The Impact of Slope Topography on Sediment Partitioning and Depositional Architecture in a Deepwater Lower Slope Setting*

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Abstract

Seismic reflection datasets of slope and base-of-slope systems are widely employed to resolve stratigraphic and architectural features and improve characterization and prediction of sediment delivery to the deep basin. Here, detailed outcrop studies integrated with core and well log data from Unit 5 of the Permian Skoorsteenberg Formation in the Karoo Basin, South Africa reveal important stratigraphic and architectural features (seismic- and sub-seismic scale) of channel and fan systems on a variable slope profile. The interpreted stepped-slope morphology is characterized by spatial and temporal changes in depositional facies and architecture, channel aspect ratio and stacking pattern. Key interpreted depositional environments include channels and overbank deposits, channel-lobe transition zones (CLTZ), frontal splays and lobes, and hemipelagic drape complexes. These architectural features reflect a combination of active and relatively passive sediment supply systems. Channel incision results from knickpoint migration headward from a relative increase of slope gradient while deposition of frontal splays and lobes is associated with a reduction in gradient and confinement. The CLTZs represent areas where flow confinement decreases abruptly, and are characterized by an assemblage of erosional and depositional features. Preferential accumulation of sediment and ‘healing’ of the slope is believed to reflect the deceleration of sediment gravity flows as they encountered lower-gradient steps and partial (flow stripping) or full confinement. We speculate that changes in the equilibrium profile and slope morphology also caused variations in the amount and rate of erosion with increased incision where knickpoints cut through bathymetric highs in an attempt to establish a graded profile. This exhumed slope succession provides an opportunity to constrain the stratigraphic and spatial distribution of this critical part of a deep-water system and emphasizes the role topography plays in partitioning sediment on siliciclastic continental slopes. Importantly, studies such as this facilitate the development of predictive models for application to sub surface datasets and are of particular relevance when predicting reservoir presence and quality in areas poorly constrained by wells and seismic.

Selected References

Adeogba, A.A., T.R. McHargue, and S.A. Graham, 2005, Transient fan architecture and depositional controls from near-surface 3-D seismic data, Niger Delta continental slope: AAPG Bulletin, v. 89, p. 627-643.

Allen, J.R.L., 1973, A classification of climbing-ripple cross-lamination: Journal of the Geological Society, v. 129, p. 537-541, doi: 10.1144/gsjgs.129.5.0537.

Deptuck, M.E., Z. Sylvester, and C. O'Byrne, 2012, Pleistocene seascape evolution above a "simple" stepped slope - western Niger Delta: SEPM Society for Sedimentary Geology, Special Publication No. 99, p. 199-222.

Prather, B.E., C. O'Byrne, C. Pirmez, and Z. Sylvester, 2017, Sediment partitioning, continental slopes and base-of-slope systems: Basin Research, v. 29, p. 394-416.

Wild, R., S.S. Flint, and D.M. Hodgson, 2005, Architecture and stratigraphic evolution of multiple, vertically-stacked slope-channel complexes, Tanqua depocentre, Karoo Basin, South Africa: Geol. Soc. London Spec. Publ. No. 244, p. 89-112.

Wild, R., S.S. Flint, and D.M. Hodgson, 2009, Stratigraphic evolution of the upper slope and shelf edge in the Karoo Basin, South Africa: Basin Research, v. 21, p. 502-527.

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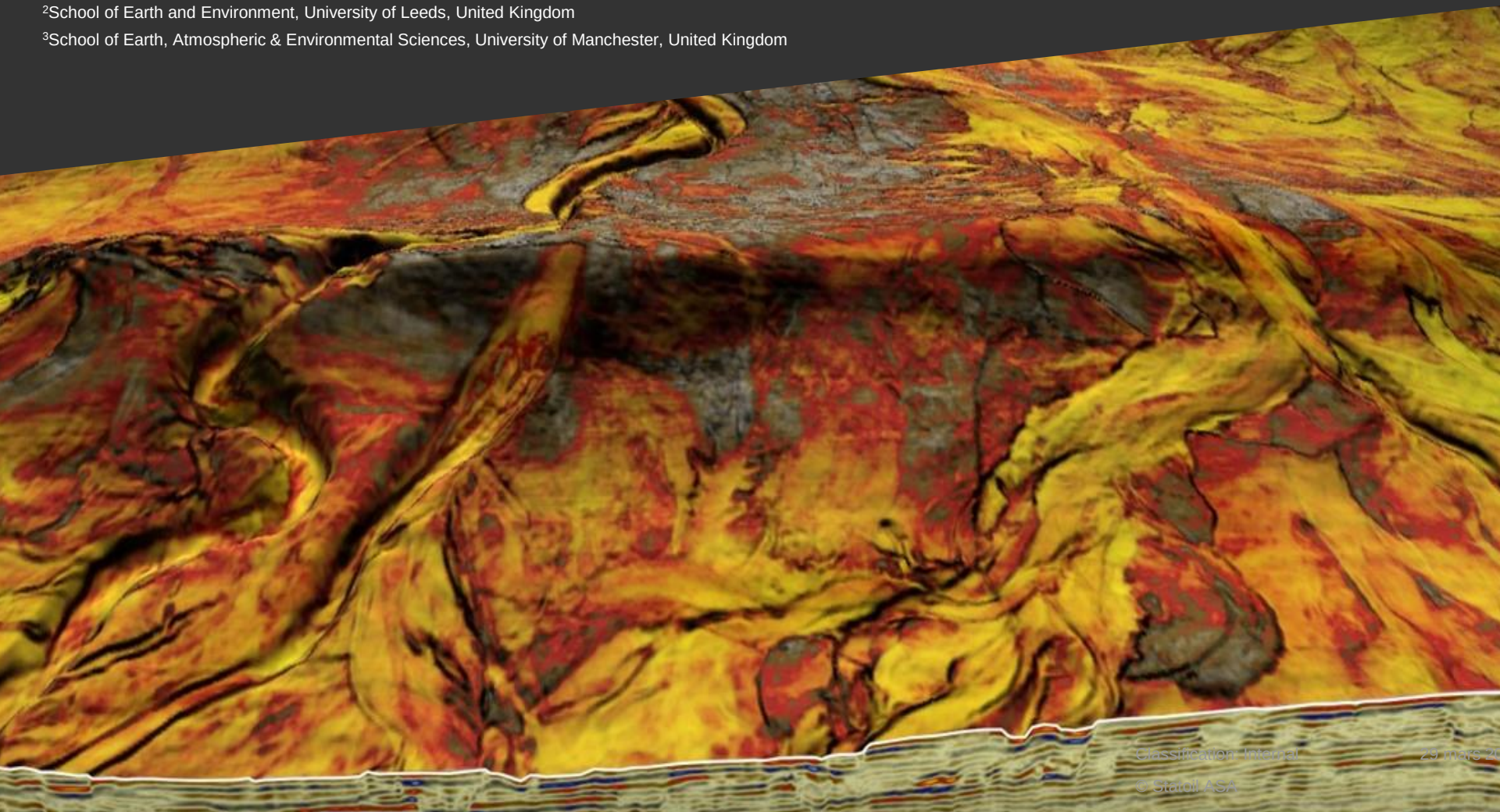
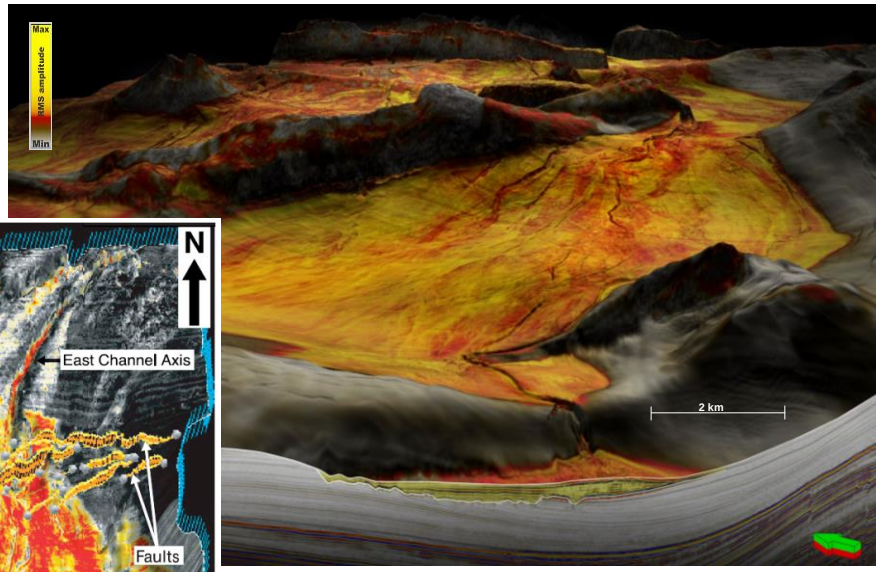


Understanding sediment partitioning in lower slope setting

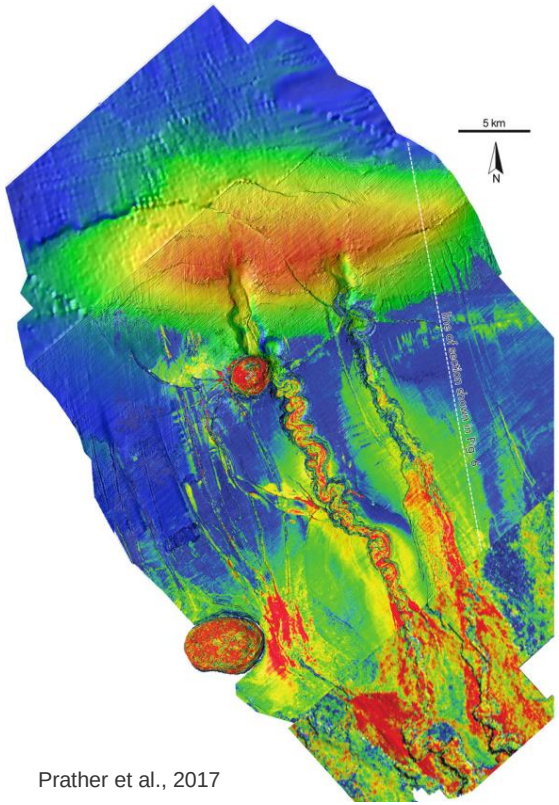
- Slope modifications, either by uplift or subsidence, sediment flux and processes influence the depositional style and architecture in terms of both character and morphology
- Depositional and / or erosional style on the slope is determined by accommodation
  - Concept of equilibrium profile
- Changes in the equilibrium profile (EP) create or destroy accommodation
  - It is the response of the depositional system to these changes that governs many aspects of their architectural development

- Unit 5, Skoorsteenberg Fm., Tanqua Karoo
  - Integrate outcrop and well datasets to investigate stratigraphic variability of the slope to basin floor transition and identify representative depositional sequences and architectures, stacking patterns and net-to-gross distributions
  - Exhibits spatial and temporal variability that reflect subtle changes in the depositional gradient and accommodation

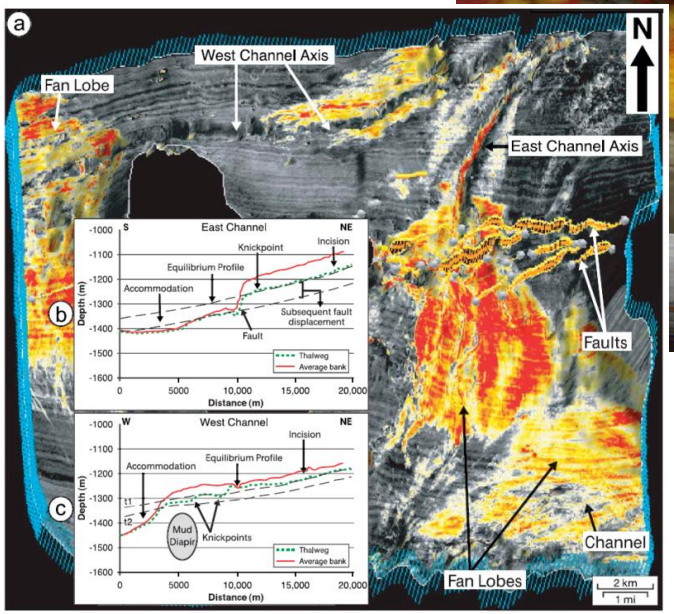
Understanding sediment partitioning in lower slope setting



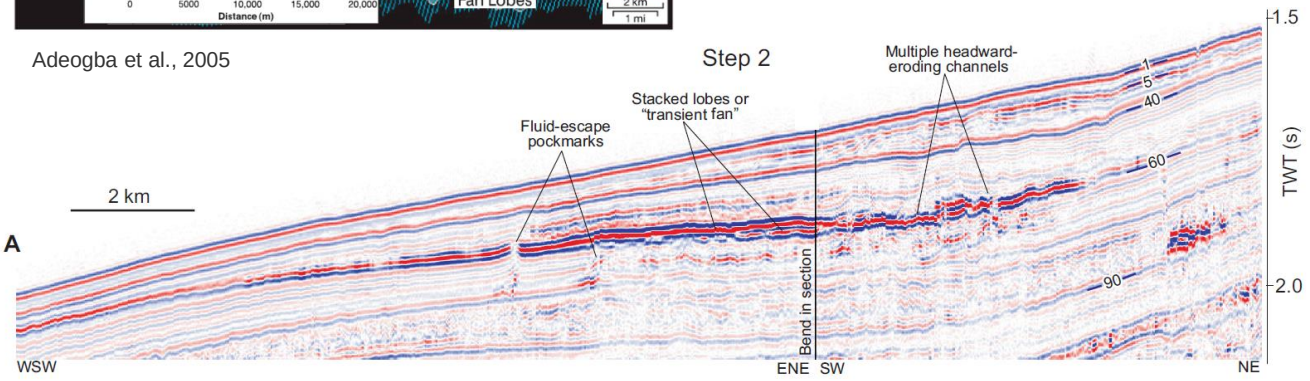
Audun Groth, 2012



Prather et al., 2017

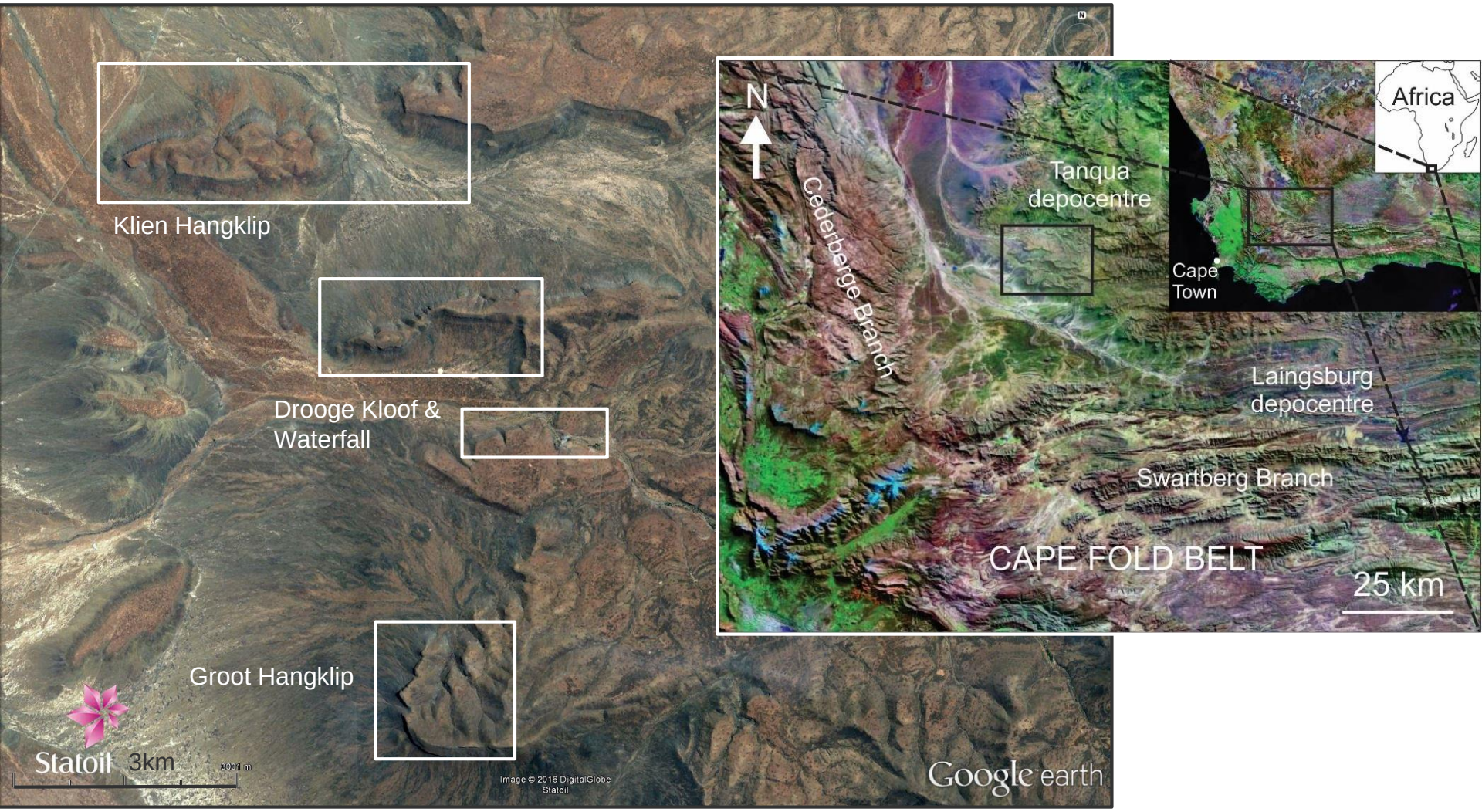


Adeogba et al., 2005



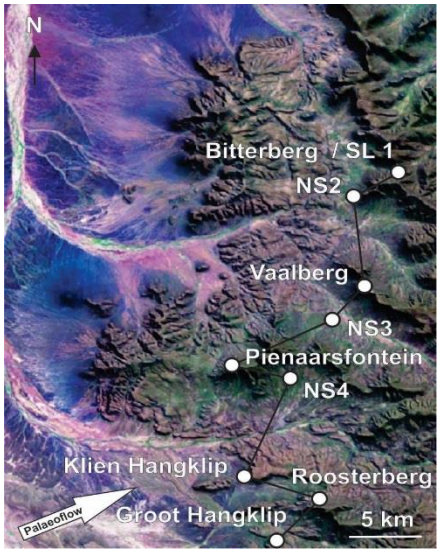
Deptuck et al., 2012

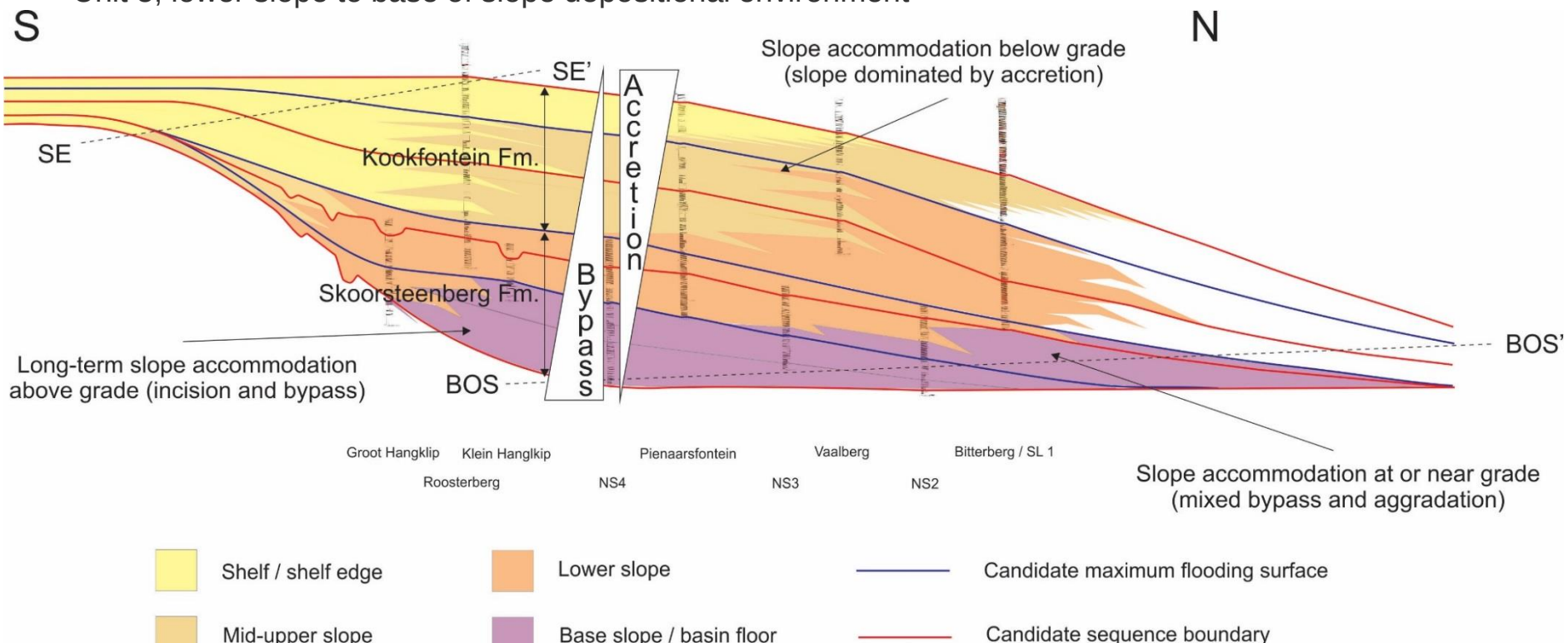
Tanqua depocentre and Hangklip study area



Tanqua depocentre stratigraphy

- Permian, early foreland basin
- Several thousand km of walked out key surfaces, many with dGPS control
- Over 50 km of cumulative measured sections
- 12 fully cored wireline research boreholes
- Extensive helicopter and drone photography
- Unit 5, lower slope to base of slope depositional environment





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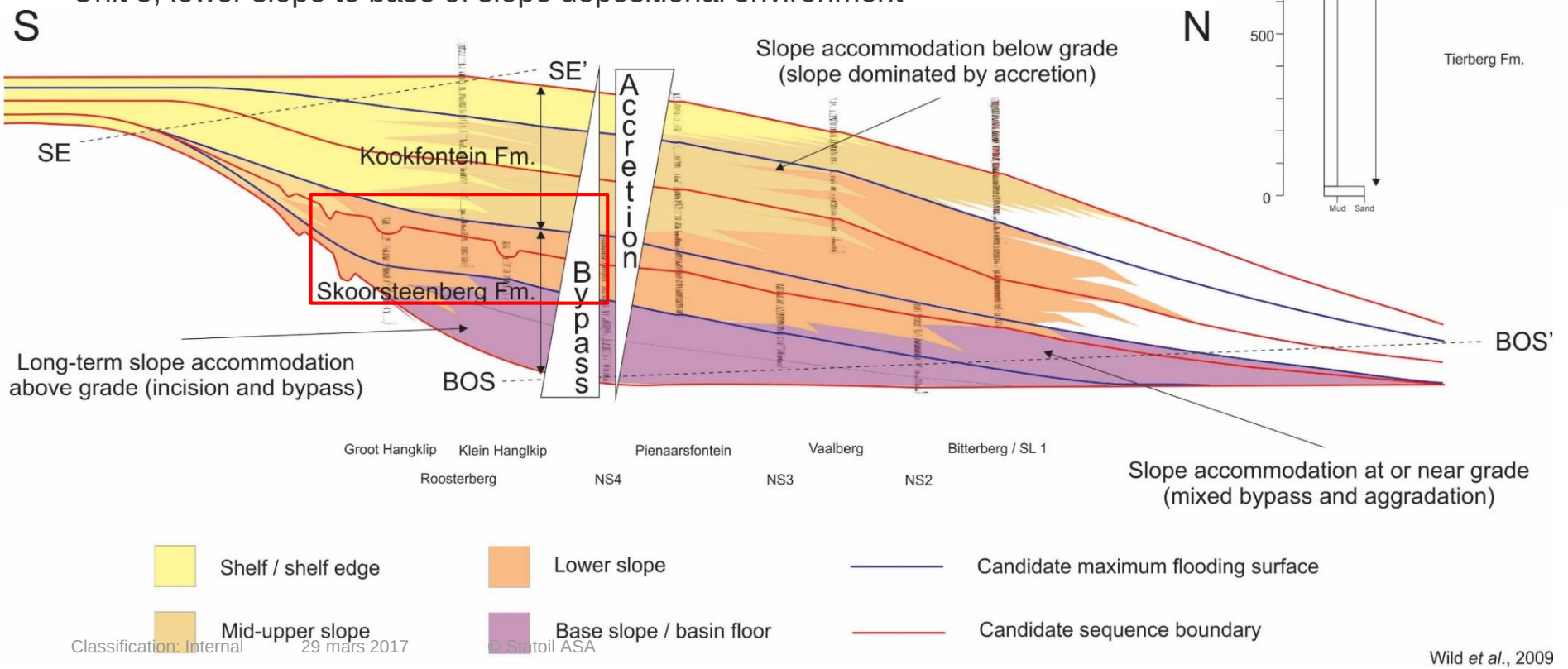
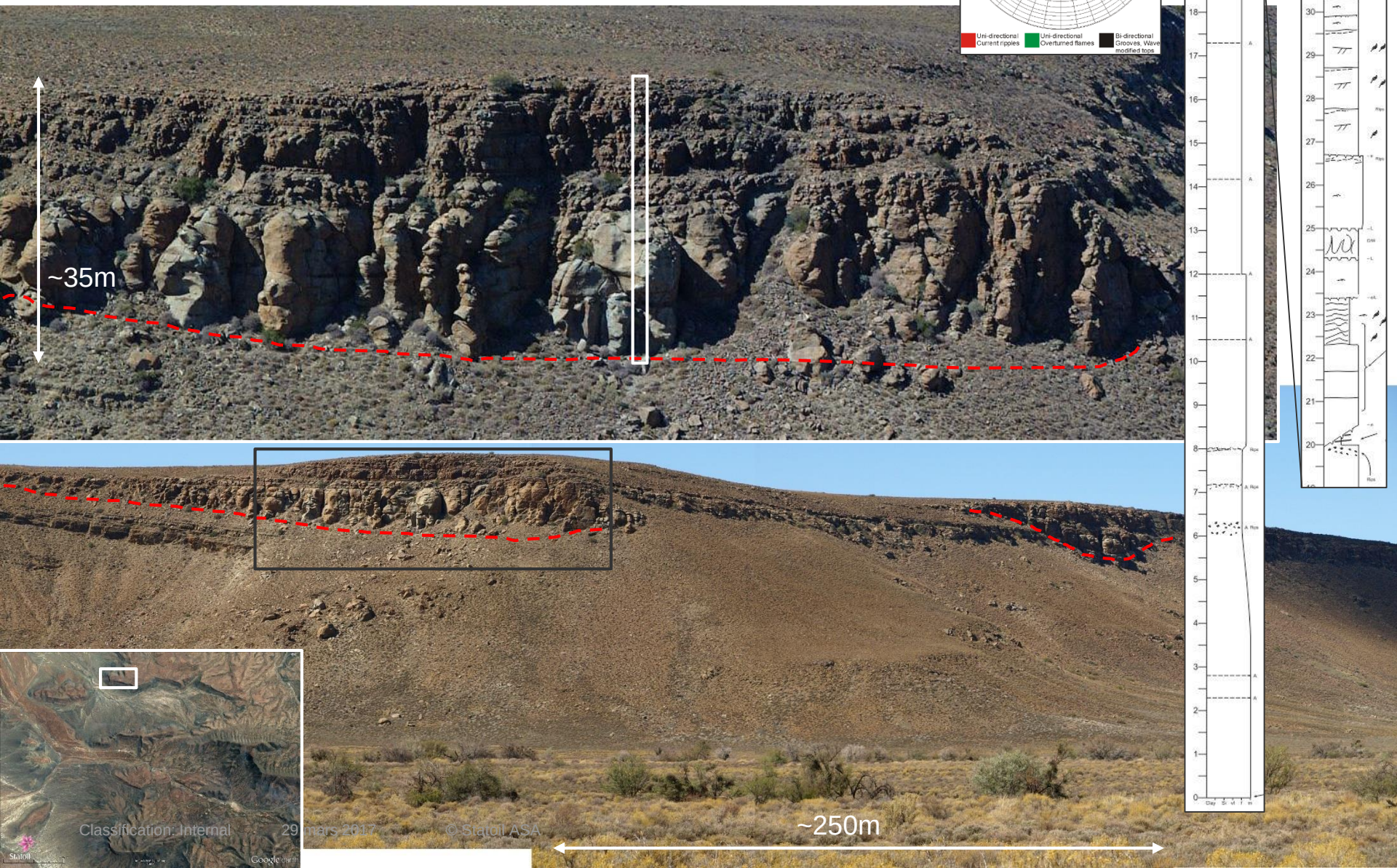


Wild *et al.*, 2009

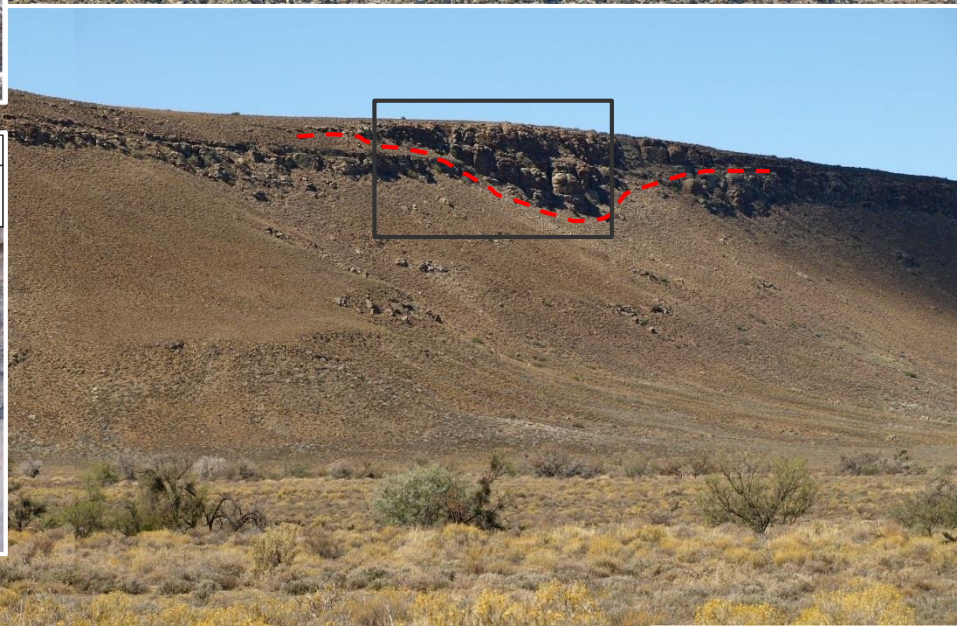
Klien Hangklip, west facing



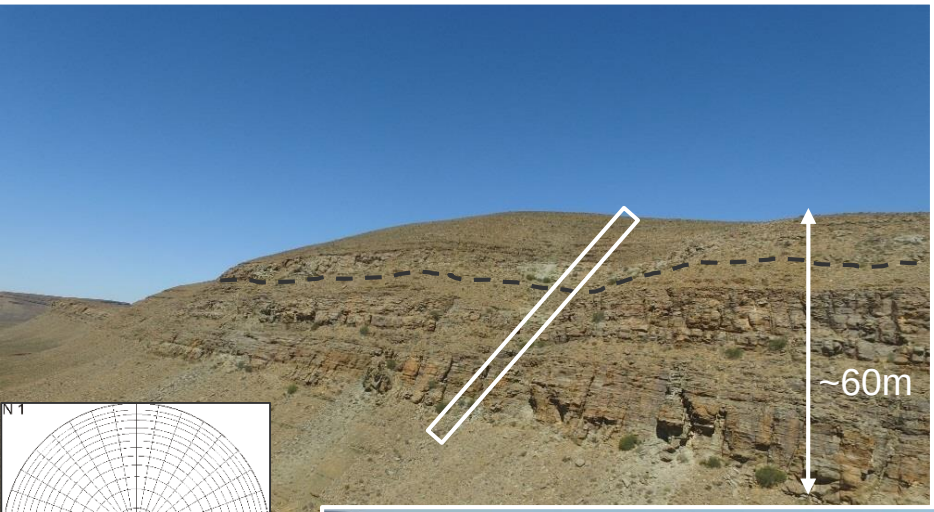
Klien Hangklip

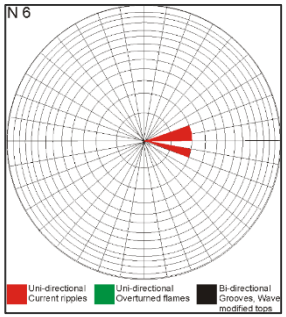
Lithofacies number	Lithology	Sedimentary structures	Turbidite divisions	Bounding surfaces	Thickness	Geometry
Sl 4	Structureless sandstone	Massive, local parallel lamination. Local scour and fill. Dewatering fabrics	Ta	Sharp to erosive base. Sharp tops	0.6-2 m. m+ packages due to amalgamation	Sheet and channel geometries

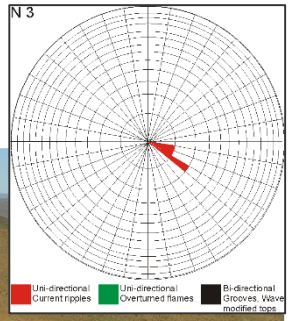
Lithofacies number	Lithology	Sedimentary structures	Turbidite divisions	Bounding surfaces	Thickness	Geometry
Sl 5	Lag	Clast and matrix supported	-	Sharp to erosional base, gradational to sharp top	Up to 0.5 m	Lenticular pockets. Local scour and fill

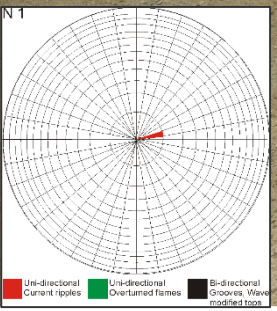


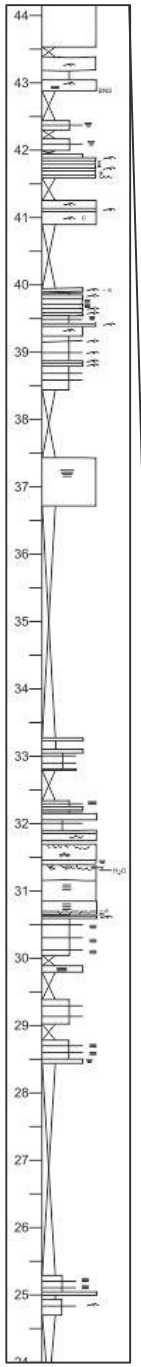
Klien Hangklip, north facing

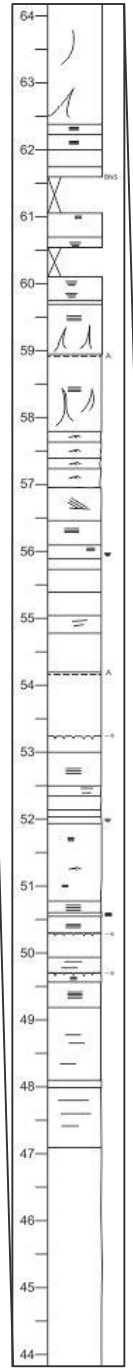


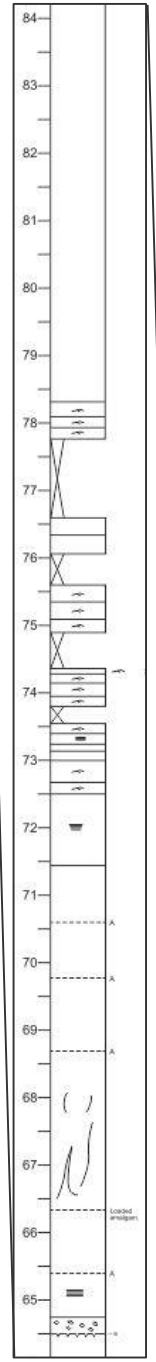


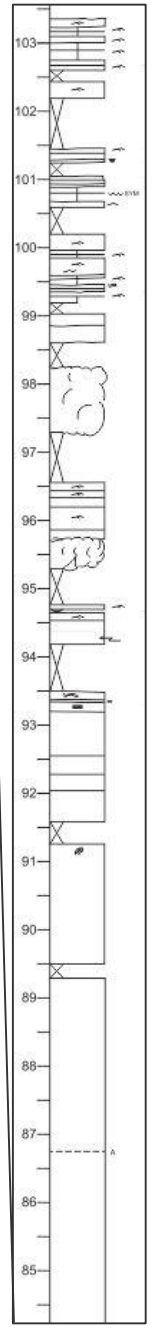




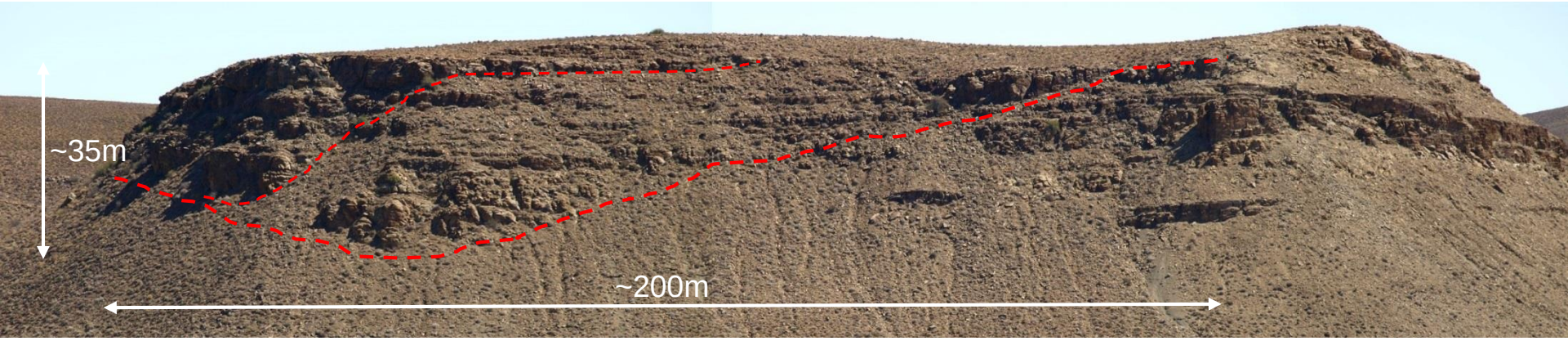




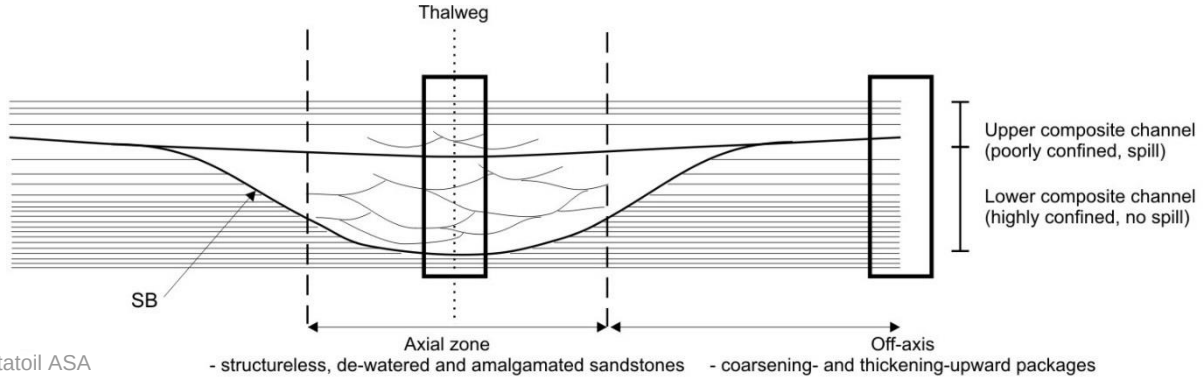




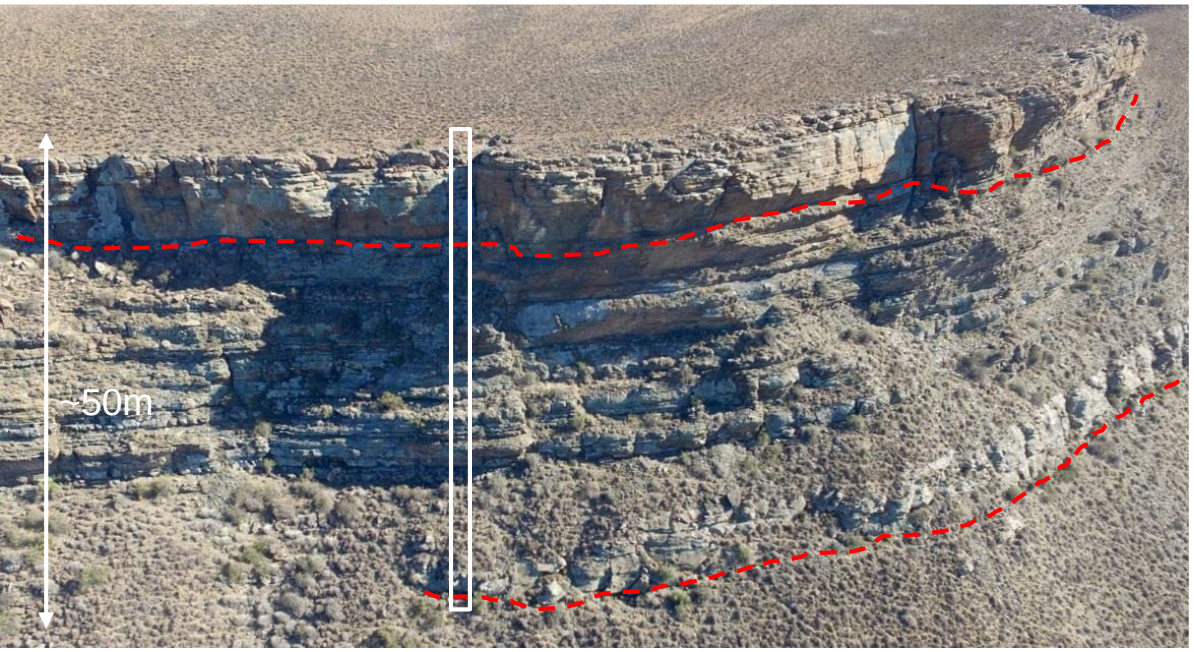
Klien Hangklip, east facing

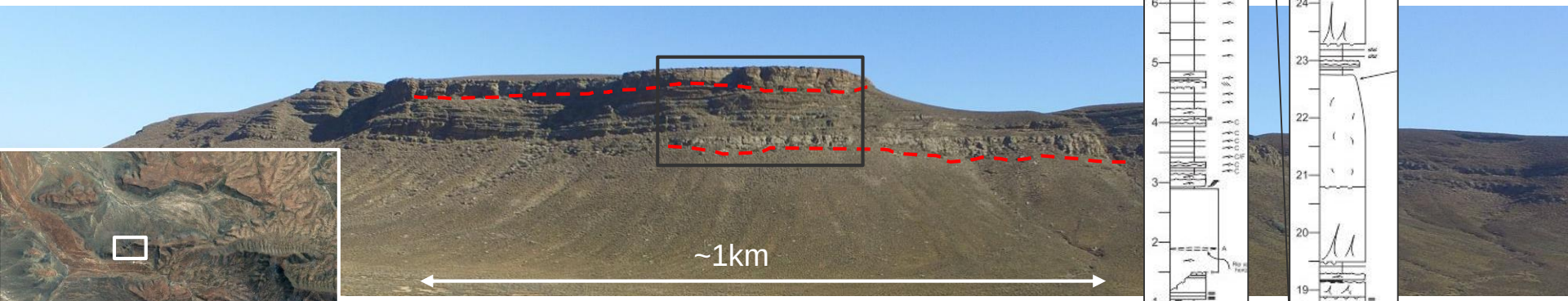


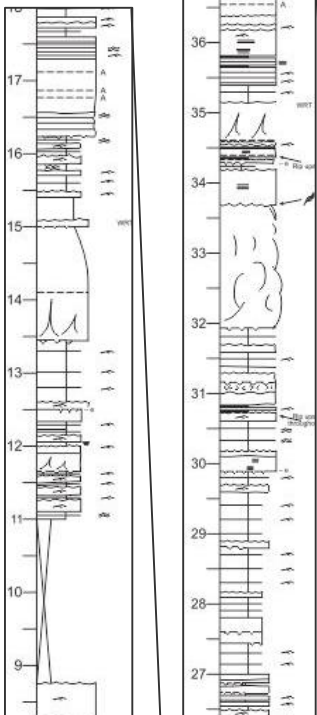
- Characterized by channel complex
- Stratigraphic evolution in depositional style and architecture
- Erosionally confined basal part
  - Composite basal erosion surface commonly overlain by lag / bypass facies
  - Complex fill style reflecting multiple episodes' erosion and deposition
- Weakly confined upper part
- Low to moderate sinuosity

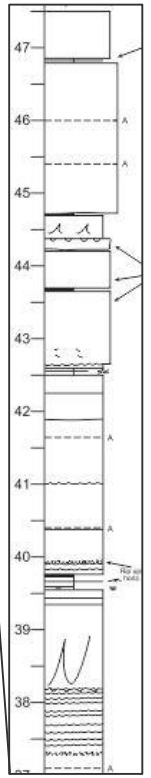


Drooge Kloof, south facing









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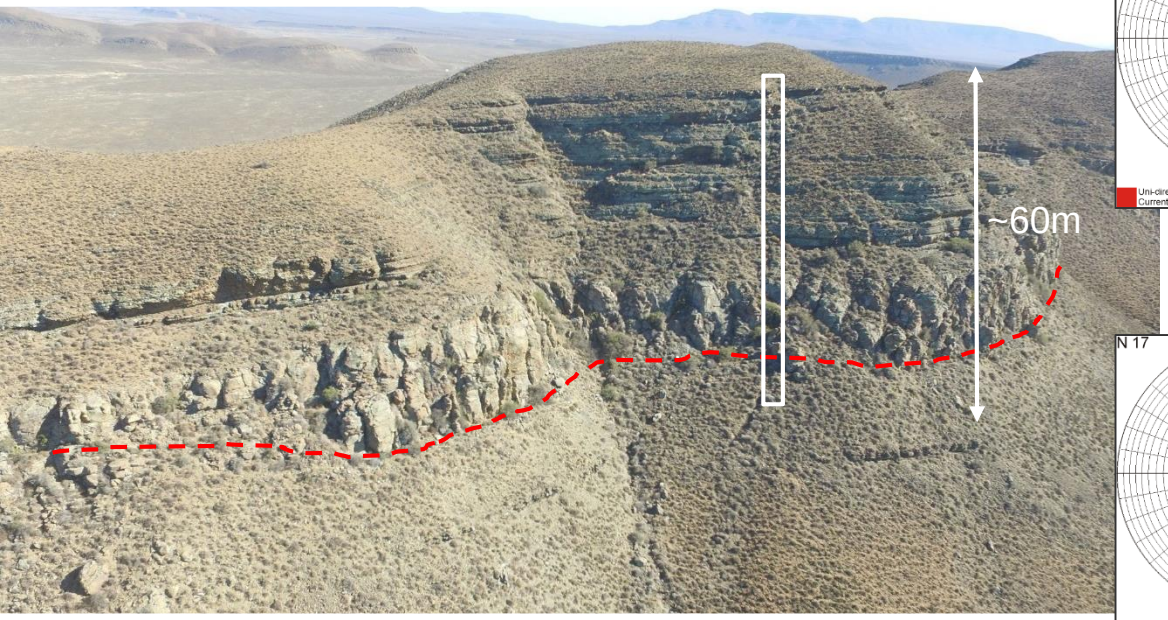
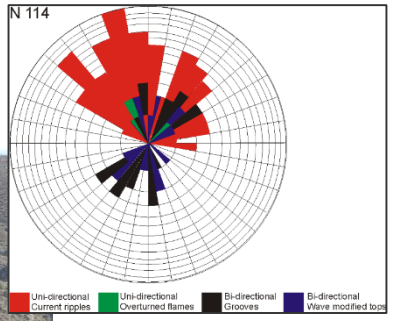
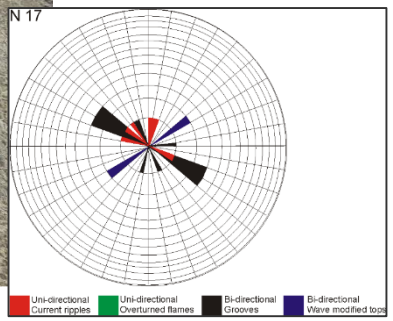
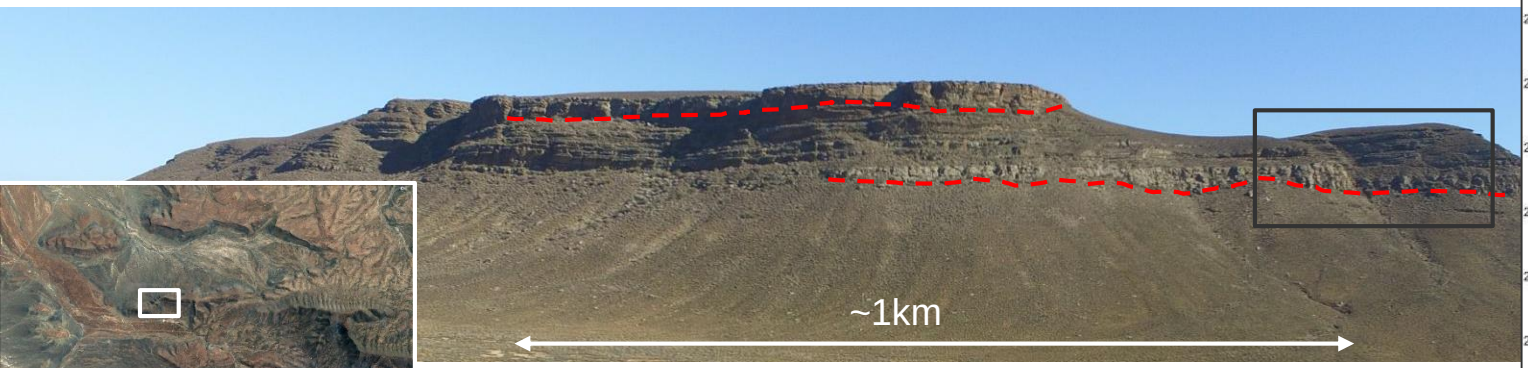
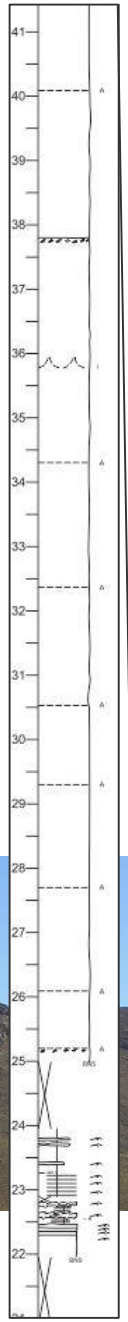
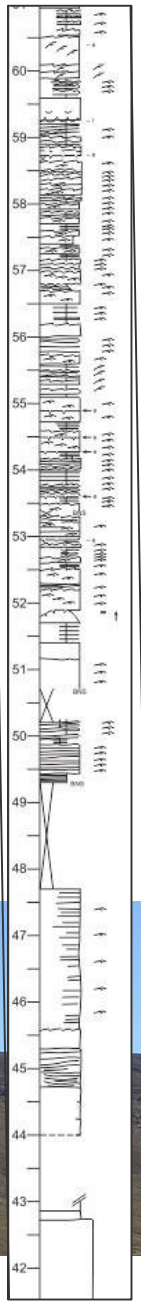


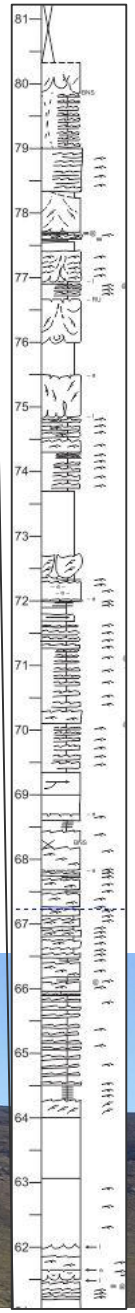






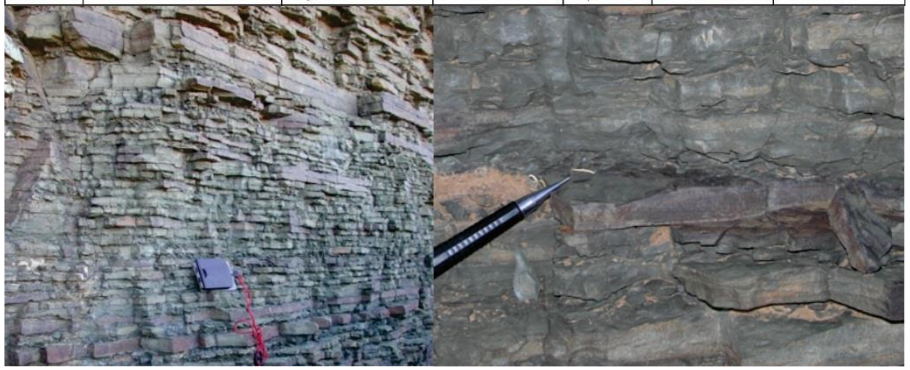






Drooge Kloof

Lithofacies number	Lithology	Sedimentary structures	Turbidite divisions	Bounding surfaces	Thickness	Geometry
Sl 1	Siltstone-sandstone interbeds	Silt to vfs have starved ripples, parallel lamination and massive nature. Prods and grooves on base	Variable. Common Tcde, Tde and Tbc	Sands have sharp base, tops gradational to sharp	0.01-0.05 m	Individual beds tabular at the outcrop scale. Units display a sheet geometry

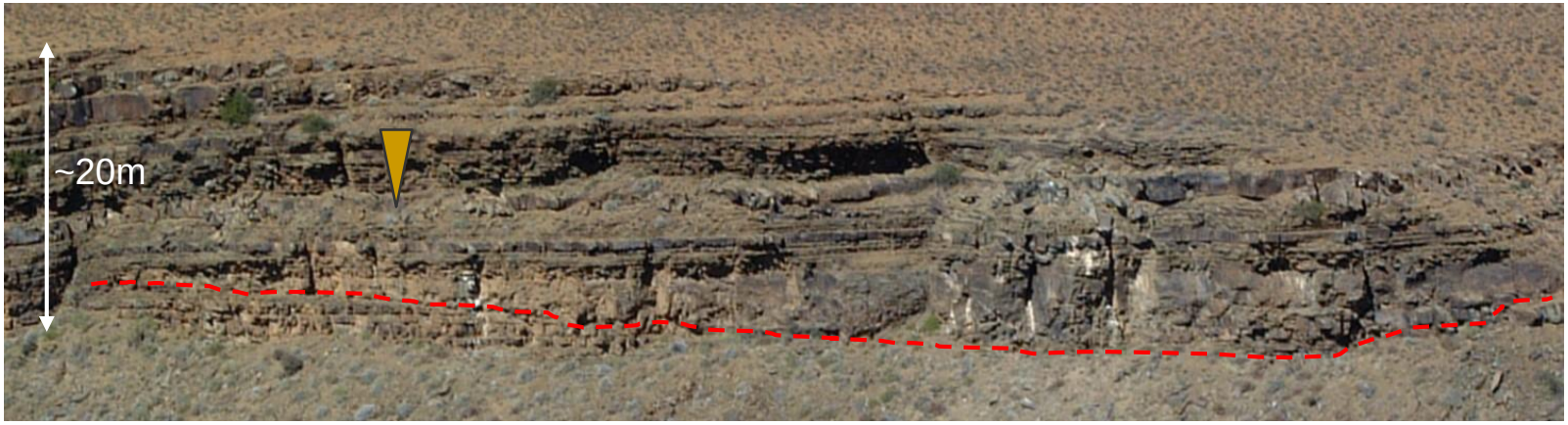


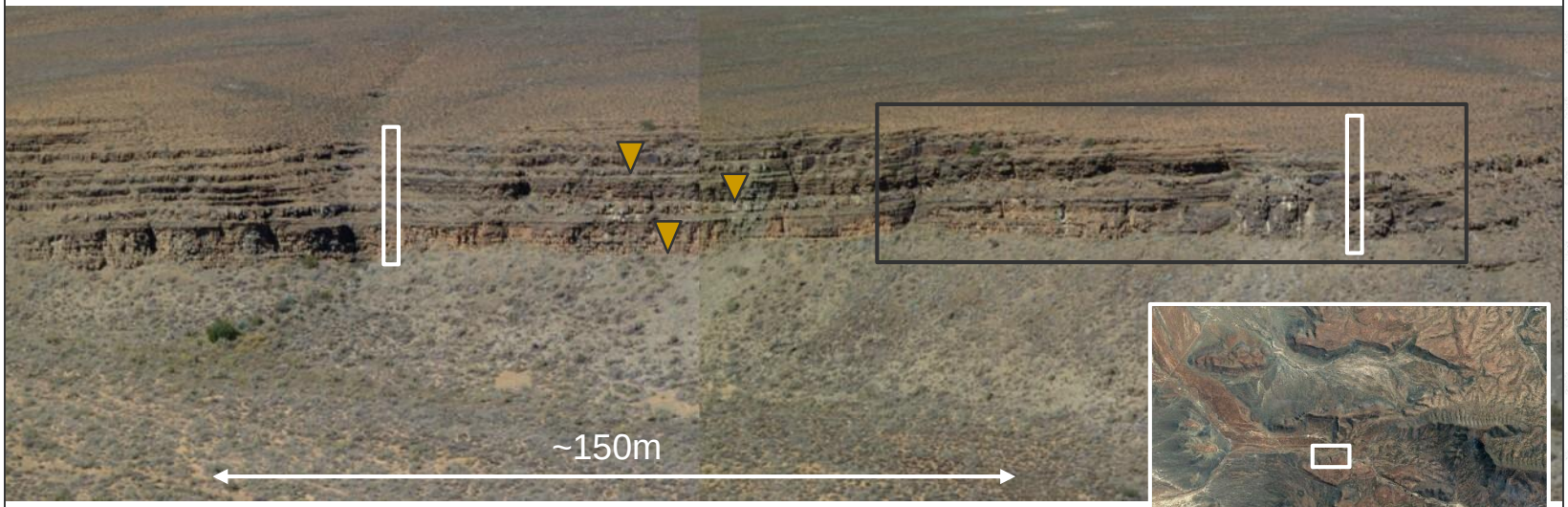
Lithofacies number	Lithology	Sedimentary structures	Turbidite divisions	Bounding surfaces	Thickness	Geometry
Sl 3	Bedded sandstone	Common massive base, parallel, climbing ripples. Some scour and fill. Dewatering	Tab and Tac common	Bases sharp. Rarely erosional	0.2-0.6 m	Tabular to locally lenticular. Units form sheet and channel geometries

Lithofacies number	Lithology	Sedimentary structures	Turbidite divisions	Bounding surfaces	Thickness	Geometry
Sl 2	Interbedded sandstone	Variable. Climbing ripples, parallel lamination, massive. Local sigmoid geometry and pinch and swell	Tcde, Tab, Ta-e (former more common)	Sharp bases to sands. Sharp to gradational tops. Upper fine layer (Te) can be absent	Sandstones usually form units dominated by bedding of 0.05-0.1 m, 0.1-0.2 m and 0.20 m+	Beds tabular. Sheet geometry to units

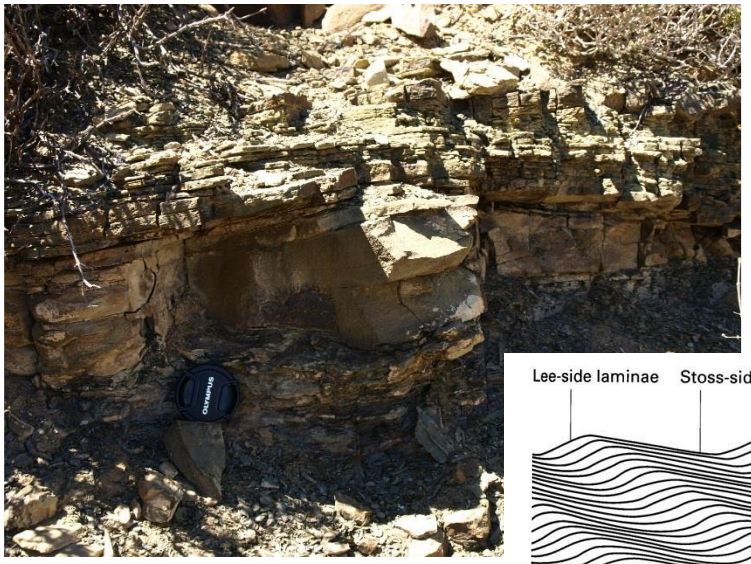
- Common climbing ripple- and upward steepening climbing ripple-laminated sandstone, stoss-side preserved climbing ripples and sigmoid bedforms

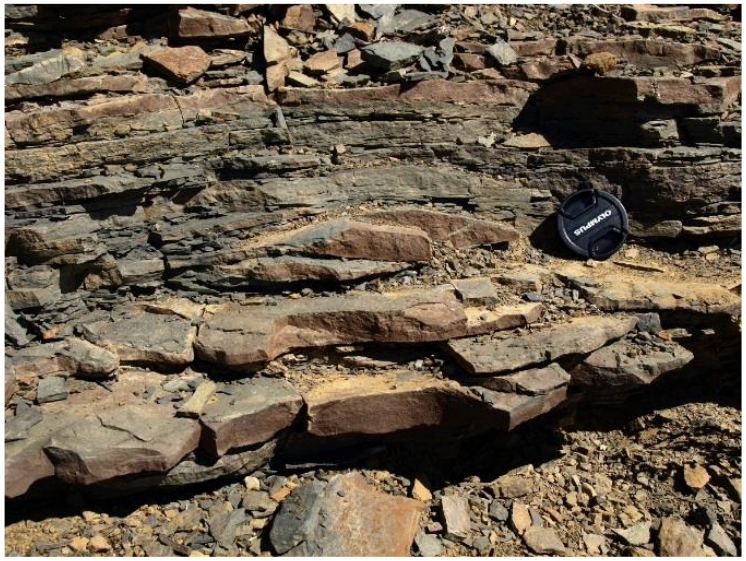
Waterfall

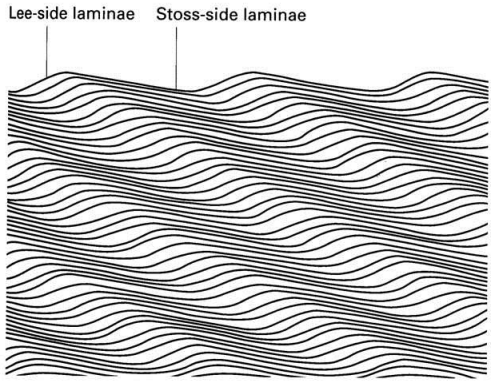




Rapid flow deceleration and aggradation

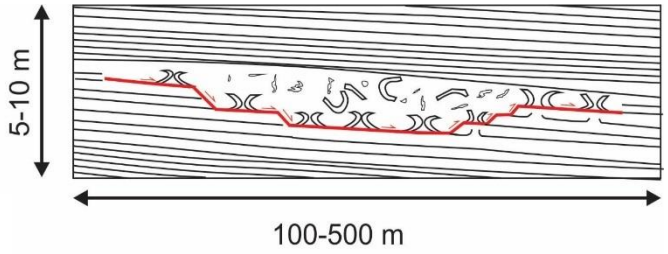


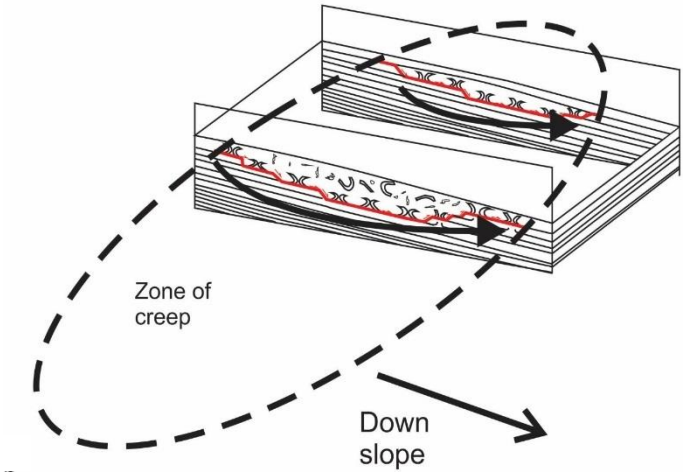




- When sedimentation rate exceeds the rate of erosion at the ripple reattachment point, the stoss-side deposition is preserved and aggradational bedforms develop (Allen, 1973)
- High climb angle and stoss-side preservation in ripple-laminated sandstones are interpreted to represent rapid aggradation rates
- Results from flow deceleration

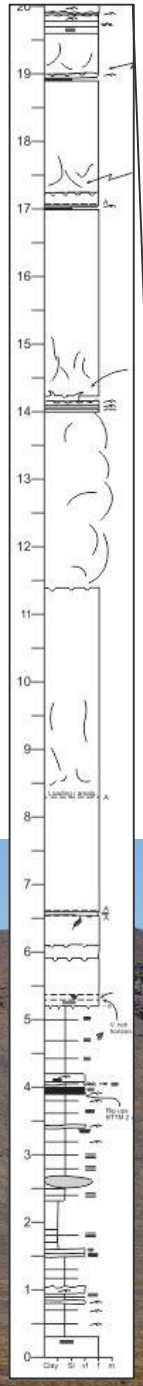
Deformation structures, slope ‘creep’

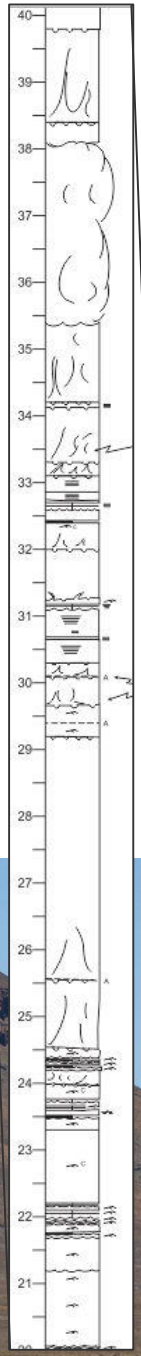


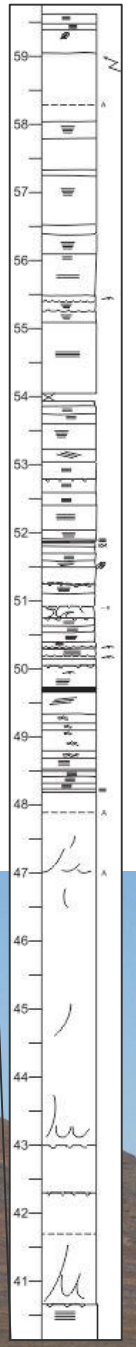


- Dominated by sheets, commonly exhibit coarsening- and thickening-upwards motif
- Laterally off-set, low relief channels and scours
- De-watering, loading and ‘creep’, supports rapid deposition, pos. influence of gradient

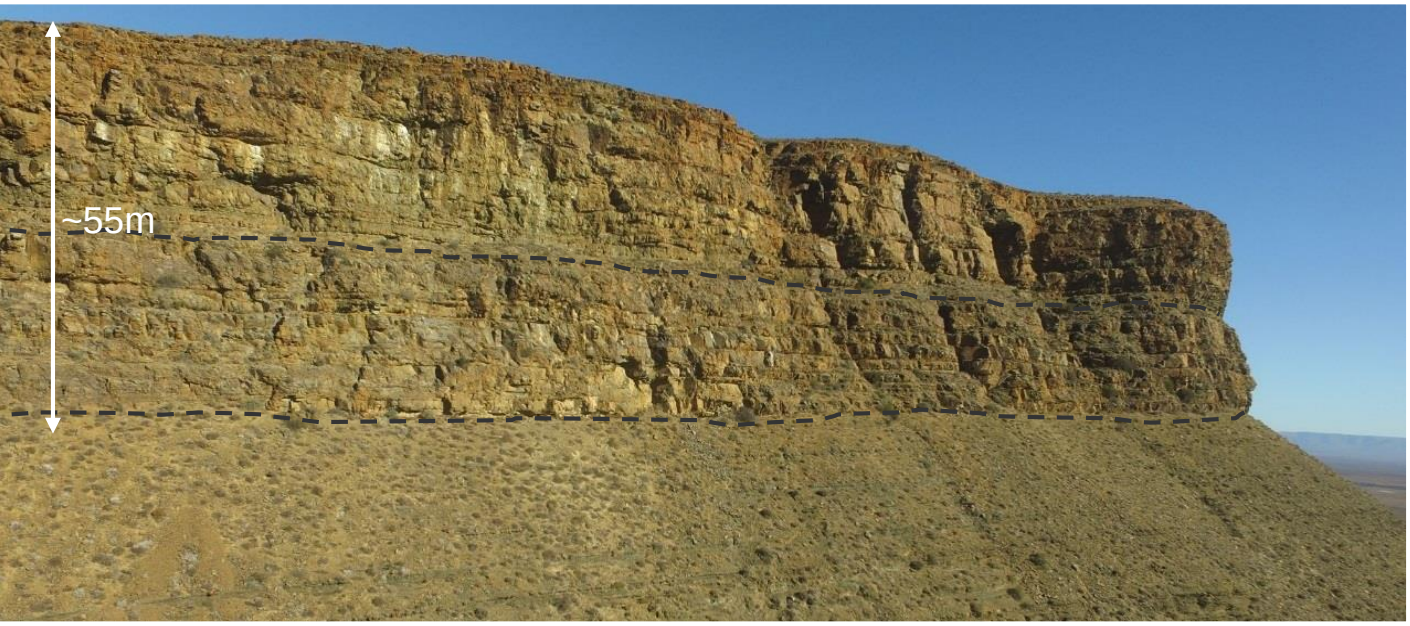
Groot Hangklip

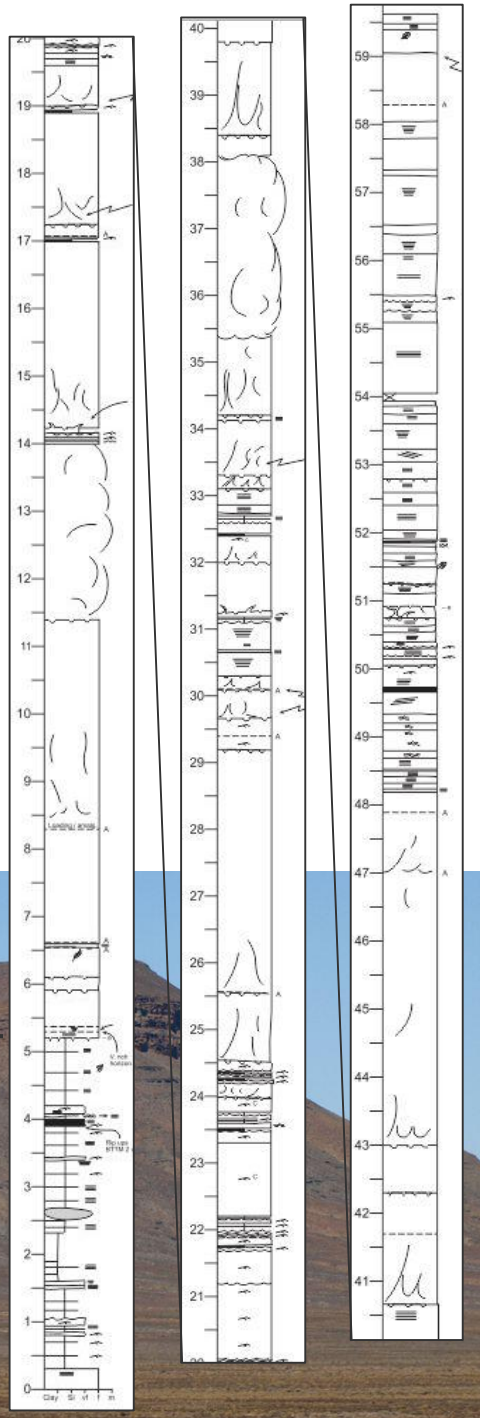






Groot Hangklip





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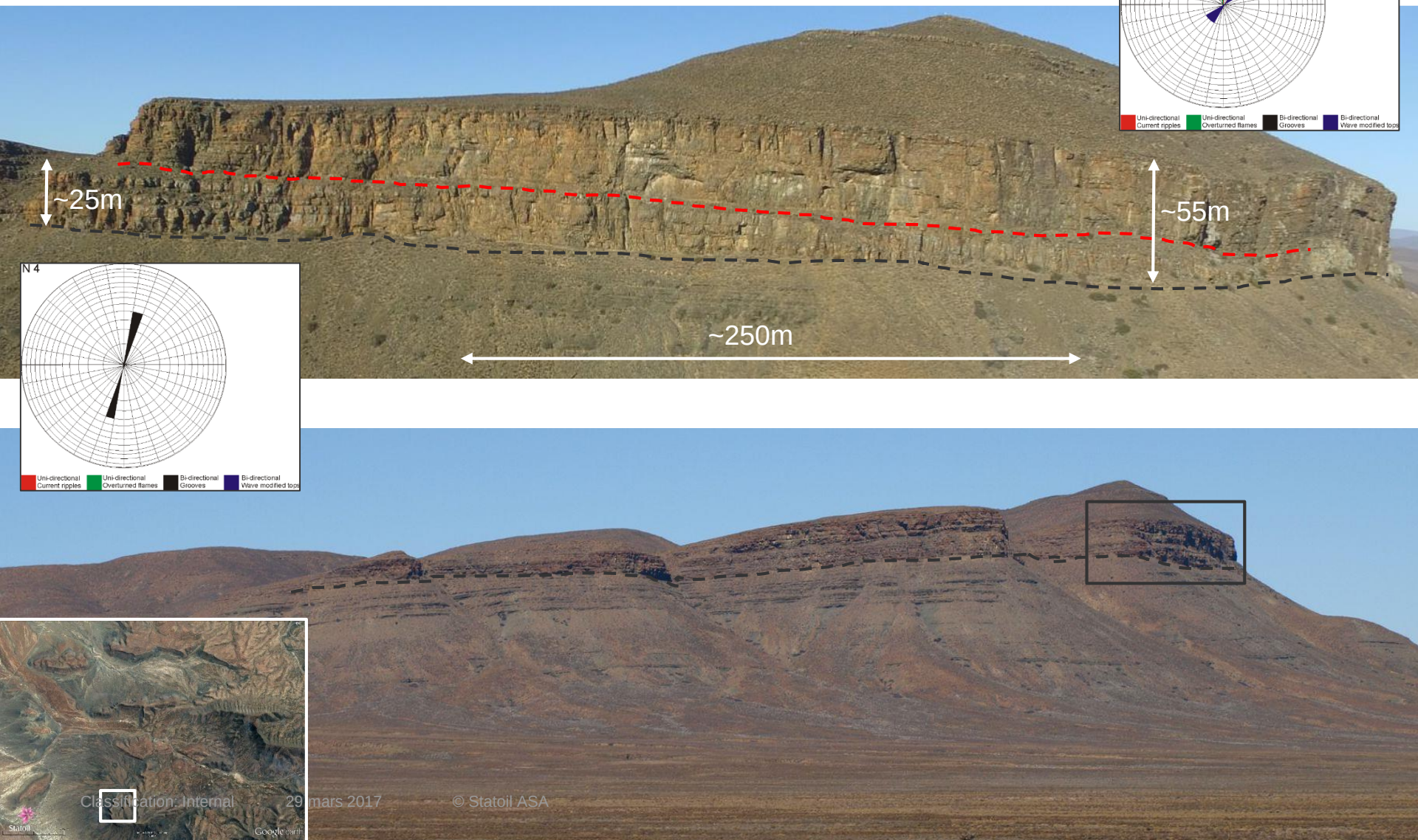

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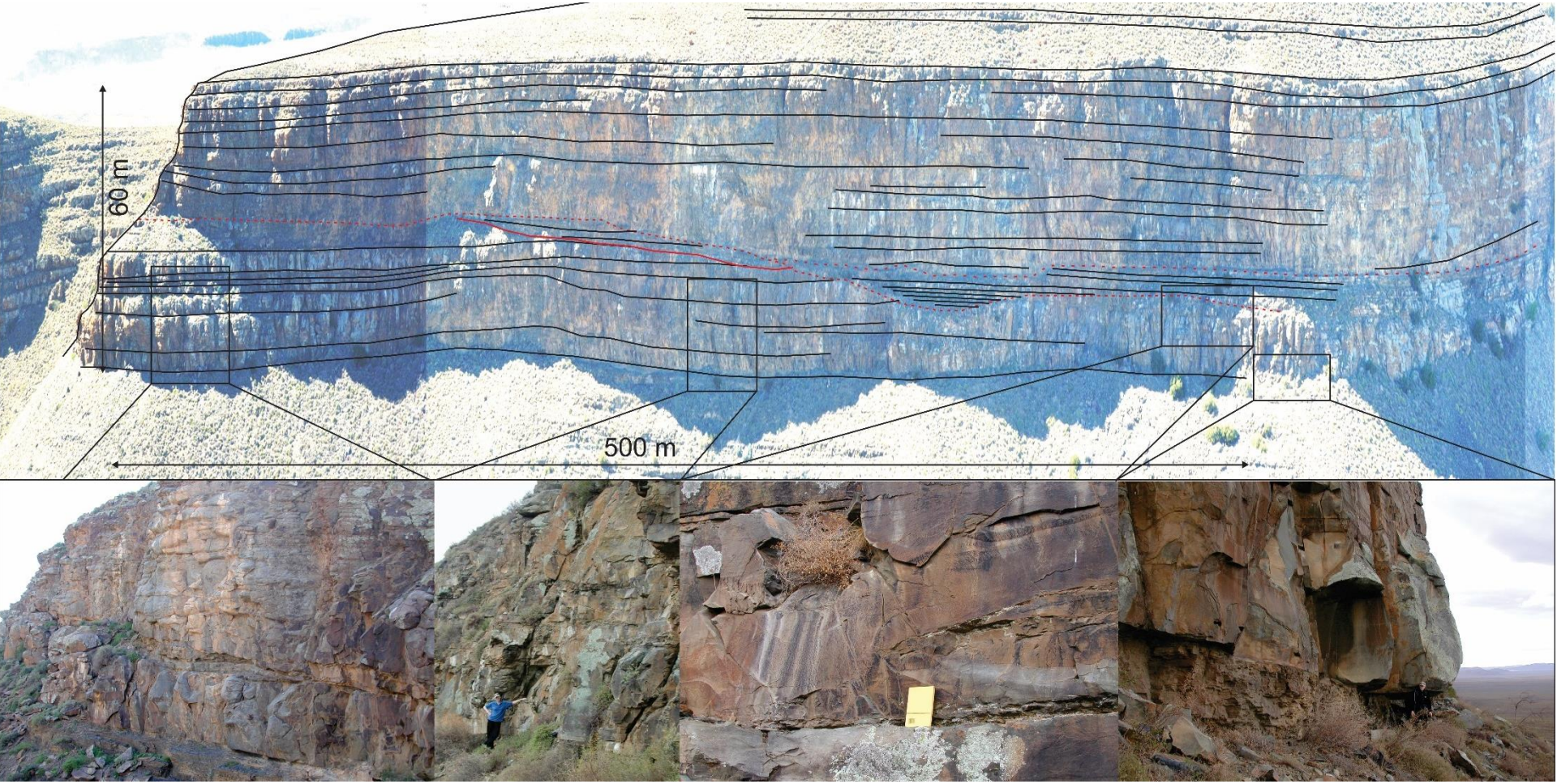
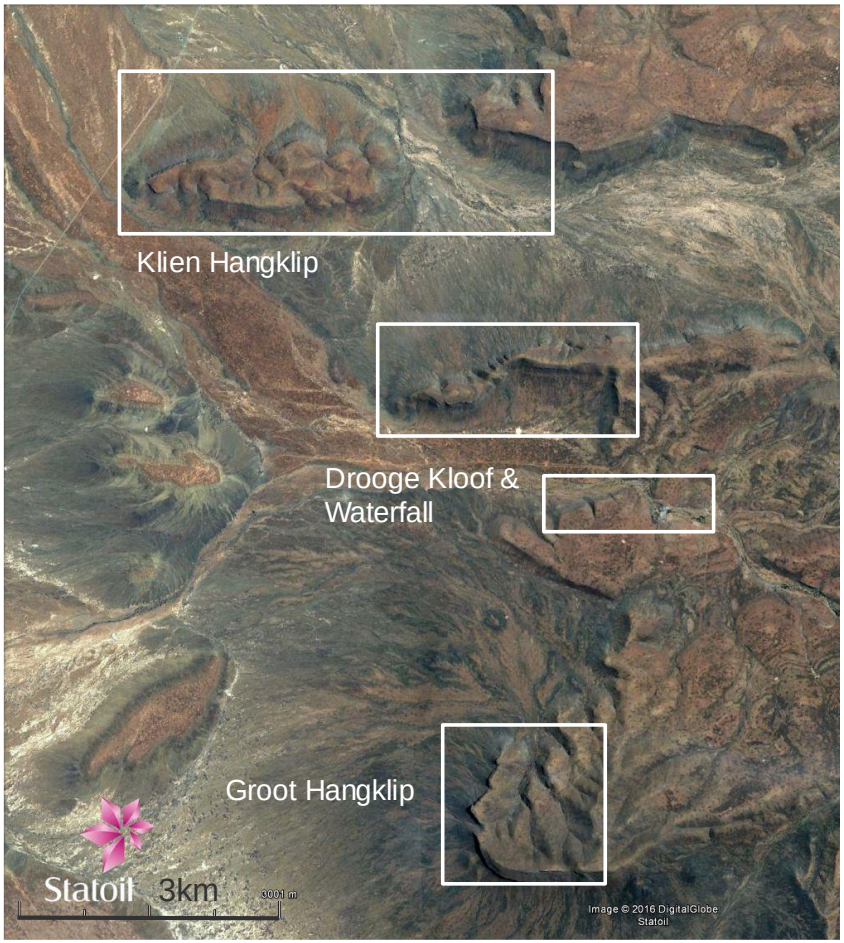
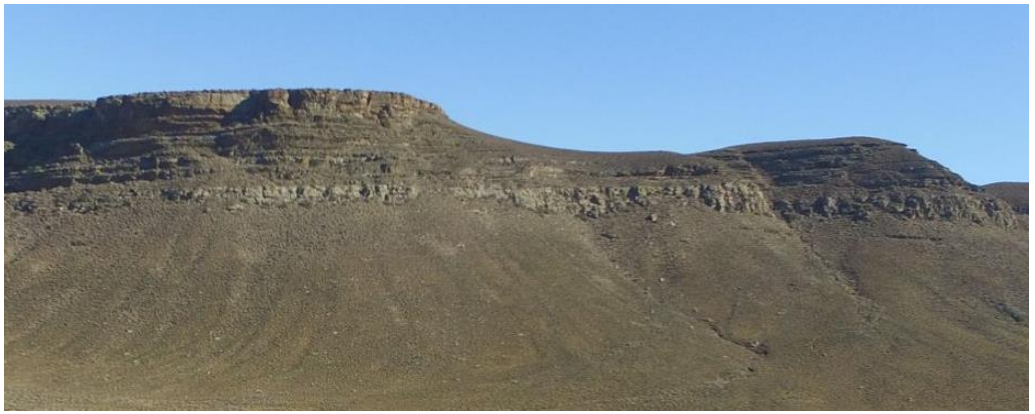


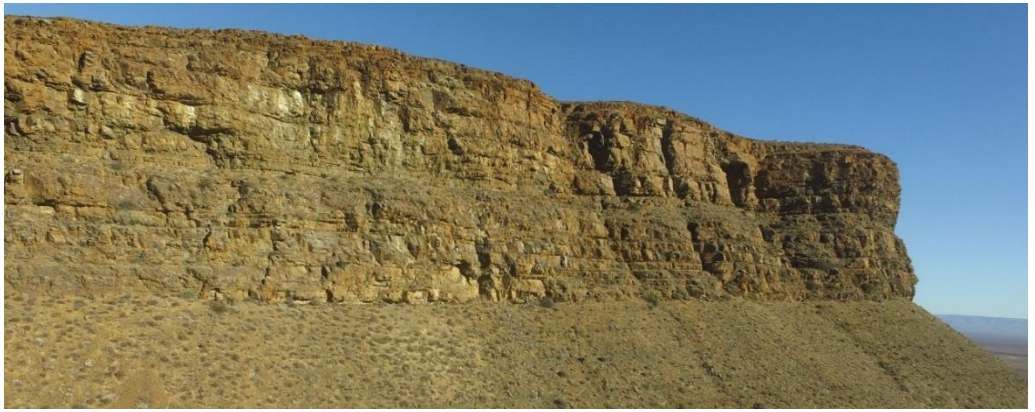
Modified from Wild et al., 2005

- Limited evidence for master container
- High N:G, structureless and de-watered sandstones
- Limited preservation of fine grained sediments

Summary of depositional facies and architecture



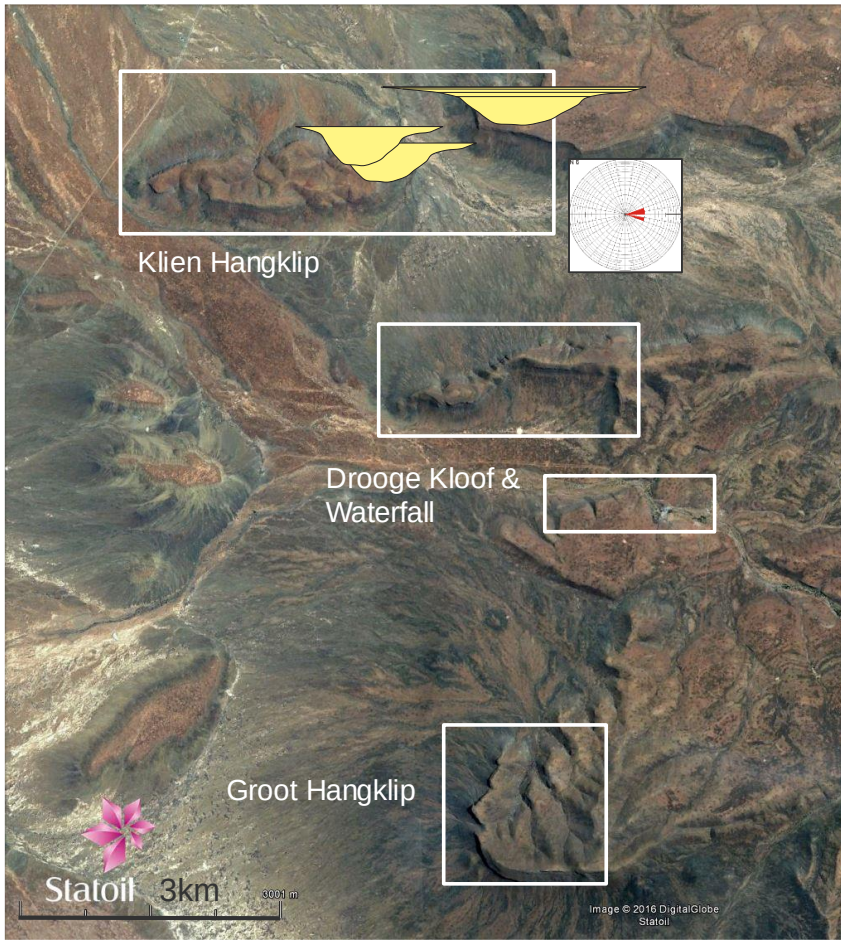


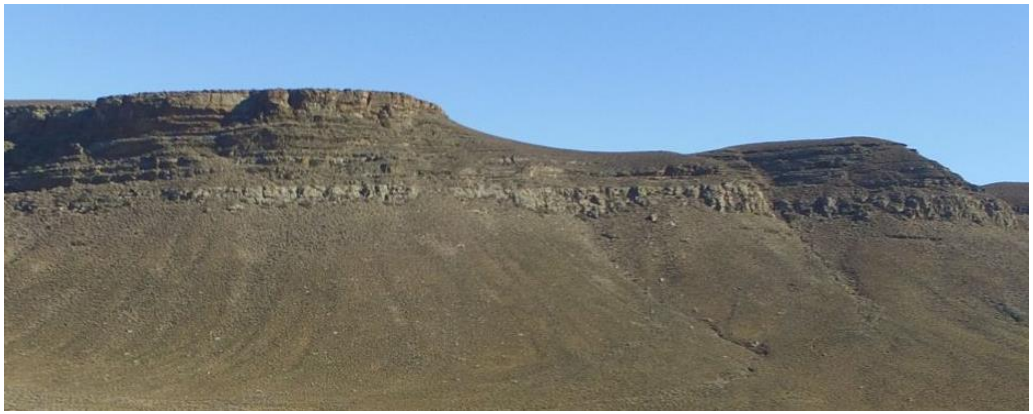


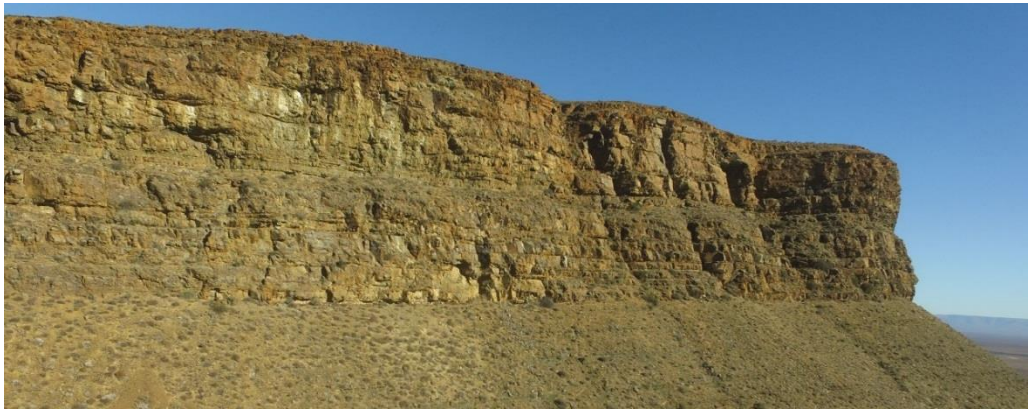
Summary of depositional facies and architecture

- Characterized by channel complex
- Stratigraphic evolution in depositional style and architecture
  - Erosionally confined basal part
  - Weakly confined upper part
- Low to moderate sinuosity

- Change in equilibrium profile results in evolution from net erosion (and bypass) to aggradation







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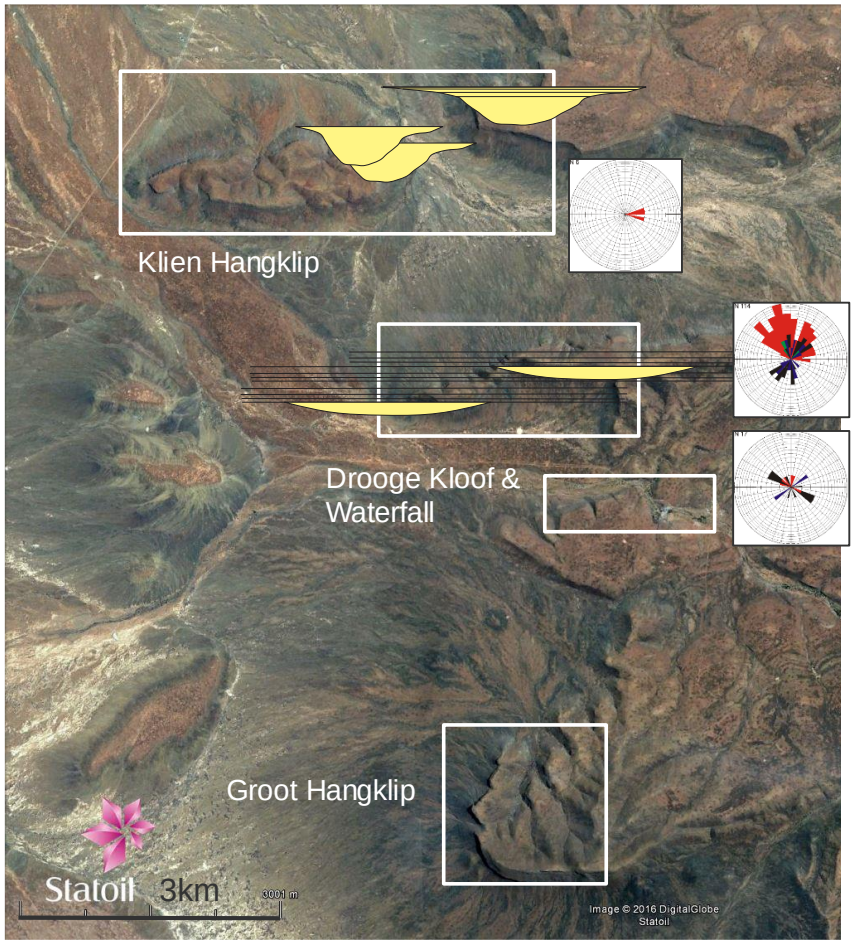

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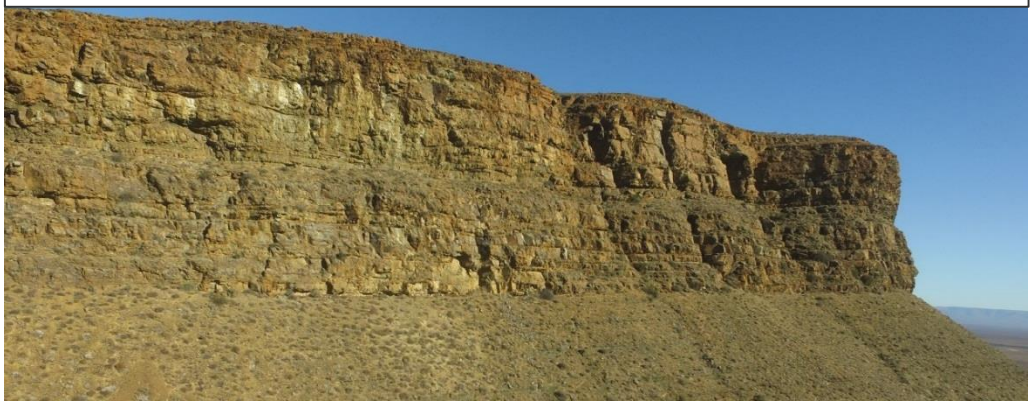
- Dominated by sheet-like geometries, coarsening- and thickening-upward packages
- High climb angle and stoss-side preservation in ripple-laminated sandstones
- De-watering, loading and ‘creep’
- Laterally off-set, low relief channels and scours

- Reduction in confinement, rapid flow deceleration and aggradation, CLTZ to frontal splay
- Repeated cycles of thin-beds and channelization reflects evolving slope profile



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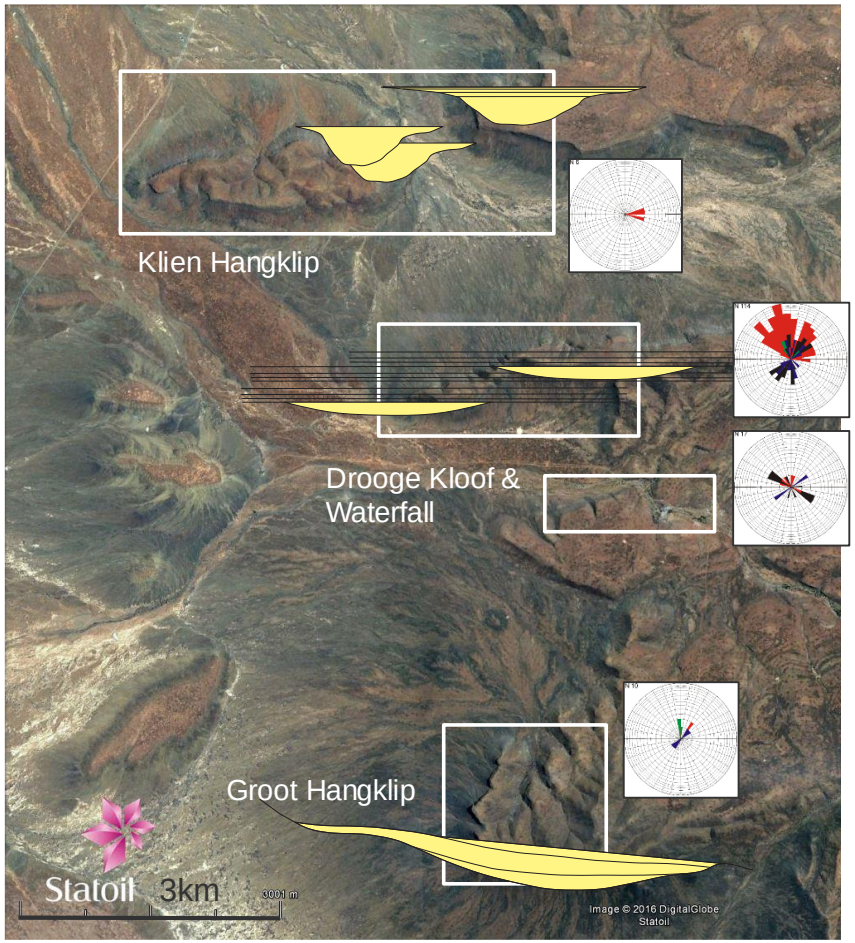

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- Limited evidence for master container
- High N:G, structureless and de-watered sandstones
- Limited preservation of fine grained sediments
- Aggradational lower unit, ev. of punctuated episodes of erosion and deposition in upper unit

- Perched accommodation / partially ponded
- Stratigraphic evolution of depositional style in response to changes in equilibrium profile (decrease in local gradient, reducing accommodation)?

Summary

- Unit 5, Skoorsteenberg Fm., Hangklip localities
  - The interpreted variable or stepped-slope morphology is characterized by spatial and temporal changes in depositional facies and architecture, channel aspect ratio and stacking pattern
    - Depositional setting defined by distinct assemblages
    - Key interpreted depositional environments include channels and overbank deposits, channel-lobe transition zones (CLTZ), frontal splays and lobes
    - Preferential accumulation of sediment and ‘healing’ of the slope is believed to reflect the deceleration of sediment gravity flows as they encountered lower-gradient steps and partial (flow stripping) or full confinement

- Provides insight on critical factors influencing sediment storage on the slope and lower slope and / or bypass to the deeper basin
  - Develop predictive concepts to aid reservoir prediction and characterization
- Stratigraphic and combined traps in base of slope setting are under-explored and have the potential to contain significant YTF both in new plays and mature basins
  - Variable slope topography and resultant impact on depositional systems is positive with respect to the play / prospectivity

Thank you for your attention

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