Reservoir Heterogeneity in Marginal Marine Settings of the Athabasca Oil Sands: Apparent Continuity of Mud Beds Between Closely Spaced Cores*

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Abstract

In the Athabasca Oil Sands Deposit, substantial bitumen resources lie along a secondary trend in the northwest. This trend is a major tributary to the main Athabasca trunk valley system of Lower Cretaceous time and is known informally as the Ells paleovalley. A comprehensive study of core near Brion Energy's MacKay assets indicates that mud beds and mud laminae deposited in marginal marine embayments within the Ells paleovalley probably have significant lateral extent. The study area includes two vertical wells spaced 15 metres apart located on Southern Pacific's McKay SAGD project. One is an older exploration well and the other was drilled as an observation well for SAGD operations. Both wells, 1AA/05-18-91-12W4 and 100/05-18-91-12W4, are cored and available in the public domain. These two cores contain multiple instances where patterns of mud bedsets and mud laminae within the prime reservoir sands can be clearly correlated from well-to-well at equivalent stratigraphic depths, indicating that individual mud laminae are continuous over 15 metres between the two cores. Correlative mud laminae appear to trap lean zones of identical thickness in both cores, presumably where structural closure is present. This observation provides further evidence for the continuity and seal potential of the mud laminae. The mud beds and laminae are interpreted to have been dynamically deposited from fluidized flow. Evidence of fluidized flow is provided by the presence of millimetre-scale current ripples in the muds. Correlative muds are observed at depths below, between, and above the trajectory of a nearby well pair at the Southern Pacific McKay SAGD project. The full lateral extent of the correlative muds may be several tens to hundreds of metres. In areas with SAGD potential where these mud beds may be abundant, they could act as tortuous steam baffles and may hamper gravity driven drainage. Although it is rare and extraordinary to have such closely-spaced cores, mud bed continuity may be inferred nonetheless in single cores from at least two phenomena: the presence of lean zones that are apparently trapped below mud laminae; and the presence of millimetre-scale current ripples in mud. A useful strategy in areas of risk may be to obtain core from closely spaced wells to determine the lateral extent of mud beds. This need not entail additional expense if scheduled observation wells can be cored and strategically placed in close proximity to older, cored, exploration wells.

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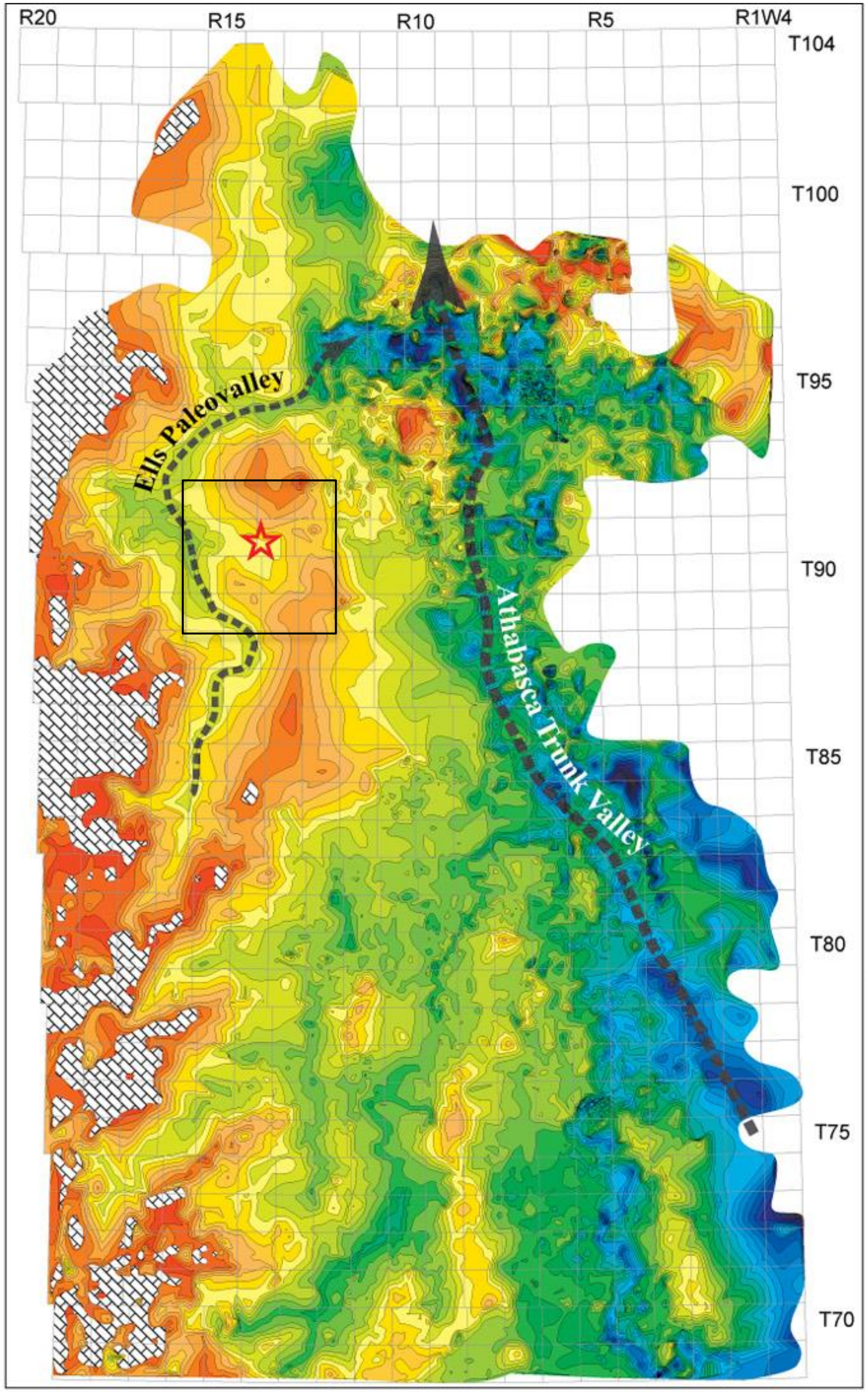


Basin Isopach Map:
Wabiskaw Marker
to
Sub-Cretaceous Unconformity
(inferred basin paleotopography)

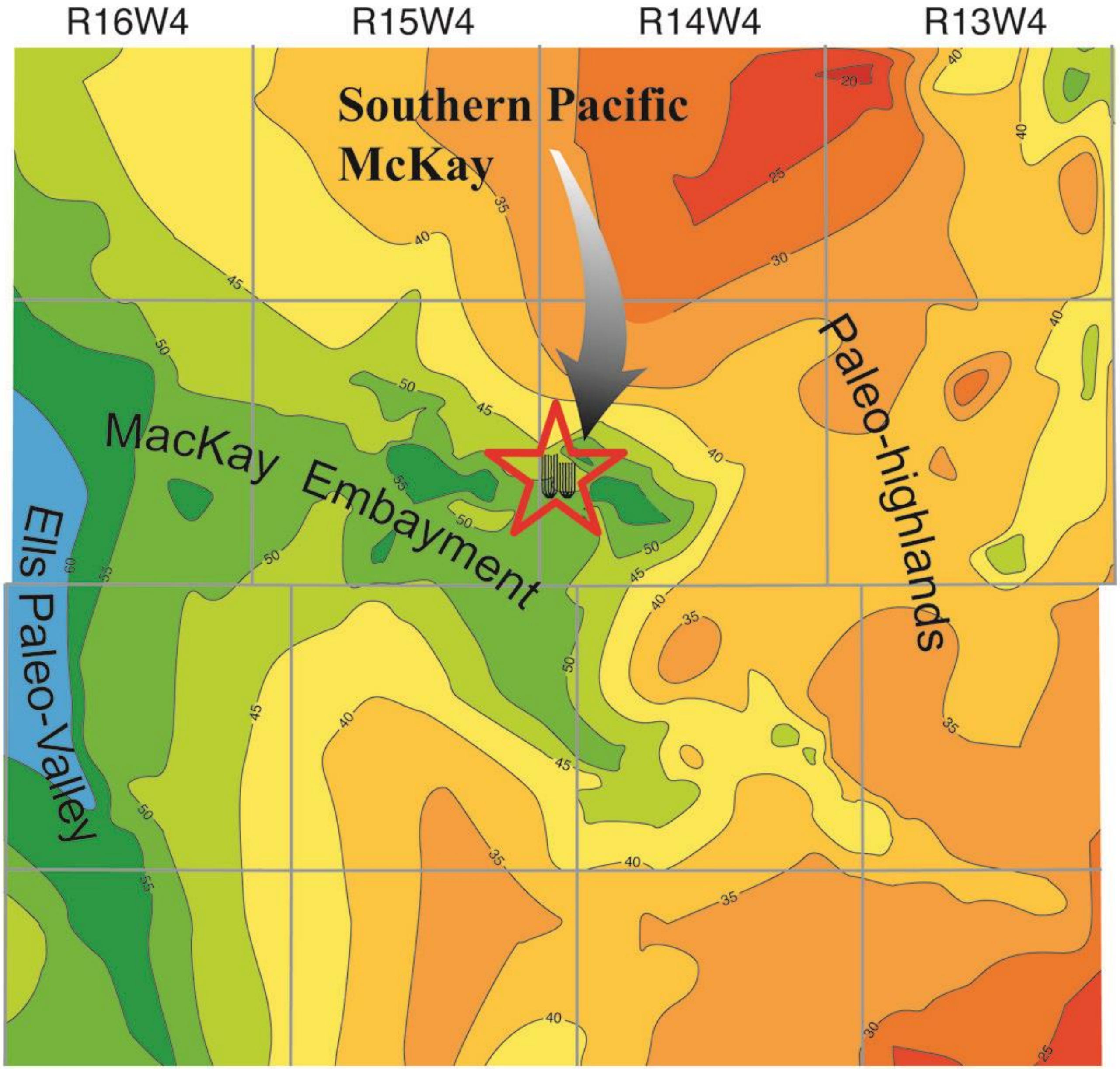
Ells Paleovalley:

- tributary to main Athabasca Trunk Valley
- study area: "MacKay Embayment"
- topographically elevated; late to feel transgression
- Consequent valley due to recessive Ireton and constrained by indurated carbonates as "highlands"

Study Area

McMurray Fm. non-deposition

Regional Upper Aptian Paleotopography on the Sub-Cretaceous Unconformity



Embayment surrounded by low highlands to the east, and opening to the Ells paleo-valley to the west at upper McMurray time.

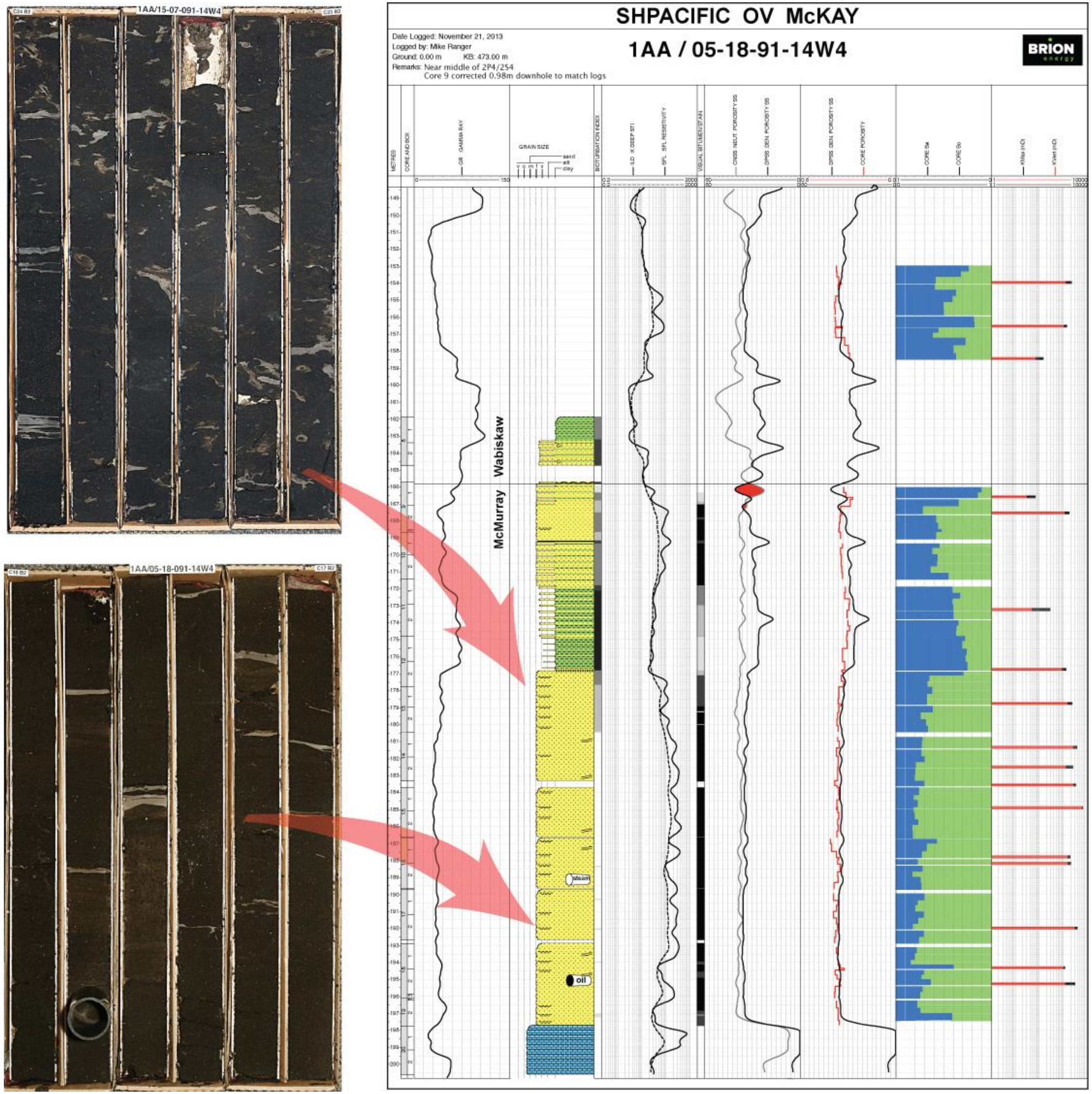
Brackish and tidal on early transgression = reservoir sands.

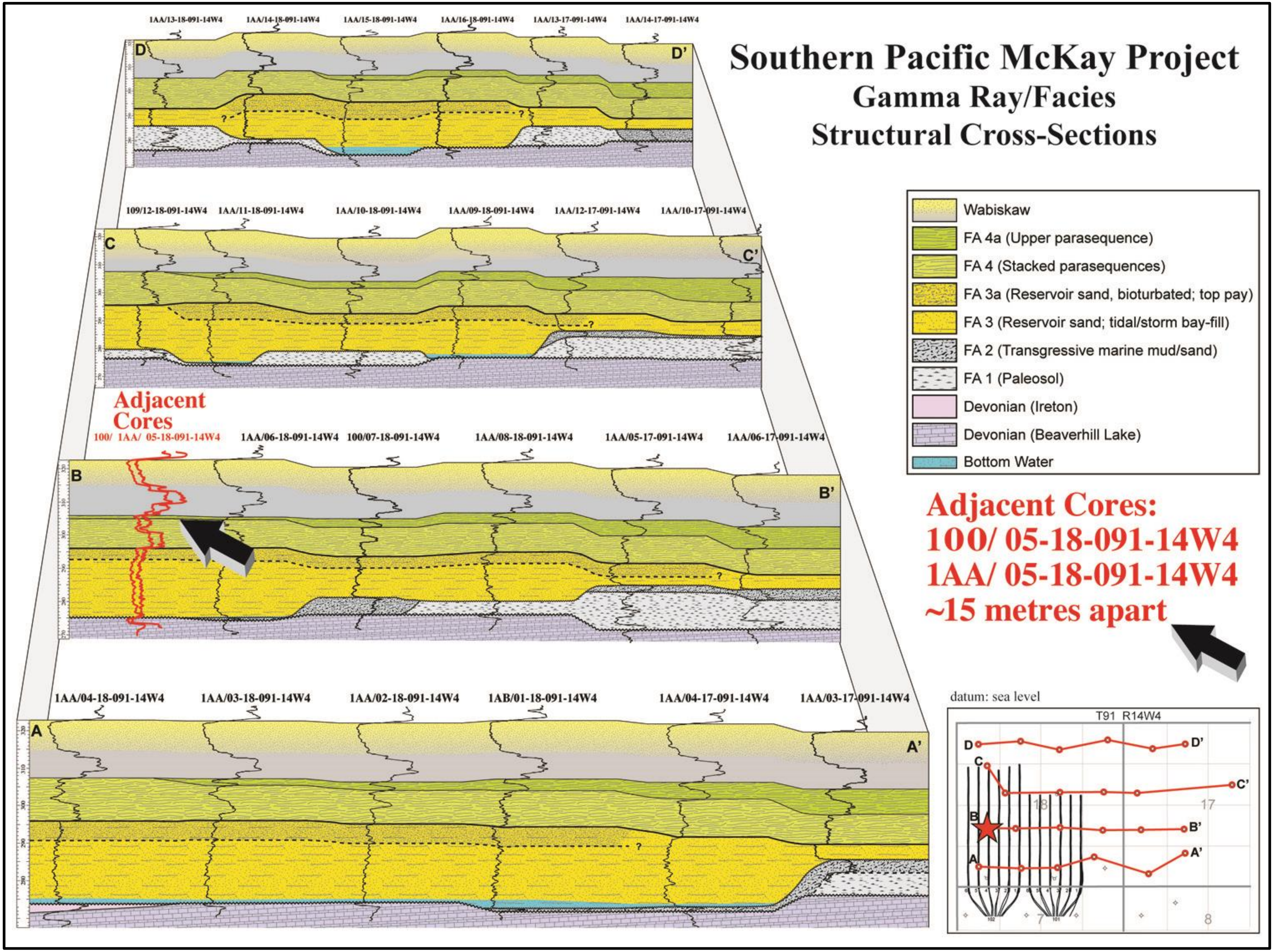
Sea level rise of only 15-20m would breach the highlands, bringing in more fully marine conditions directly from the east.

Isopach: Wabiskaw Maximum Flooding Marker to Sub-Cretaceous Unconformity

contour interval: 5m

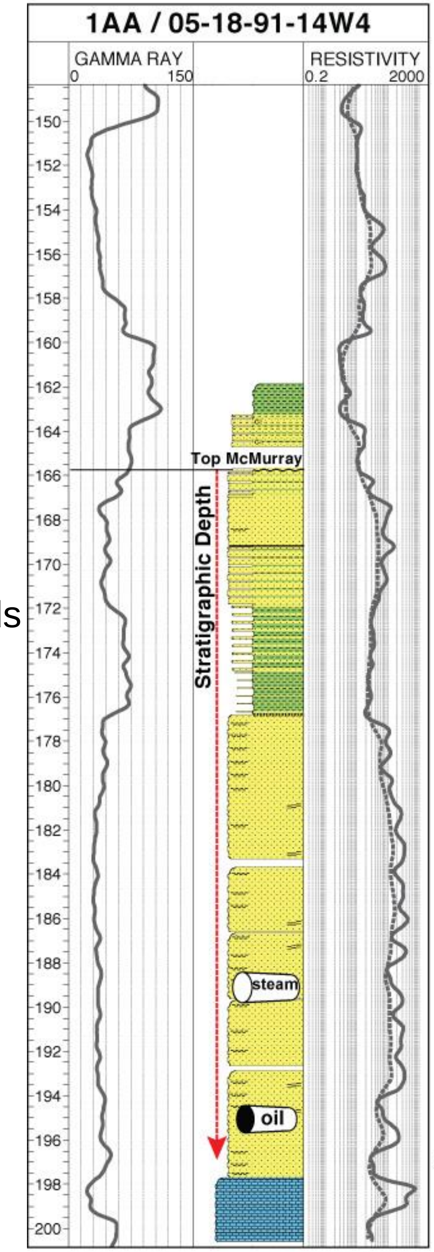
Tide / Storm Dominated Embayment




Southern Pacific McKay Project
Gamma Ray/Facies
Structural Cross-Sections
1AA/13-18-091-14W4
1AA/14-18-091-14W4
1AA/15-18-091-14W4
1AA/16-18-091-14W4
1AA/13-17-091-14W4
1AA/14-17-091-14W4
D
D'
109/12-18-091-14W4
1AA/11-18-091-14W4
1AA/10-18-091-14W4
1AA/09-18-091-14W4
1AA/12-17-091-14W4
1AA/10-17-091-14W4
C
C'
Adjacent Cores
100/ 1AA/ 05-18-091-14W4
1AA/06-18-091-14W4
100/07-18-091-14W4
1AA/08-18-091-14W4
1AA/05-17-091-14W4
1AA/06-17-091-14W4
B
B'
1AA/04-18-091-14W4
1AA/03-18-091-14W4
1AA/02-18-091-14W4
1AB/01-18-091-14W4
1AA/04-17-091-14W4
1AA/03-17-091-14W4
A
A'
Wabiskaw
FA 4a (Upper parasequence)
FA 4 (Stacked parasequences)
FA 3a (Reservoir sand, bioturbated; top pay)
FA 3 (Reservoir sand; tidal/storm bay-fill)
FA 2 (Transgressive marine mud/sand)
FA 1 (Paleosol)
Devonian (Ireton)
Devonian (Beaverhill Lake)
Bottom Water
Adjacent Cores:
100/ 05-18-091-14W4
1AA/ 05-18-091-14W4
~15 metres apart
datum: sea level
T91 R14W4
18
17
7
8

Examples of Correlateable Mud Bedsets at Same ***Stratigraphic Depth***

Bedset A



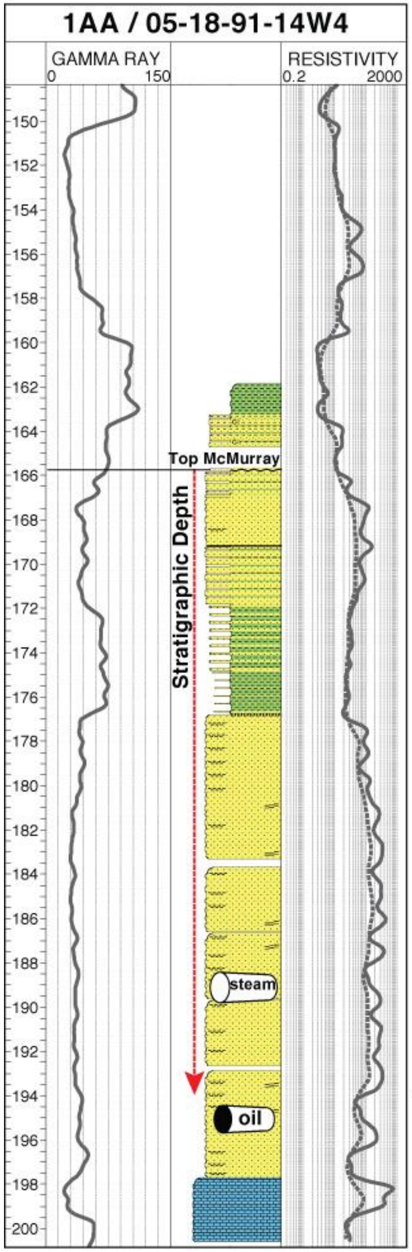
Note:

- Number & thickness of mud beds
- Internal Laminae on mm scale
- Bioturbation pattern
- Lean Zones

note the core sleeve boundaries:
- near the top of 1AA/
- near the middle of 100/

Examples of Correlateable Mud Bedsets at Same ***Stratigraphic Depth***

Bedset B

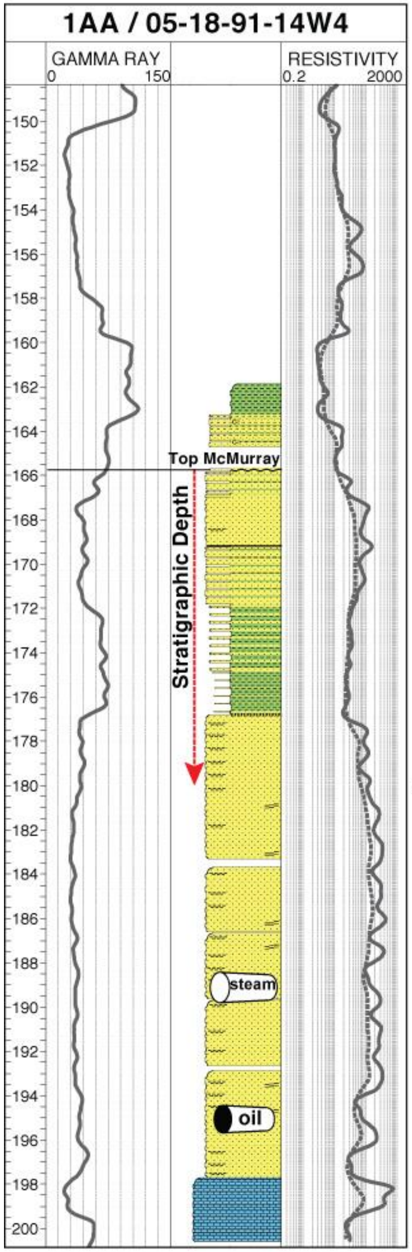


Note:

- Number & thickness of mud beds
- Ripple drapes
- Lean Zones
- Flat top; Bottom fills irregularities

Examples of Correlateable Mud Bedsets at Same ***Stratigraphic Depth***

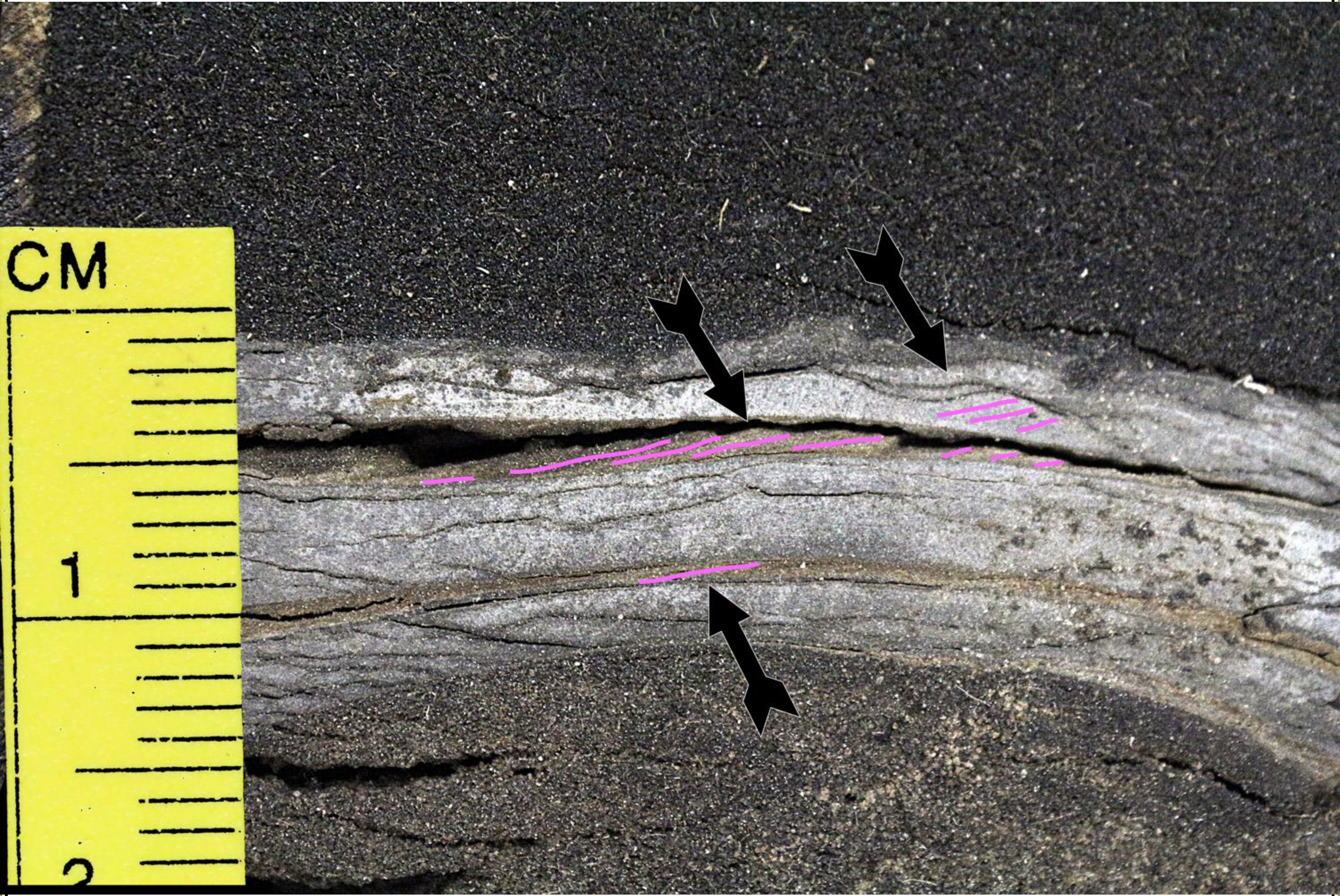
Bedset C



Note:

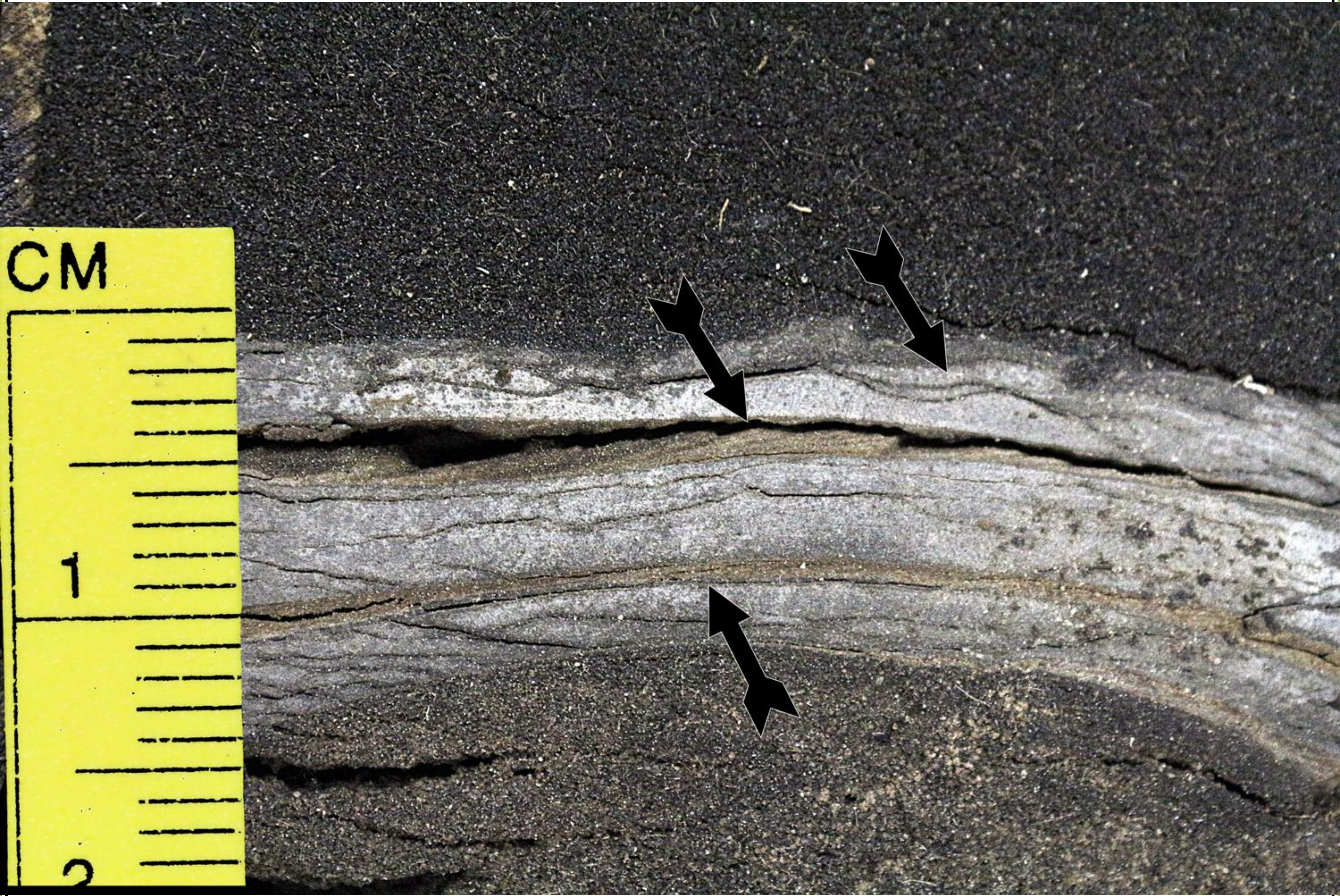
- Number & thickness of mud beds
- Bioturbation pattern

Ripples and cross-stratified mud laminae in the MacKay area cores.



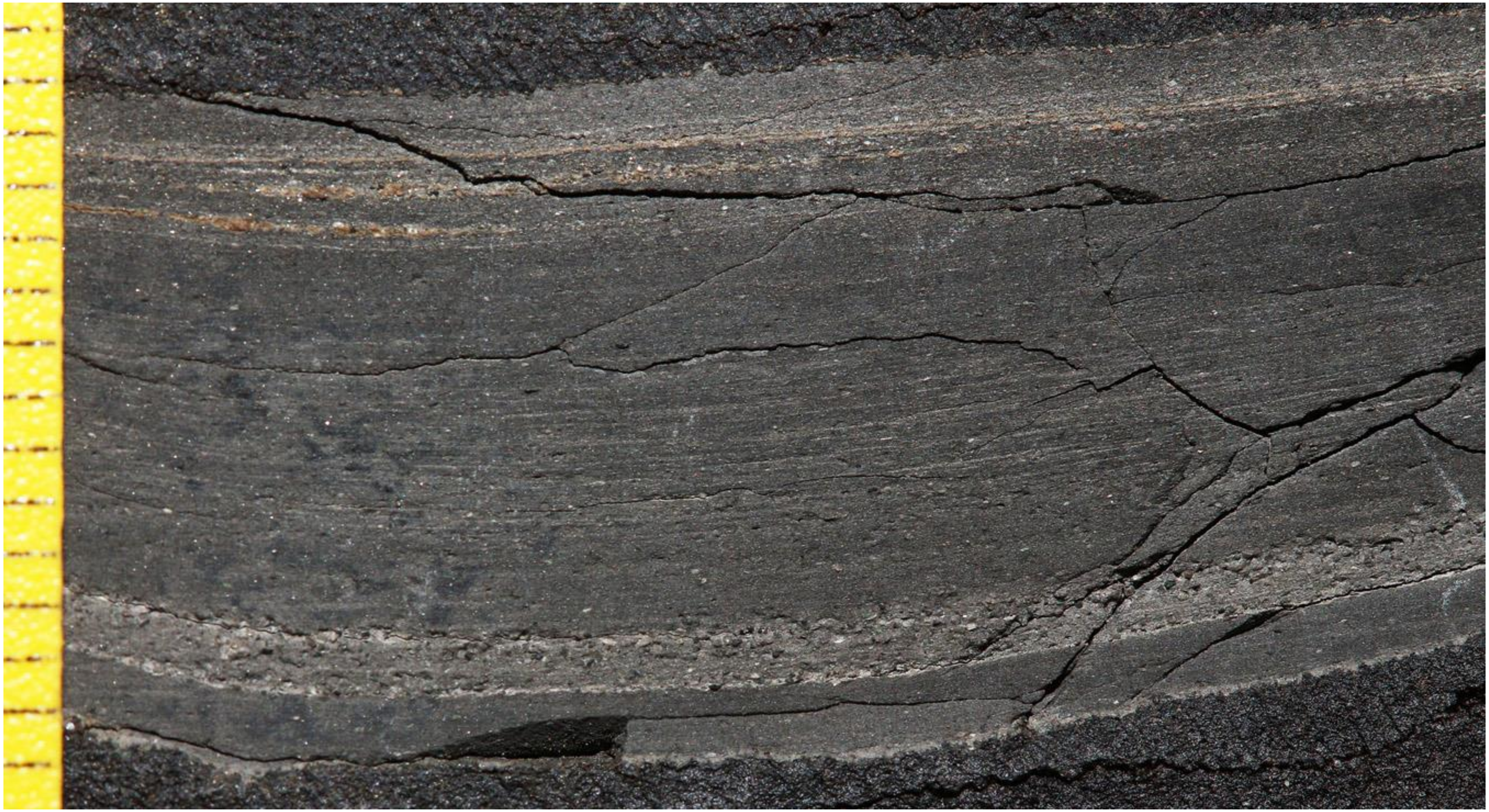
Example

Ripples and cross-stratified mud laminae in the MacKay area cores.



Example

Horizontal laminae and faint cross-stratified mud in the MacKay area cores. lamina scale: < 10 microns

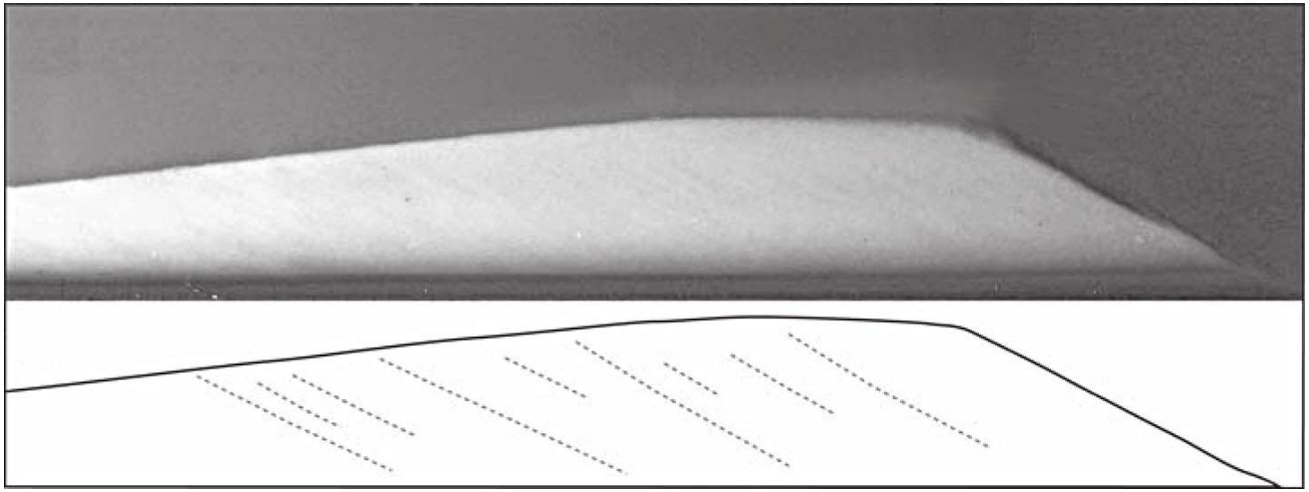


millimetres

FLUIDIZED MUD FLOWS

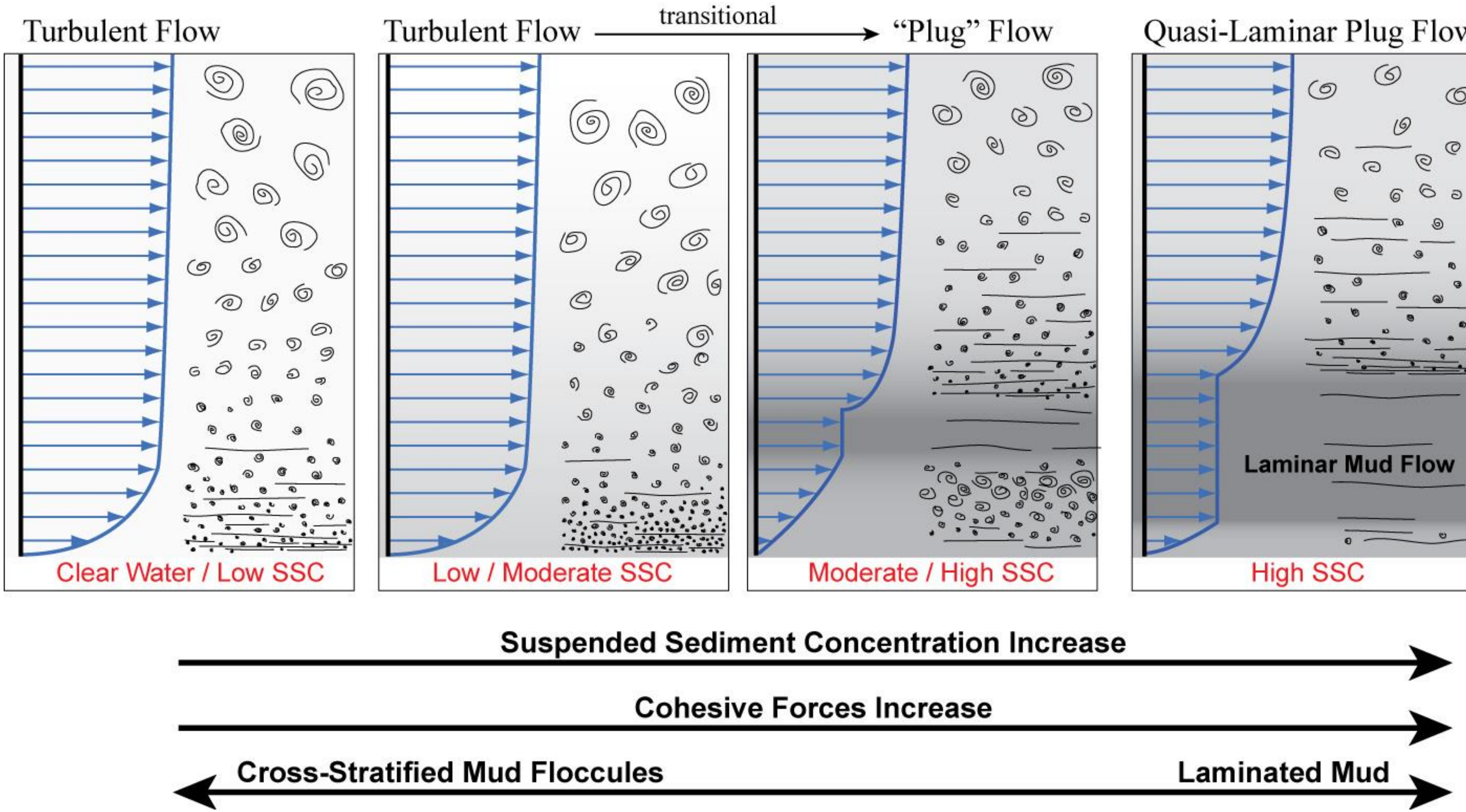
Given suspended sediment concentrations greater than about 1 gm/L, mud can be mobilized, distributed and deposited dynamically by turbulent to laminar "fluidized flow" in the near-bed environment.

- Flow structures on a "micro-scale".
  - Current cross-stratification under turbulent flow conditions.
  - Parallel-laminated mud under fluctuating flow conditions.
- Examples documented in the rock record from both tidal (e.g. MacKay & Dalrymple, 2011) and deltaic/shelf environments (e.g. Bhattacharya & MacEachern, 2011), where hyperpycnal flow provides the depositional dynamic.
- May be particularly common in tidal environments due to mud concentration and trapping in the Turbidity Maximum Zone (MacKay & Dalrymple, 2011).
- Demonstrated in flume studies (Schieber & Southard, 2009).



Flume Photo & Interpretation: Flocculated Kaolinite Clay Ripples (Schieber & Southard, 2009)

HYDRODYNAMIC MODEL



Redrawn & Modified from: MacKay and Dalrymple, 2011; (originally based on Baas et al., 2009)
Dynamic Mud Deposition (Cretaceous Bluesky Fm., Peace River Oil Sands)

IDENTIFYING FLUIDIZED MUD FLOWS IN CORE

Some of the features for differentiating and recognizing mud deposited dynamically by fluidized flow vs gravitational settling in the tidal environment:

- mud drapes settling out of suspension are expected to have *uniform thickness*; whereas dynamic flows fill sea bed irregularities (~ flat upper mud surface)

- in high energy sand environments, slow accumulation of mud is unlikely;

- in tidal environments, mud beds thicker than ~1mm are *unlikely to settle from suspension over the time span of tidal half-cycles*; requires moderate to high *Suspended Sediment Concentrations;*

- *relatively low bioturbation indices* may indicate rapid deposition and continually-recurring dynamic movement of mud;

- *lack of significant grading*: grading is a common feature of fallout from suspension plumes; although not unexpected in hyperpycnal dynamic deposition of mud;

- *cross-laminations on a micro scale in* muds*: moderate SSC –turbulence dominant*.

- *presence of extremely fine (< 10 microns) horizontal laminations: dominance of laminar flow in higher Suspended Sediment Concentrations;*

partially after MacKay & Dalrymple, 2011

Extent of Lateral Continuity of Mud Laminae?

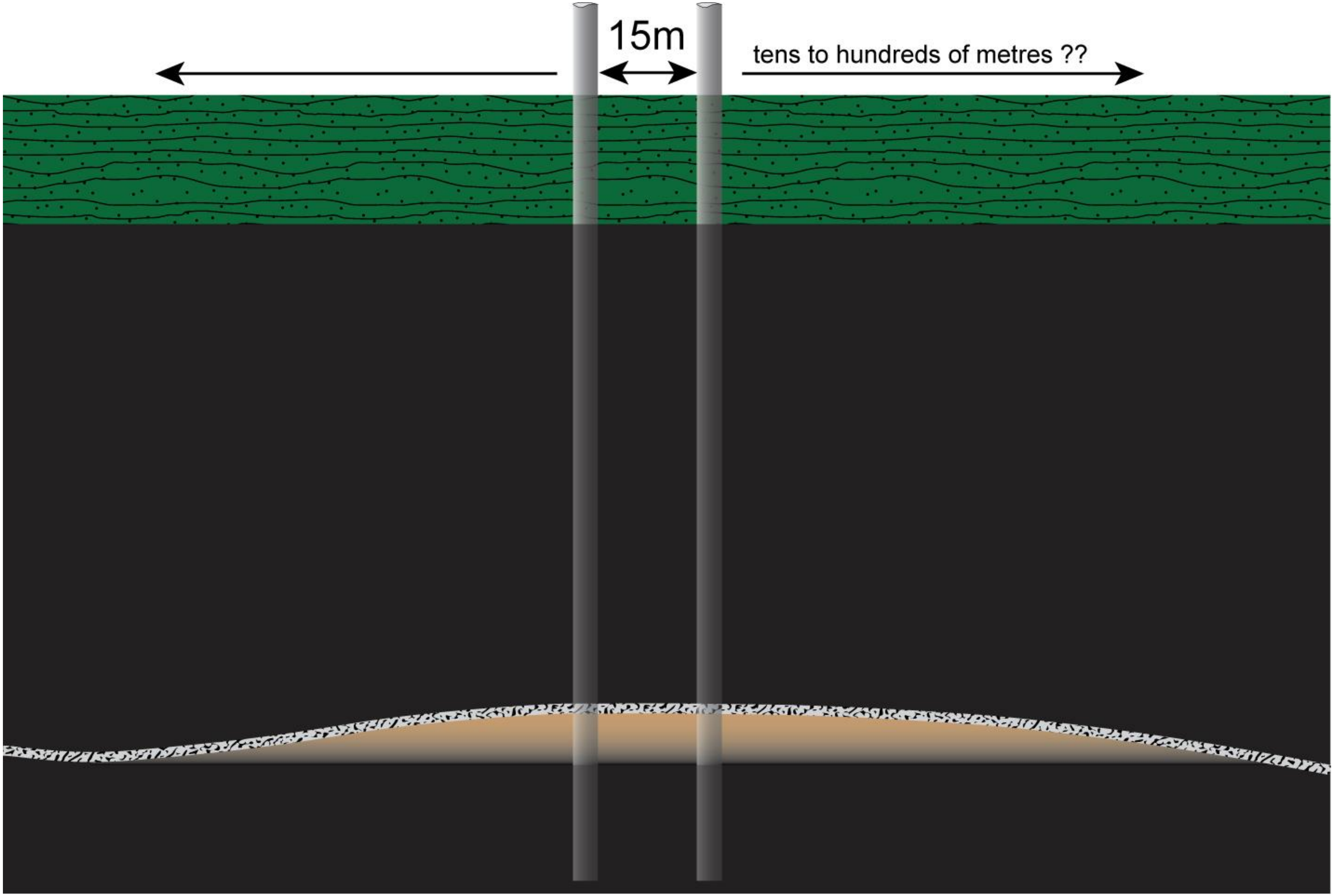
- Unknown lateral extent of the mud laminae at MacKay.
  10’s of metres? 100’s of metres?
- Next nearest core is ~ 600 metres away: similar characteristic patterns of mud laminae not recognized there
- Some recent outcrop studies (Book Cliffs) suggest at least 10’s of metres.
  (Eide et al. 2014, AAPG Bull.)
- Evidence from internal “lean zones” (high $S_{w)}$

Bedset A

Base of
Lean Zone

Bedset B

Base of
Lean Zone



Lean zones beneath continuous muds:
“micro-traps” with local structural closure

CONCLUSIONS

- Oil sands resources in MacKay area of the Ells paleovalley comprise upper McMurray bay fill sands in a marginal marine setting.
- The MacKay area is a tide- and possibly storm-dominated embayment; originally brackish and evolving to more fully marine with little to no fluvial dynamics.
- Reservoir heterogeneities in the oil sands encountered here present different geological challenges than those encountered in the main Athabasca trunk valley.
- Mud beds and laminae are observed to have lateral continuity between 2 cores approximately 15 metres apart; Possibly a few tens- to hundreds of metres in extent.
- Continuity at those scales is also supported by the presence of apparently continuous lean zones, up to 30 cm thick, beneath the correlated mud beds; Such lean zones within the reservoir should elicit attention.
- At MacKay (and other non-fluvial bays/embayments ?) the thin mud beds and laminae were apparently emplaced by fluidized mud flow.
- Impact of these mud beds on the success of SAGD is unknown at this time but may represent a risk requiring further study.
- May be prudent to drill and core some closely-spaced wells; for example an observation well could be strategically placed near an existing exploration well.

Acknowledgement

Thanks to:

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References:

Baas et al., 2009

Bhattacharya & MacEachern, 2011

Eide et al. 2014

MacKay & Dalrymple, 2011

Schieber & Southard, 2009