

Flow-Substrate Interaction at the Fringes of Deep-Marine Lobes: Skoorsteenbberg Fm., Tanqua Karoo*

Ian Kane¹, Anna S. Pontén², David M. Hodgson³, and Brita Vangdal⁴

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Abstract

Observations and interpretations of sedimentary facies in deep-marine lobe deposits have been strongly influenced by models developed from relatively small, coarse-grained foreland basins. Whilst these models are valid for similar systems, today's ultra deep-water subsurface exploration targets are typically associated with sedimentary systems that are up to orders of magnitude larger, with a much narrower grain-size range. In this contribution, the spatial and stratigraphic distribution of the various facies associated with a fine-grained, deep-marine lobe complex (Fan 3, Skoorsteenbberg Fm., Tanqua Karoo) are presented and characterized to improve understanding sediment transport processes in such environments. The stratigraphy of Fan 3 is exceptionally well-exposed and well-constrained, making it an ideal place to observe this variability. The dataset includes helicopter-based photomosaics, measured sections, and thin sections from oriented samples. QEMSCAN® (Quantitative Evaluation of Minerals by SCANning electron microscopy) analysis, including mineralogical and textural analysis of different bed types, was undertaken to support outcrop observations. Grain-size distributions, including quantification of clay content, can be established from these data and, in conjunction with the outcrop data demonstrate a progressive enrichment of clay and fine grained particles towards the distal and marginal parts Fan 3 lobes. It is demonstrated that predictable spatial and stratigraphic facies distributions can be recognized. Here, this distribution is attributed to an increase in near bed flow concentration due to flow deceleration and collapse in response to flow expansion and entrainment of clay and silt from the substrate; this is recorded in the deposits, from axis to off-axis positions, by increased clay content, decreased erosional capability of flows, and progressively stronger internal deposit heterogeneity. The model differs from previous models as the flow transformation is thought to be highly localized, occurring due to autocyclic flow evolution in medial to distal lobe localities; the model and quantification of flow transformation distance has important implications for estimating the spatial and stratigraphic distributions of heterogeneities/reservoir quality for such beds in deep-marine lobe deposits, which in many areas form important hydrocarbon reservoirs, and for interpreting the significance of these deposits in core and outcrop datasets.

Selected References

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Statoil

Flow-substrate interaction at the fringes of deep-marine lobes: Skoorsteenberg Fm. Tanqua Karoo

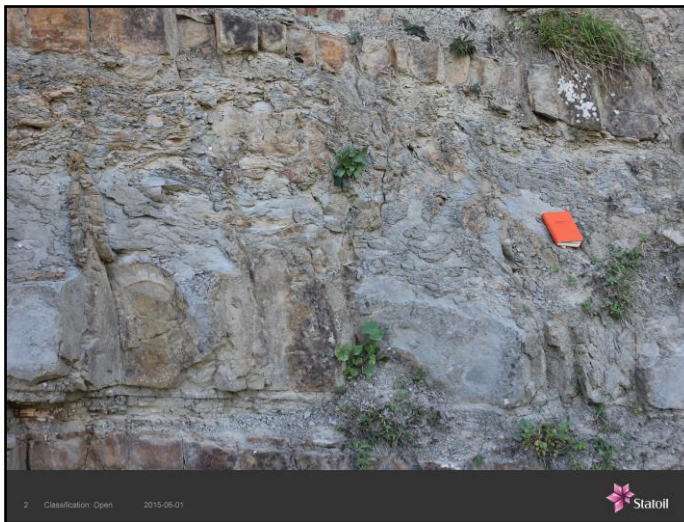
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Classification: Open

2015-06-01



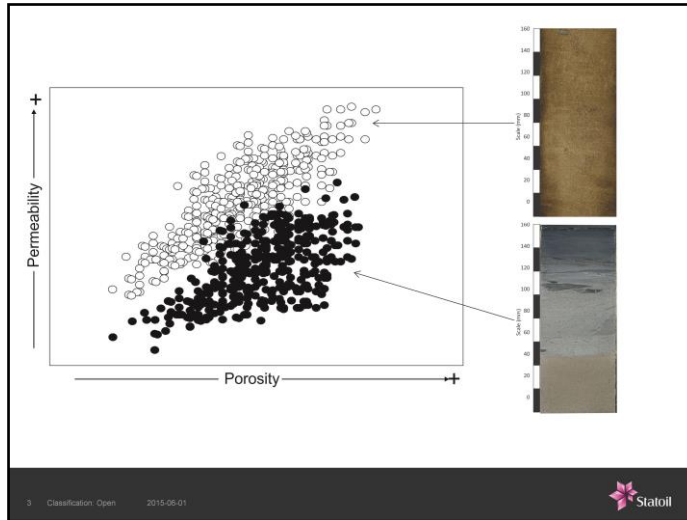
2 Classification Open 2015-06-01



Presenter's notes: Hypothesis: the transition from turbulent to laminar behaviour is due to an increase in near-bed flow concentration due to deceleration and/or erosion of substrate sediment associated with the channel-lobe transition.

Can this be constrained using an outcrop analogue?

Can facies be better related to architectural elements? Simple sheets?

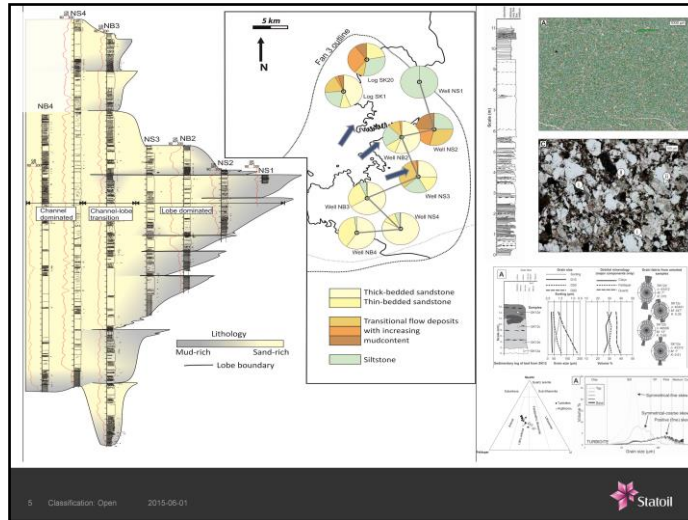


Presenter's notes: See them in big fine grained systems.

Skoorsteenberg Fm., Permian, Tanqua Karoo, South Africa



Presenter's notes: The Karoo Basin is interpreted as a retro-arc foreland basin developed inboard of a fold and thrust belt during the late Palaeozoic to early Mesozoic.



Presenter's notes: **Aims and objectives**

Trace out individual lobes within Fan 3.

Characterise deposit types.

Document lateral and stratigraphic facies variability.

Document the observed progressive downslope transition from turbidites to argillaceous sandstones.

Develop conceptual model for flow evolution.

Turbidites



Presenter's notes: Clear indications of interaction with substrate.
It's not the LDTs that turn into TFDs is it? Too low concentration?

Typically:

Few mm to 6 m thick.

Erosive bases.

Graded m-f-vf up to silty tops.

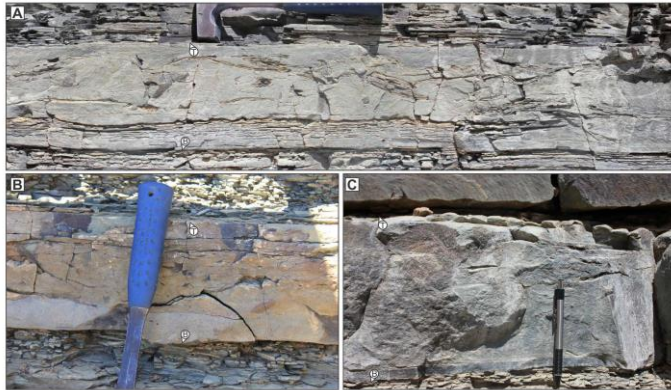
Often 'classical' sequence of structures (Bouma).

Clast-rich in upper parts (layer-bound).

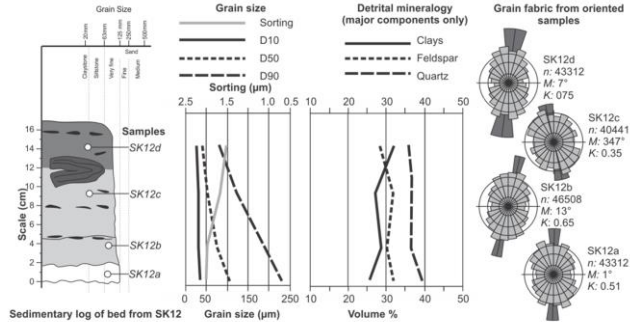
Interaction of turbidity currents with substrate



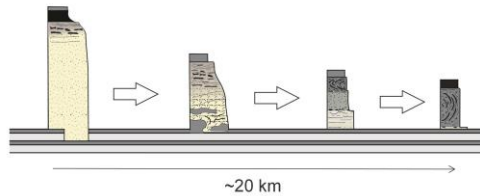
Argillaceous sandstones



Grain size, composition, fabric: argillaceous sandstone



Process model



Presenter's notes: From turbidites deposited by well-mixed turbidity currents, to TFDs by progressively more stratified flows.

Flow stratification

Bulk Richardson number (Ri)

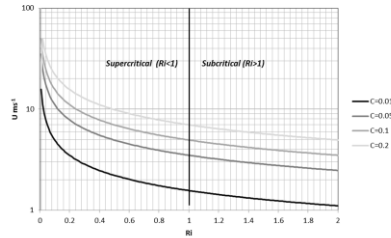
$$Ri = \frac{RgCh}{U^2}$$

$$R = \left(\frac{\rho_s}{\rho_f} \right) - 1$$

Fan 3 channel depths (H) ~6-12 m

$H/h \leq 1.3$ (Mohrig & Butties, 2007)

Minimum estimate of ~16 m



Ri , as a product of mean flow velocity and sediment settling velocity, modulates the density stratification and grain-size stratification of the flow.

Presenter's notes: Figure 16. Bulk Richardson number plotted against layer averaged flow velocity for a range of Fan 3 turbidity currents, from dilute flows ($C=0.1$ volumetric concentration, i.e., 1% concentration) to more concentrated flows up to 20%. Flow deceleration increases Ri and thus the flows are progressively more strongly density stratified. Lower concentration flows can reach lower velocities whilst maintaining supercritical behaviour. Higher concentration flows are more prone to subcritical behaviour.

Sediment settling

Stokesian settling (w_s)

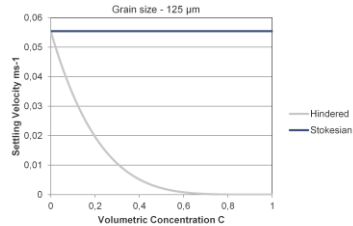
$$w_s = \frac{2(\rho_s - \rho_f)gr^2}{9\mu}$$

With 'natural particles' (w_{sn}) Zhiyao et al. (2008)

$$w_{sn} = \frac{v}{d} d_*^3 [38.1 + 0.93 d_*^{12/7}]^{-7/8}$$

In 'natural flows' Richardson and Zaki (1954)

$$w_{hs} = w_{sn}(1 - C)^n$$



Settling velocity decreases with increasing flow concentration

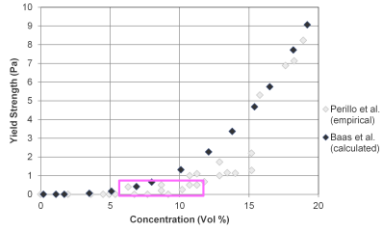
Particle support by yield strength

Criteria for grain support (Hampton, 1970)

$$d_{max} = \frac{8.4\tau_y}{(\rho_p - \rho_f)g}$$

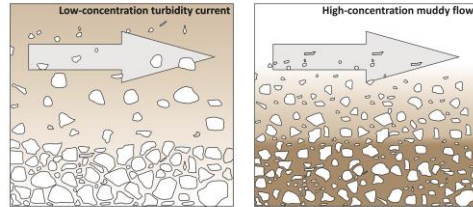
Yield strength estimation (Wan, 1982)

$$\tau_y = 1280 \left(\frac{C}{100} \right)^3$$

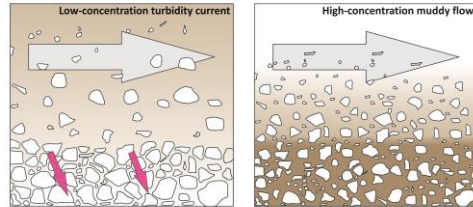


Presenter's notes: Hampton (1970) demonstrated that this was a reliable approximation for sand particles submerged in a clay-water matrix. For our 125 μm quartz grains, that equates to a very low yield strength, 0.2 Pa, required to maintain grains in laminar support (Figure***). Estimates of flow concentration by analogy to physical experimental data (from Perillo et al. in review) suggest concentrations in the range of 6 % would be required to generate the necessary yield strength to support our 125 μm quartz grains (Figure **). The experimental data from Perillo et al. (in review) are illustrated alongside calculated yield strength values from the experimental flows of Baas et al. (2011) purely for comparison (Figure **). Here, yield strength values were calculated following Wan (1982): Figure 17. Experimental data for varied clay/silt/sand mixtures (from Perillo et al., in review) and calculated yield strength values for the range of experimental flows of Baas et al., (2011), using Wan (1982). Using the estimated yield strength values to support 125 μm quartz grains, the empirical data and the formulation of Wan (1982) suggest minimum concentrations in the range of 6%, negating the effects of shear thinning.

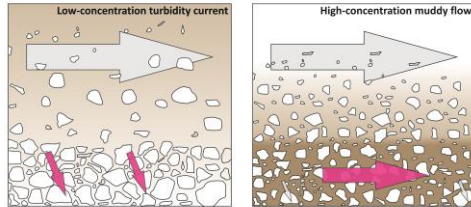
Why would rheologically stratified flows form?



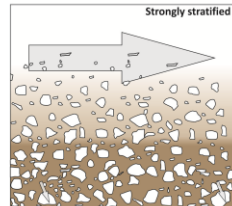
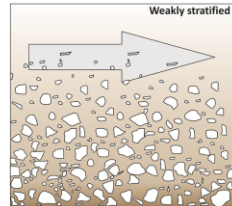
Why would rheologically stratified flows form?



Why would rheologically stratified flows form?



Abrupt flow transformation?



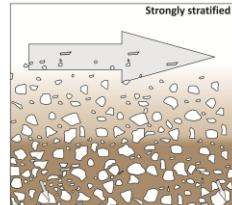
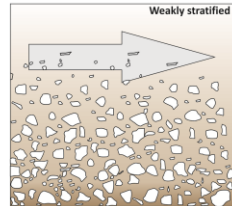
Abrupt flow transformation?

Flux Richardson number (R_{if})

$$R_{if} = \frac{\rho_s - \rho_f}{\rho_f} \frac{ghw_{hs}C_{gel}}{U^2} \phi_f (1 - \phi_f)^5$$

$$\phi_f = C/C_{gel}$$

(Wintwerp & Kesteren, 2005)



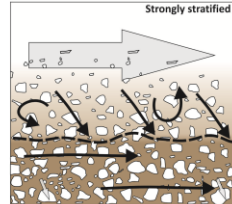
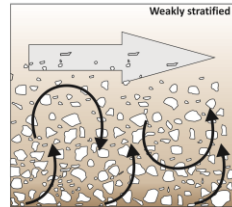
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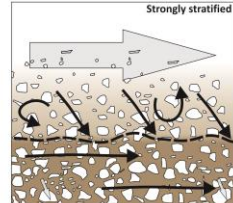
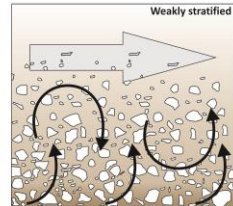
$$\phi_f = C/C_{gel}$$

(Wintwerp & Kesteren, 2005)

Critical flux Richardson number (R_{ifcr})

$$R_{ifcr} = 0.15 - 0.2$$

(Turner, 1973; Tennekeks and Lumley, 1994)



Abrupt flow transformation?

Flux Richardson number (R_{if})

$$R_{if} = \frac{\rho_s - \rho_f}{\rho_f} \frac{ghw_{hs}C_{gel}}{U^2} \phi_f (1 - \phi_f)^5$$

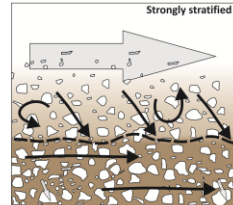
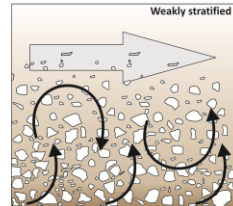
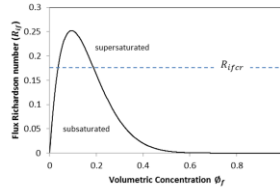
$$\phi_f = C/C_{gel}$$

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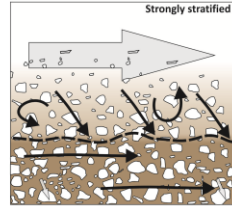
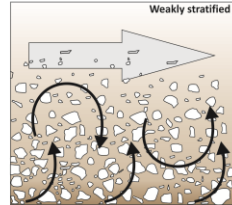
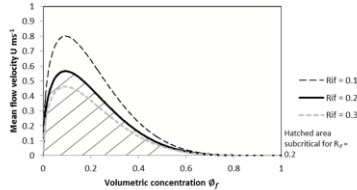
$$\phi_f = C/C_{gel}$$

(Wintwerp & Kesteren, 2005)

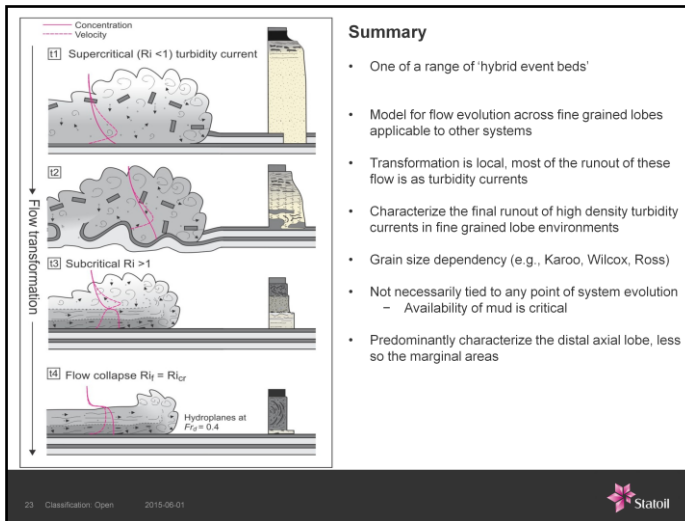
Critical flux Richardson number (R_{ifcr})

$$R_{ifcr} = 0.15 - 0.2$$

(Turner, 1973; Tennekeks and Lumley, 1994)



Presenter's notes: Figure 19. Computed values of the flux Richardson number R_{if} for a systematically increasing volumetric concentration, ϕ_f . Initially R_{if} increases with increasing ϕ_f but then decreases, partly due to hindered settling effects acting against buoyancy effects. At a critical value, $R_{ifcr}=0.2$ (Tennekeks and Lumley, 1994), the flow becomes supersaturated meaning that effective mixing between layers is inhibited, and the turbulent flow field above the higher concentration lower layer, collapses.



Presenter's notes: Figure 21. Summary diagram of flow evolution and deposit type for flows which start out, at t1, fully turbulent and well mixed, capable of eroding and entraining substrate and characterized by supercritical Ri numbers. As flows decelerate from the channel-lobe transition (t2), they lose their power, leaving substrate interaction preserved and resultant deposits clast and mud rich. Further deceleration and enrichment in cohesive and fine grained material (t3) results in the concentration profile becoming increasingly stratified, characterised by subcritical Ri values. A dense lower layer forms, which continues to move downslope owing to its high water content (due to clays and very fine silts), grains are supported by yield strength but coarser grains settle resulting in a relatively well sorted sand fraction within a mud-rich matrix. Overlying layers are muddier and less well sorted. Finally (t4), the strength of the internal stratification hinders vertical mixing, characterised by the flux Richardson number, Ri_f which when it reaches a critical value, induces collapse of the overlying turbulent flow field and en-masse settling of the sediment in the upper layer to form a debris flow. Deposits typically have a thin relatively clean siltstone or sandstone at their base and an overlying ungraded mud-rich sandstone.

Transitional flow deposits, Karoo
(AAPG, ACE 2015, Denver)

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