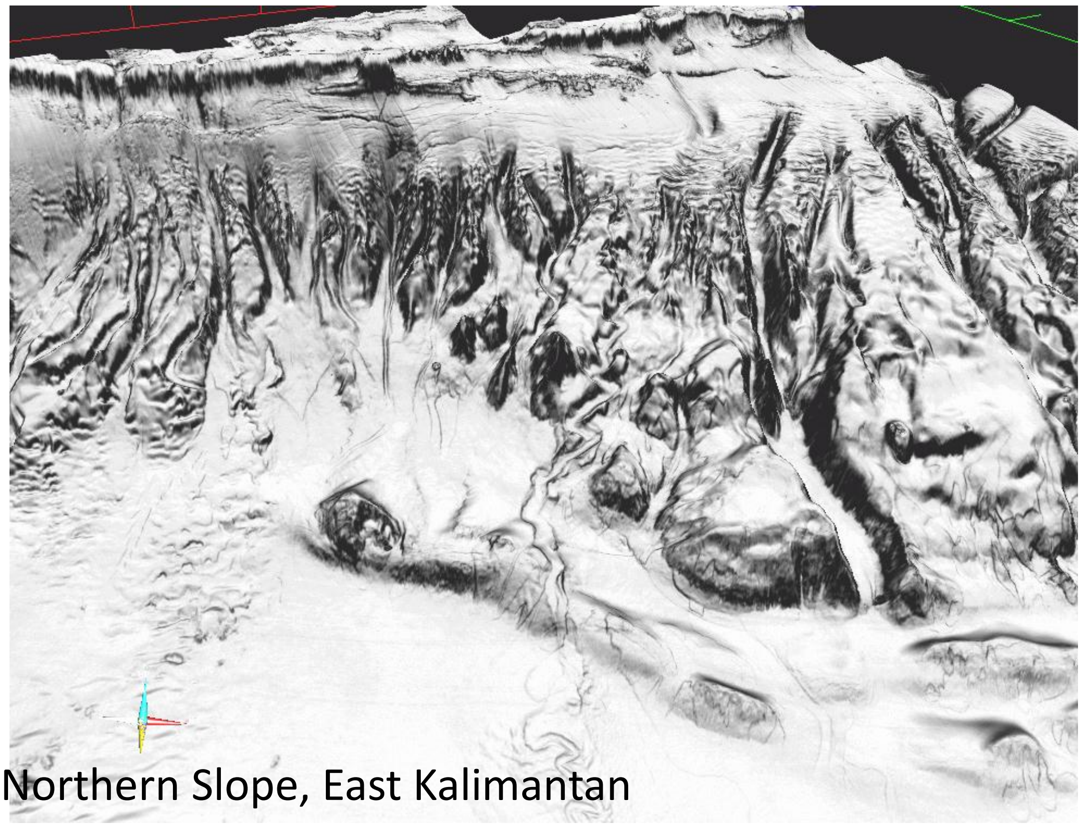
Nile Delta



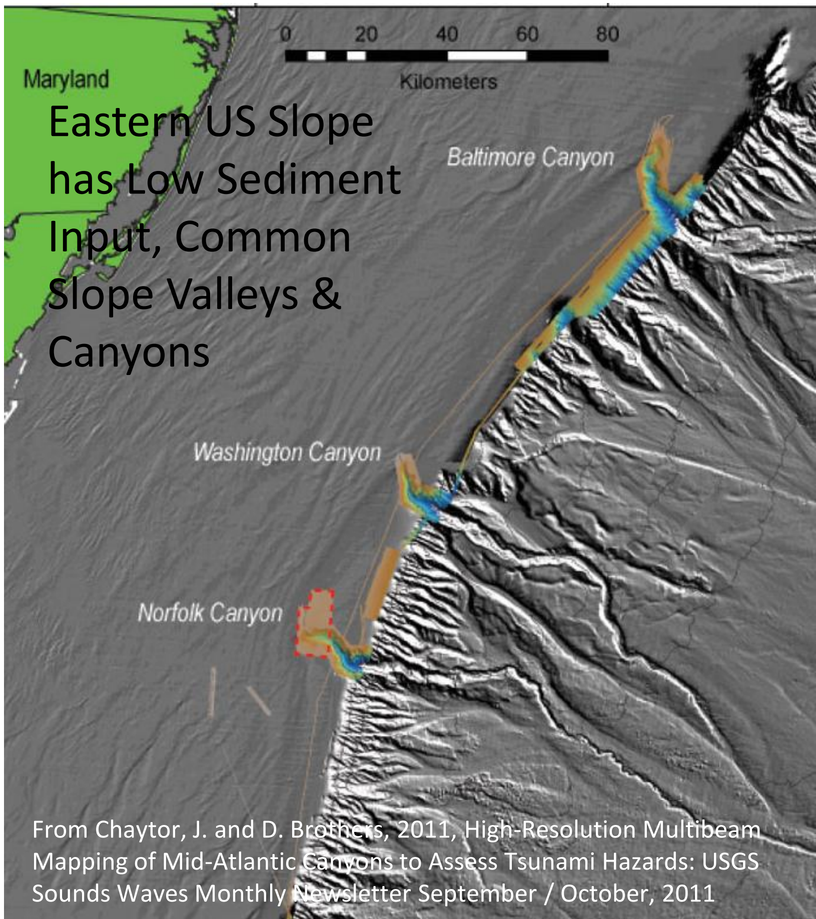
From Bayon, G., Henderson, G.M. and Bohn, M., 2009. U-Th stratigraphy of a cold seep carbonate crust. Chemical Geology, 260: 47-56.

Summary & Implications

- Slope valleys & canyons form by slumps and mass flows where sediment input is not sufficient to keep them filled
- Deep cuts (valleys, canyons) in the slope are generally not caused by erosion associated with turbidites → slope valleys do not imply sand
- Valleys & canyons occur on many other slopes where sediment supply is limited (eastern US, Zhemchug Canyon, others)



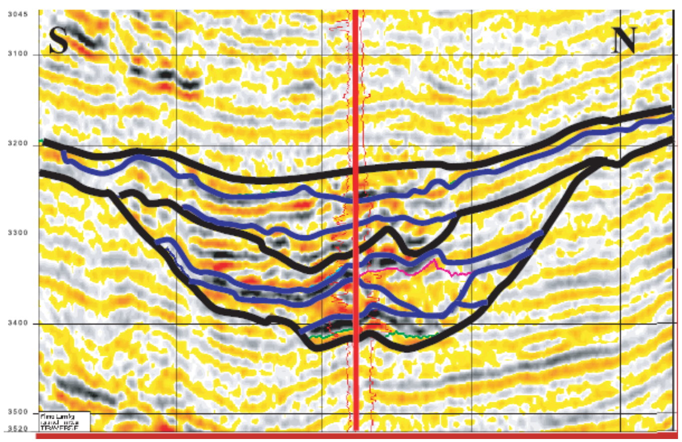
Northern Slope, East Kalimantan



From Chaytor, J. and D. Brothers, 2011, High-Resolution Multibeam Mapping of Mid-Atlantic Canyons to Assess Tsunami Hazards: USGS Sounds Waves Monthly Newsletter September / October, 2011

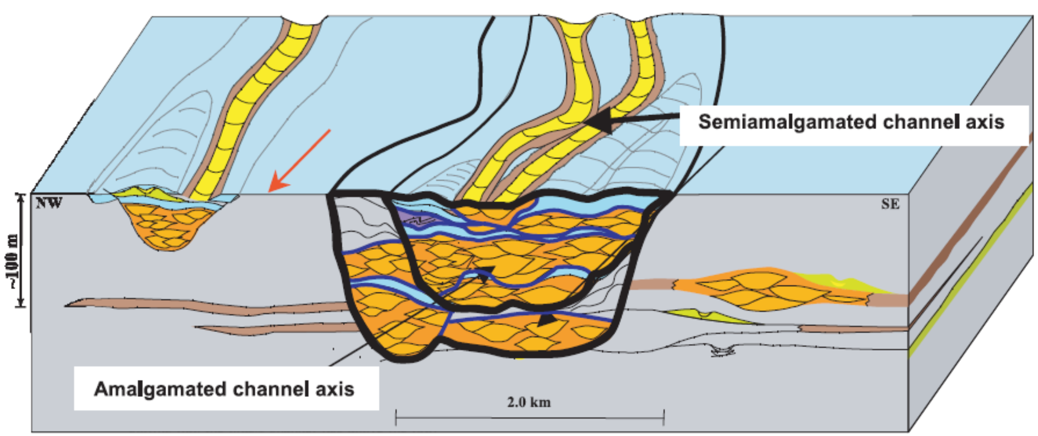
Slopes dominated by channel-levee complexes commonly have modest net-to-gross (for sand) because channel-levee complexes create bathymetric highs causing channel complexes to migrate (compensational stacking)

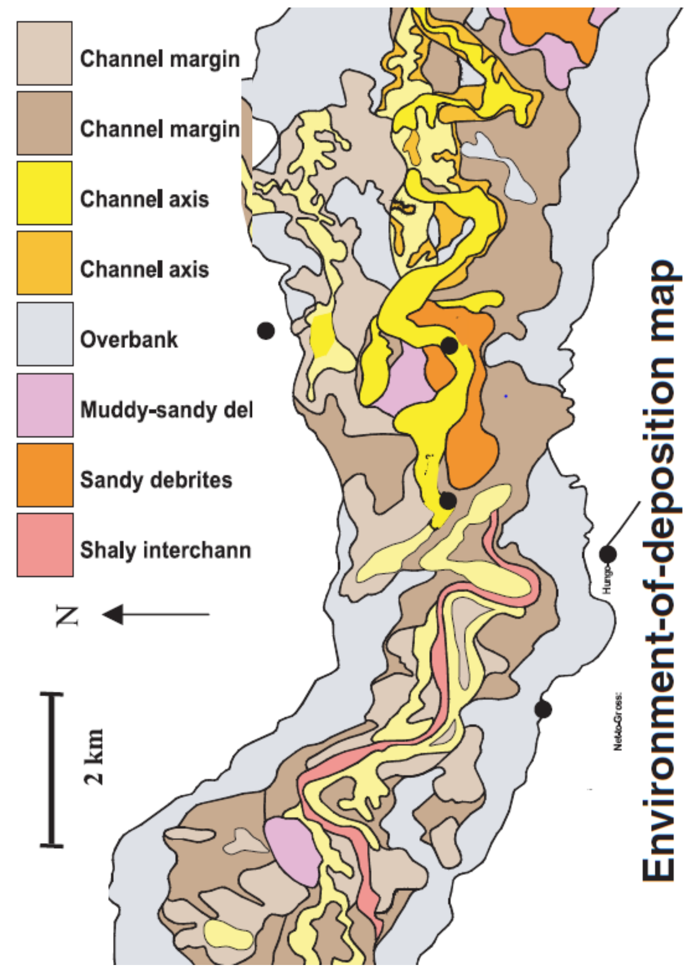
Slope Valleys can Concentrate Thick Turbidite Sands (amalgamated channels). Many of the Largest Slope Turbidite Fields occur in Amalgamated Channel Sands in Slope Valleys



Kizomba, Deepwater Angola

From Reeckmann, S.A., Wilkin, D.K.S., Flannery, J.W., 2003. Kizomba, a deep-water giant field, Block 15 Angola. In: Halbouty, M.T. (Ed.), Giant Oil and Gas Fields of the Decade 1990-1999., AAPG Memoir, vol. 78, p. 227-236.



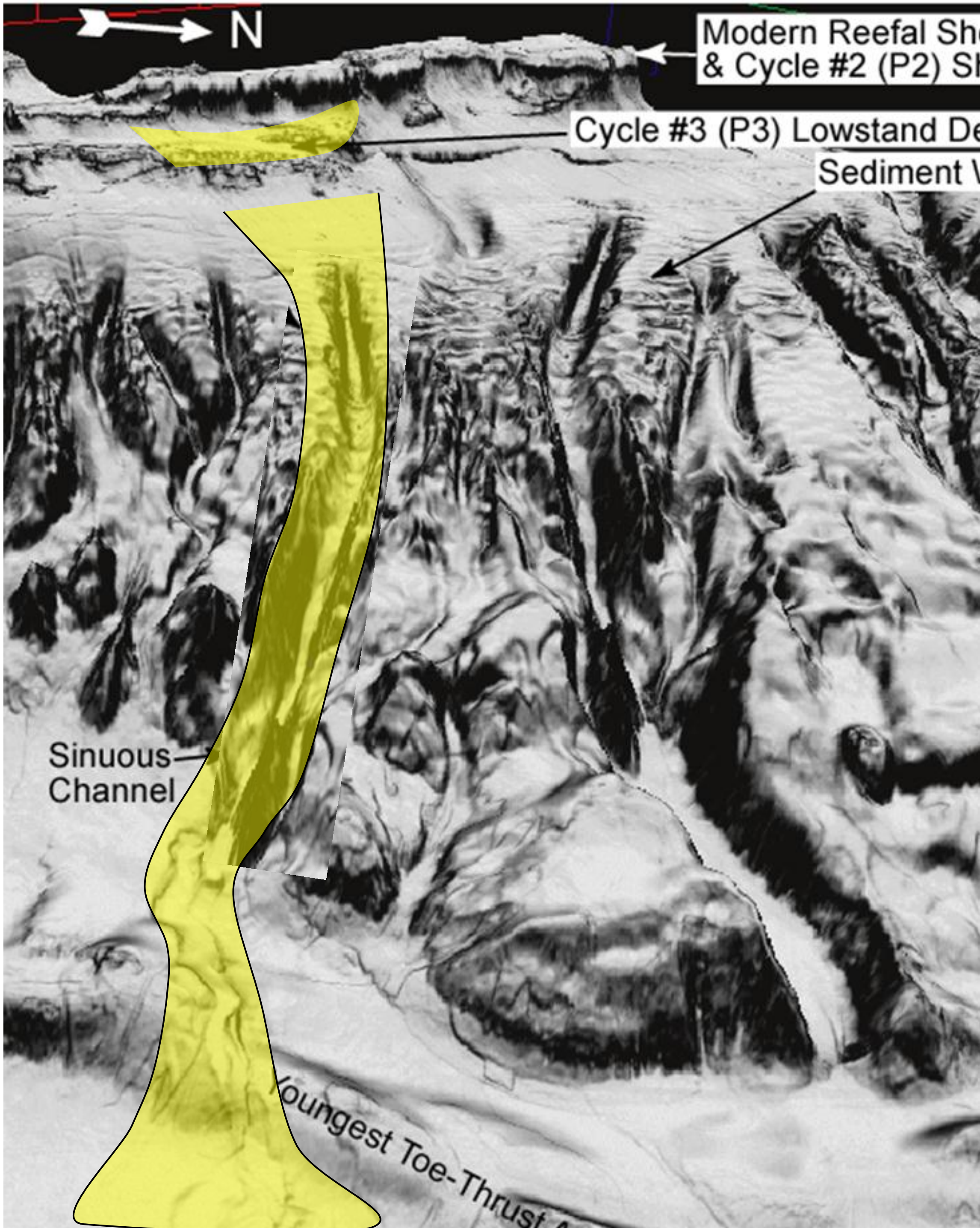


AMALGAMATED TURBIDITE CHANNEL SANDS FORM IN SLOPE VALLEYS BY

1. Erosion of the slope valley by mass wasting & debris flows during times of low sedimentation

2. Fluvial & shelfal depositional systems deliver sands to the shelf margin. Sands are transported & deposited by turbidites in channels that are confined by the slope valley

3. Turbidites are generally not responsible for erosion of the slope valley



Modified from Saller et al., 2004

Thanks to

- AAPG, AAPG Foundation, Shell, Cobalt International Energy
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- And many others

Development Team

Exploration Team

Regional Team