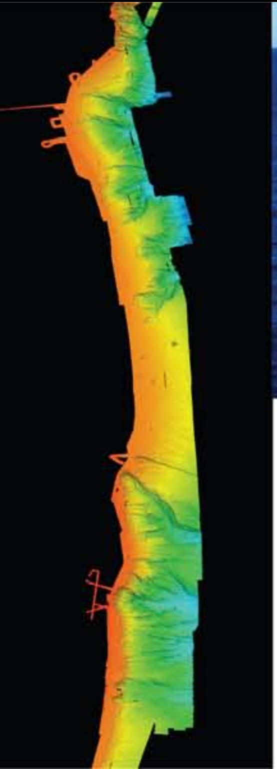
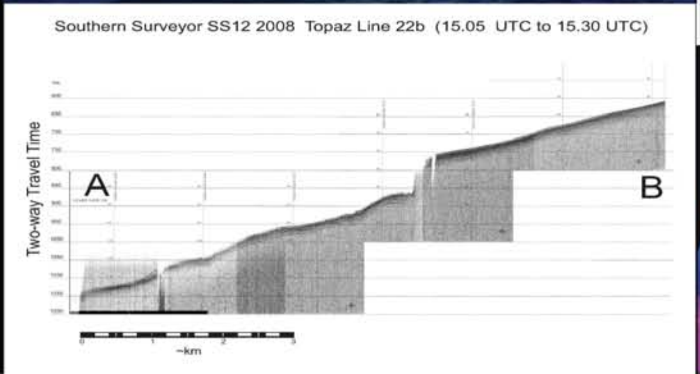
Submarine Landslides on the Upper East Australian Continental Margin

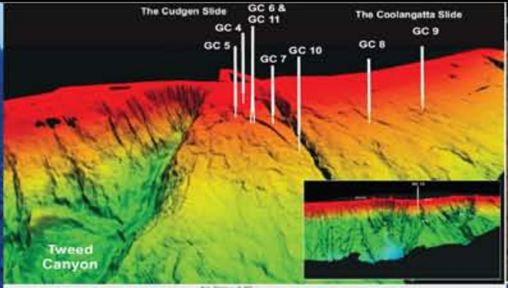
AIG Introductory Presentation November 2011

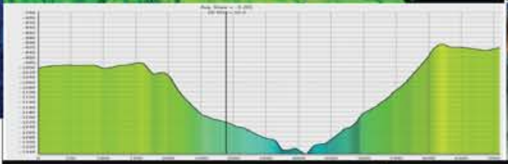
SAMANTHA CLARKE | PhD CANDIDATE

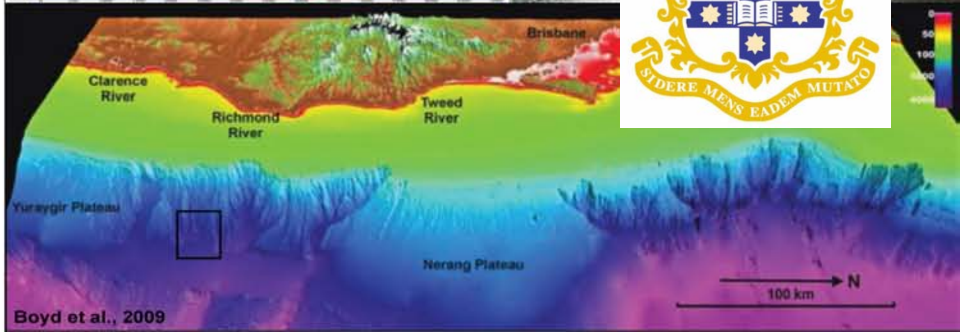
GEOCOASTAL RESEARCH GROUP | UNIVERSITY OF SYDNEY











OVERVIEW

BACKGROUND

- Project Aims
- Submarine landslides & the Australian context

THE SE AUSTRALIAN MARGIN

- General characteristics & morphology
- Data set & Study Area

FAILURES ON THE MARGIN - SUMMARY OF RESULTS

- Slope morphology
- Sediment properties
- Dating
- Stability analysis

CONCLUSIONS…so far

BACKGROUND

PROJECT AIMS: WHAT ARE WE TRYING TO DO?

1. ***WHY?*** submarine landslides are occurring
    - Sediment physical properties
    - Slide morphology
    - Failure mechanisms
2. ***WHEN?*** failures have occurred in the past
    - Radiocarbon ages
3. ***HOW?*** they occur – past & future
    - Location, size, possible trigger mechanisms
    - Slope stability analysis
    - Threat assessment – tsunamis?

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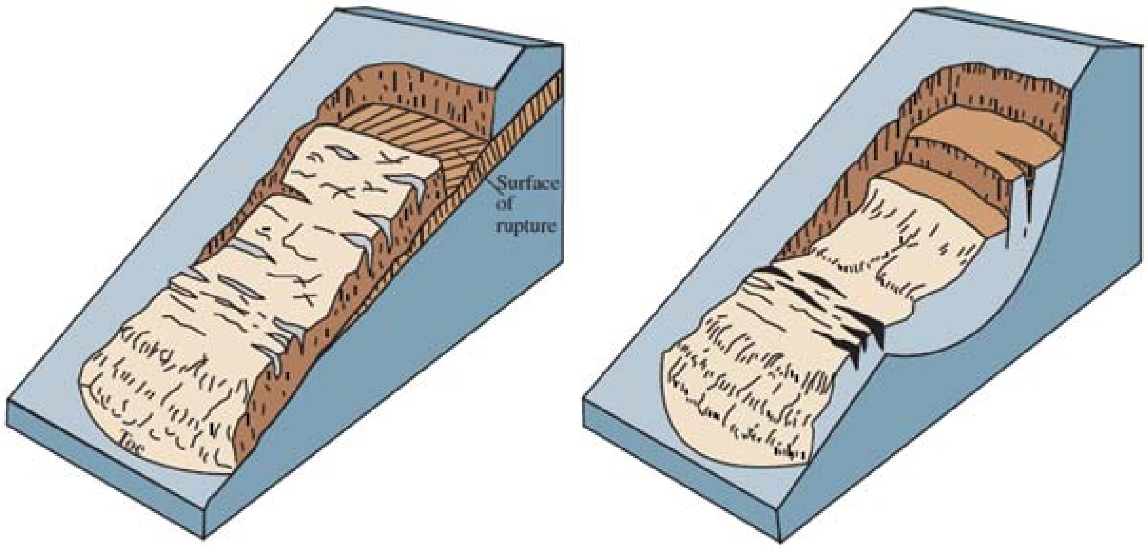
SUBMARINE LANDSLIDES



Types of submarine slope failures: (left) planar/translational failure, (right) circular/rotational failure, which also displays multiple scarps as a result of retrogressive failure (Highland & Johnson, 2004)

SIZE AND EXTENT

- Common in geologic record
- Triggers not well understood
- Shallow gradients
- Wide range of scales - up to 3000 km^3

CONSEQUENCES

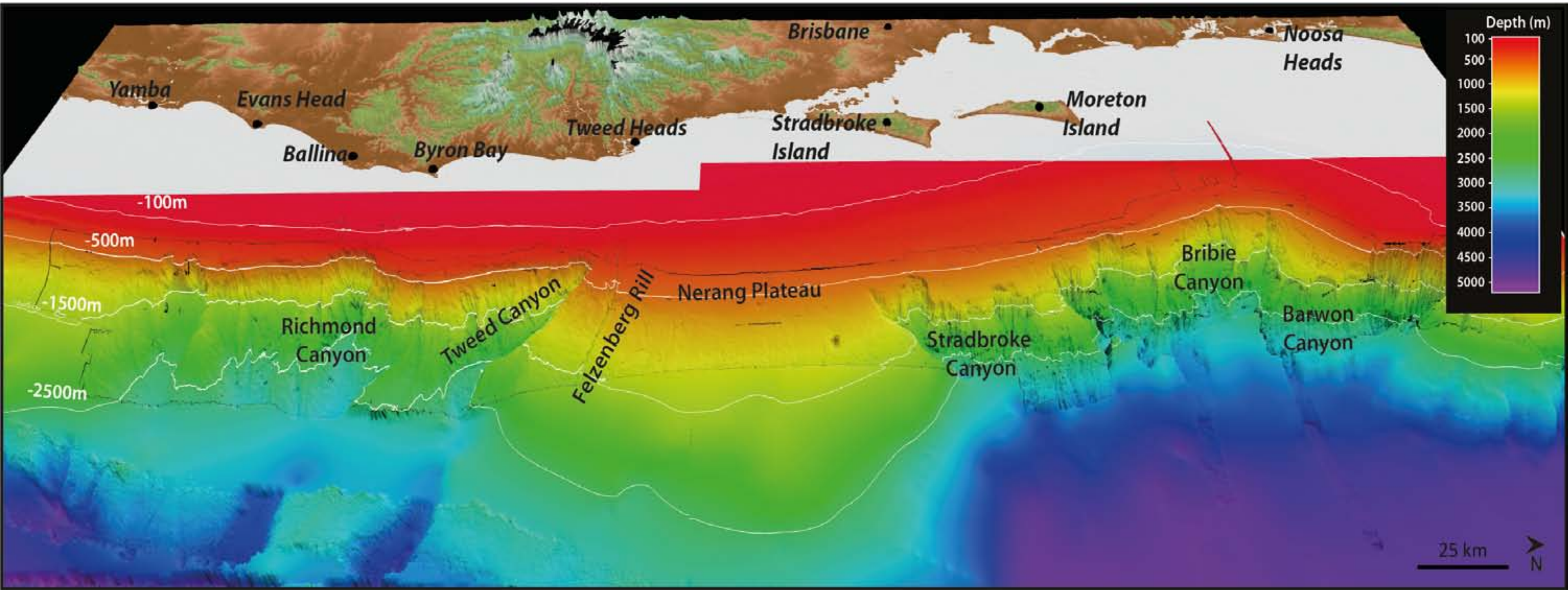
- Damage to seabed infrastructure
- Subsidence of coastal areas
- Tsunami generation

TRIGGERS

- Earthquakes, Storm wave loading, Erosion (slope over-steepening), Rapid sedimentation (under-consolidation), Weak layers, Gas hydrate dissociation, Sea-level changes, Glaciation and isostatic uplift, Volcanic activity, Diapirs, Creep

BACKGROUND

- Australian coastline vulnerable → 85% of population & much critical infrastructure <50 km offshore
- **Cause + Potential** of submarine landslides NOT determined
- Australia's tectonic setting – passive, geologically stable margin
- Recent investigations → many large, geologically young (< 20 ka) submarine landslides



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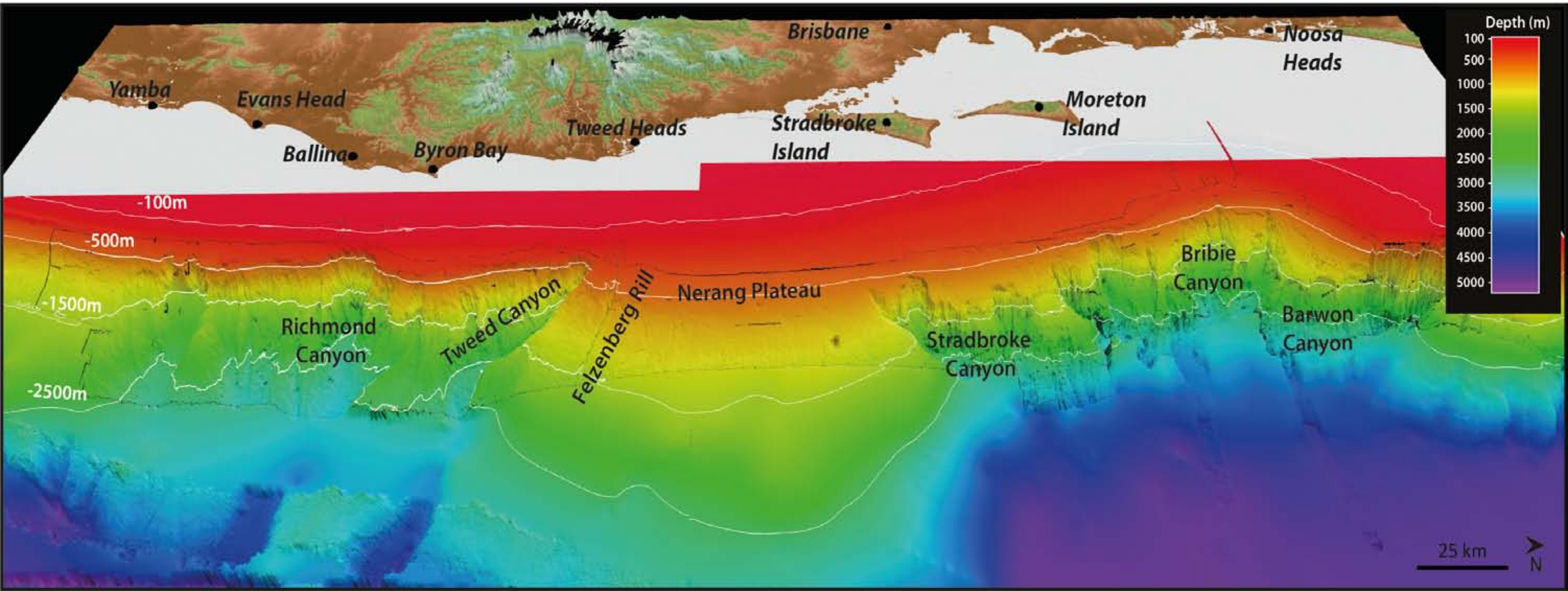
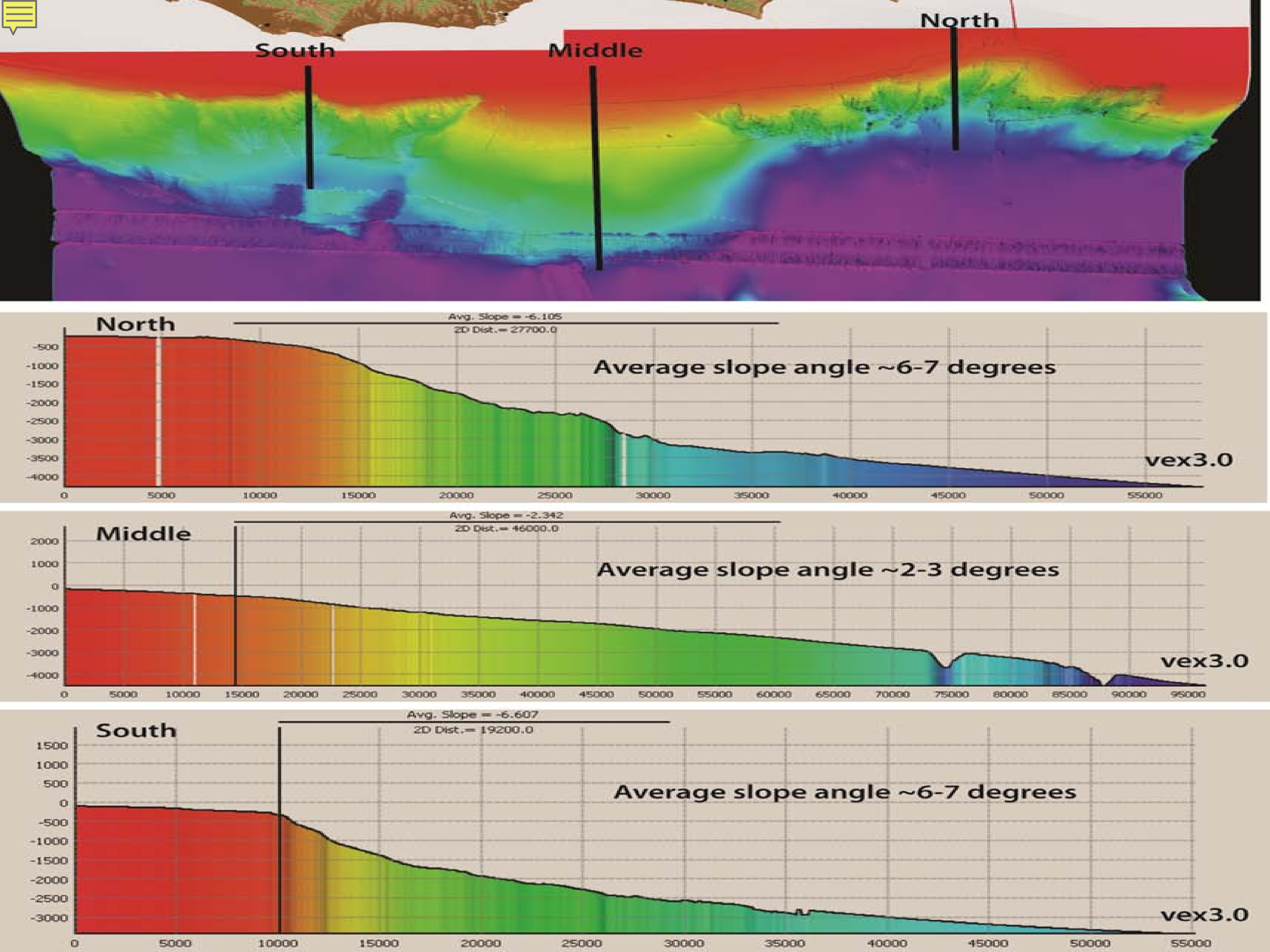
SOUTHEAST AUSTRALIAN MARGIN

General Characteristics of the Margin

- Sediment-deficient
- Mass-transport dominated
- Continental slope = submarine landslide features
- Passive, steep, narrow margin
- Alterations between plateaus & incised segments of margin
- Average slopes of 2.5-8.5°





South
Middle
North
North
Avg. Slope = -6.105
2D Dist.= 27700.0
Average slope angle ~6-7 degrees
vex3.0
Middle
Avg. Slope = -2.342
2D Dist.= 46000.0
Average slope angle ~2-3 degrees
vex3.0
South
Avg. Slope = -6.607
2D Dist.= 19200.0
Average slope angle ~6-7 degrees
vex3.0

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DATA SET

- Southern Surveyor Research Cruise *SS2008-12*

SOUTHEAST AUSTRALIAN MARGIN

DATA SET

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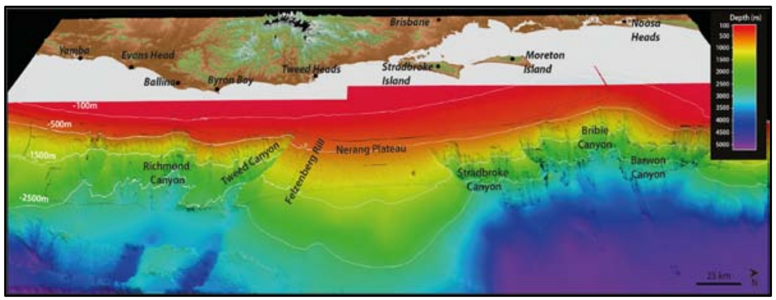
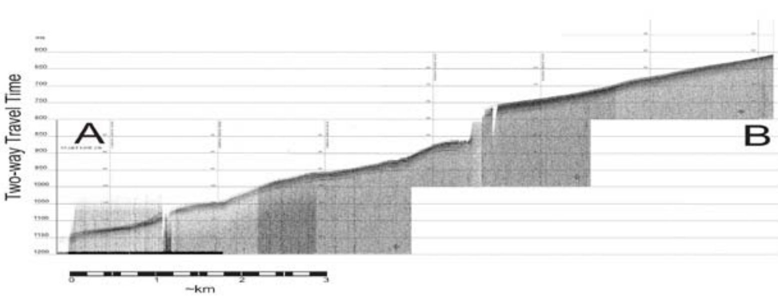
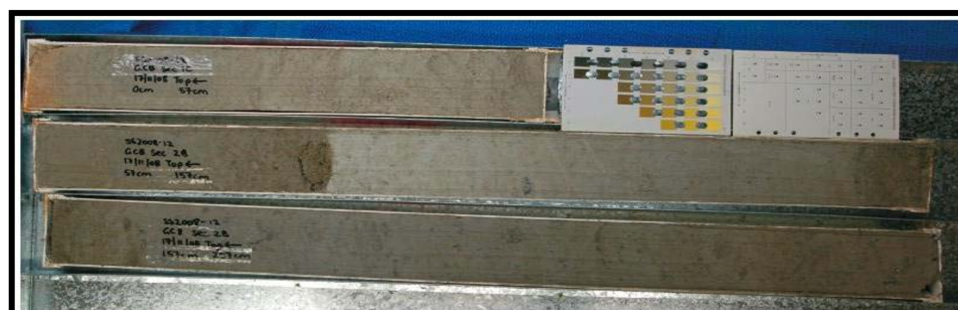
- ~13,000 km^2 of Multibeam Echosounding (MBES) & high-resolution Topas sub-bottom profiling data



Southern Surveyor SS12 2008 Topaz Line 22b (15.05 UTC to 15.30 UTC)

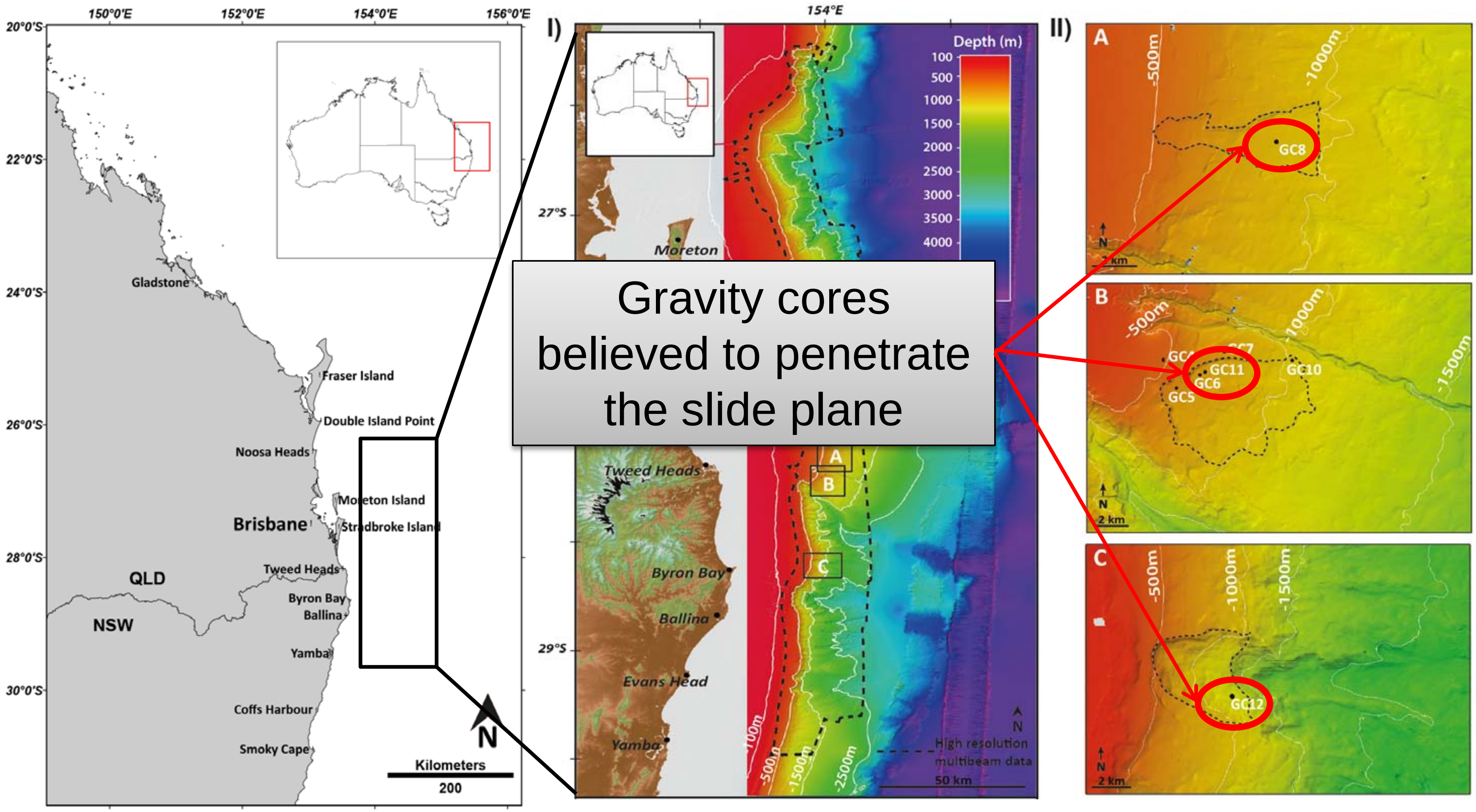


- 12 Gravity Cores, 16 Dredges, 8 Grabs

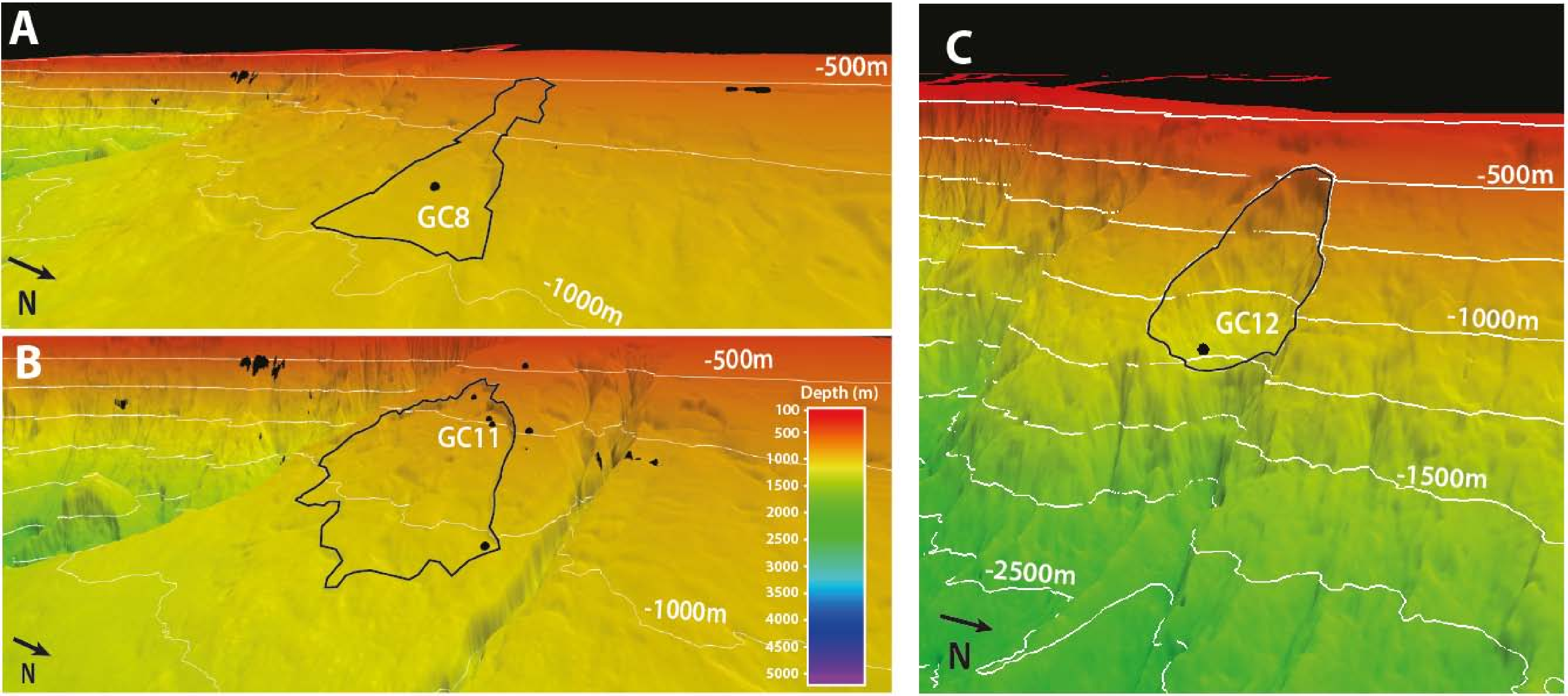


SOUTHEAST AUSTRALIAN MARGIN

Study Area



STUDY AREA



A
-500m
GC8
-1000m
N
B
-500m
GC11
-1000m
N
Depth (m)
100
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
C
-500m
GC12
-1000m
-1500m
-2500m
N

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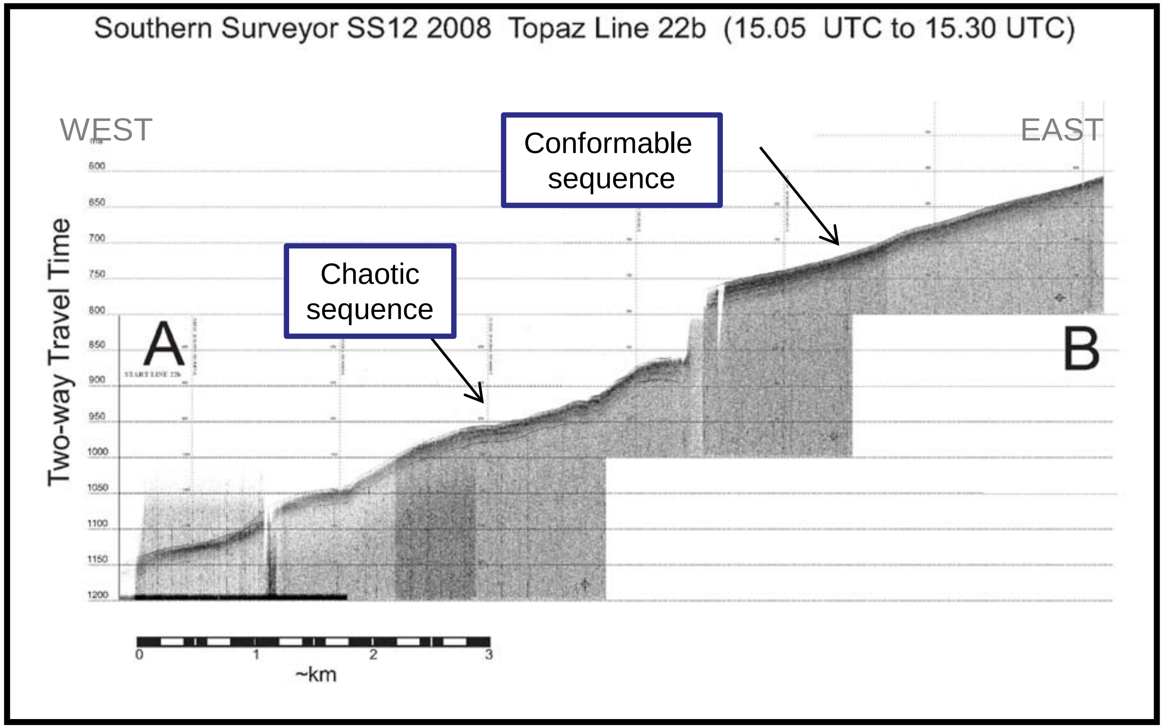
RESULTS

SLOPE MORPHOLOGY

- Combination of sub-bottom profiles & multibeam bathymetry data



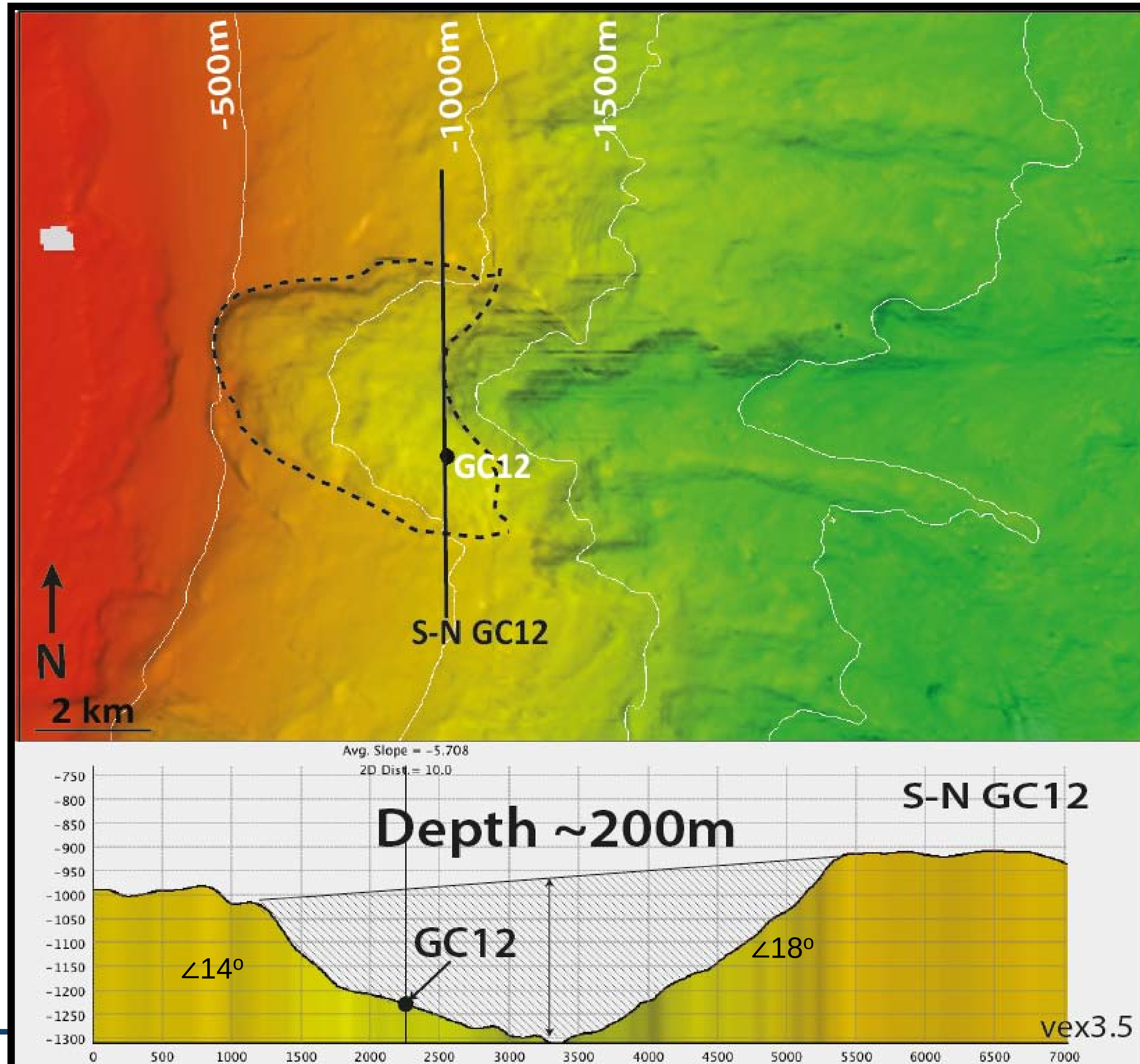
- Slide feature – widespread erosional features

RESULTS

SLOPE MORPHOLOGY

Large sediment slides (canyons)

- < 0.5 km^3 to 20 km^3
- Average slopes 3 - 7^o
- Head walls and sides >17^o slopes – still standing
- No detectable slide debris

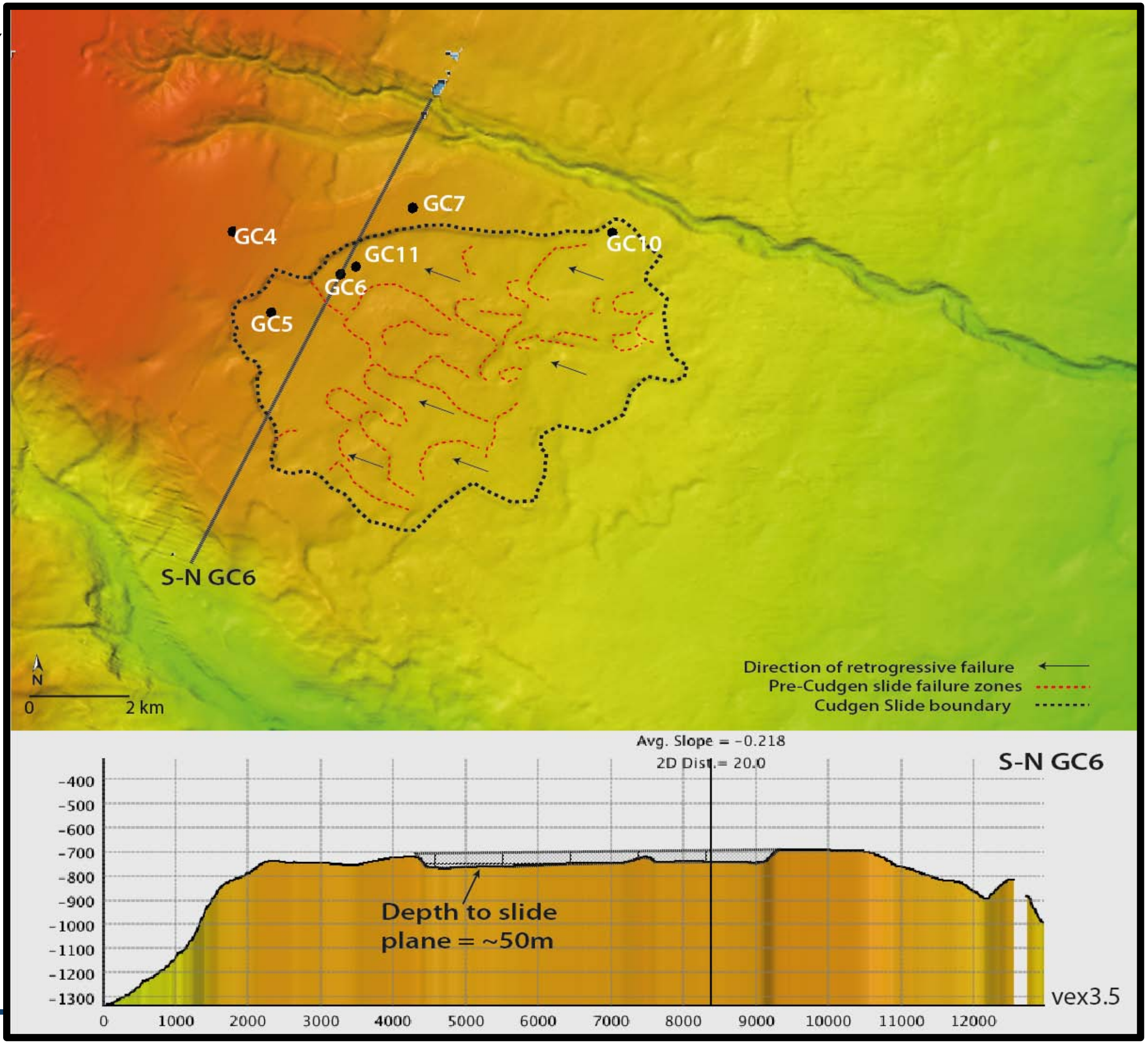


RESULTS

SLOPE MORPHOLOGY

Shallow failures (plateau)

- Widespread slides
- Slopes < 2º



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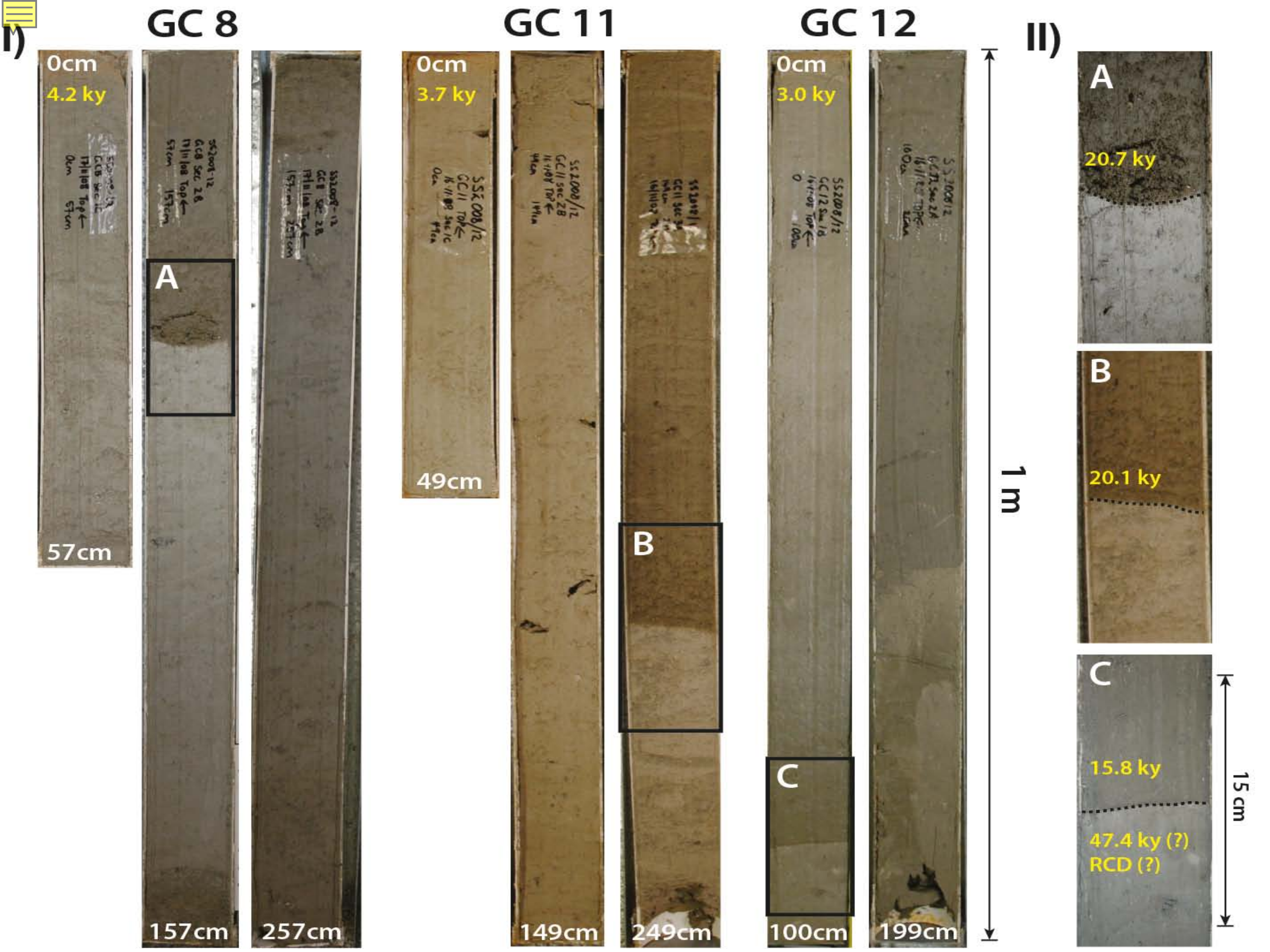
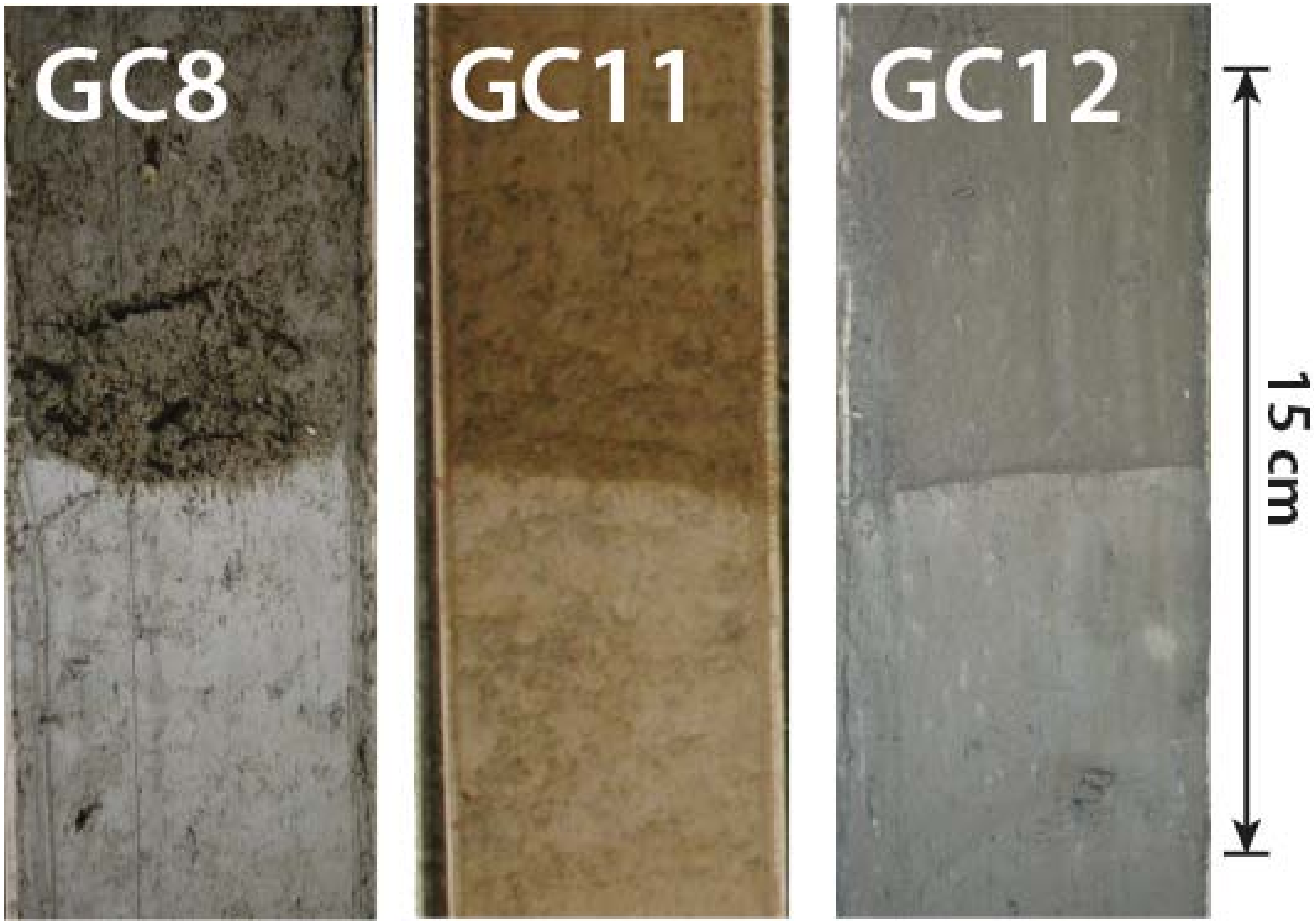

I)
GC 8
0cm
4.2 ky
57cm
A
157cm
257cm
GC 11
0cm
3.7 ky
49cm
B
149cm
249cm
GC 12
0cm
3.0 ky
C
100cm
199cm
1 m
II)
A
20.7 ky
B
20.1 ky
C
15.8 ky
47.4 ky (?)
RCD (?)
15 cm

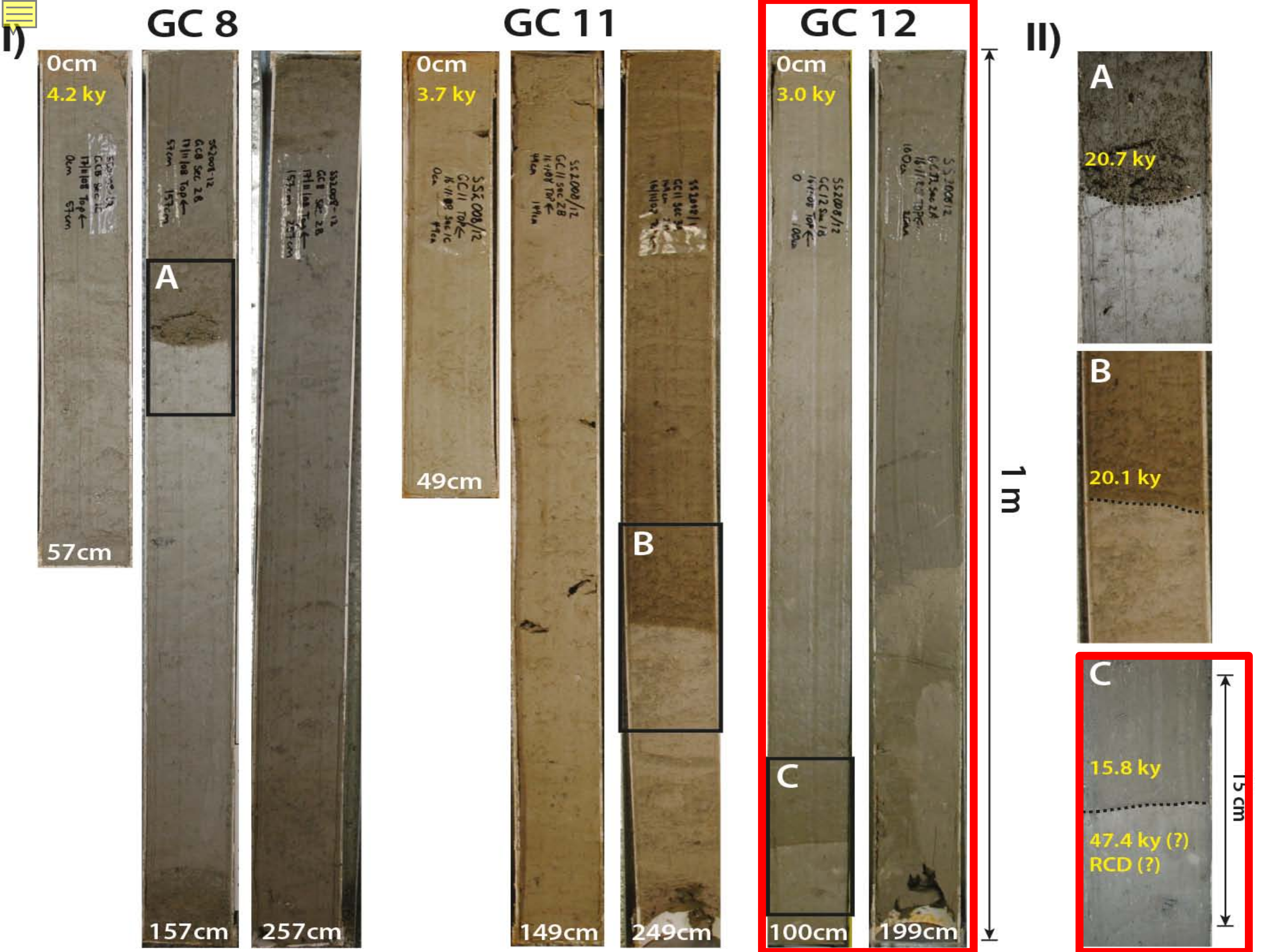
FAILURES ON THE CONTINENTAL SLOPE

"THE BOUNDARY FEATURE"

- Strong visual difference
- Sediment noticeably firmer below



Note: Dashed line denotes slide plane boundary



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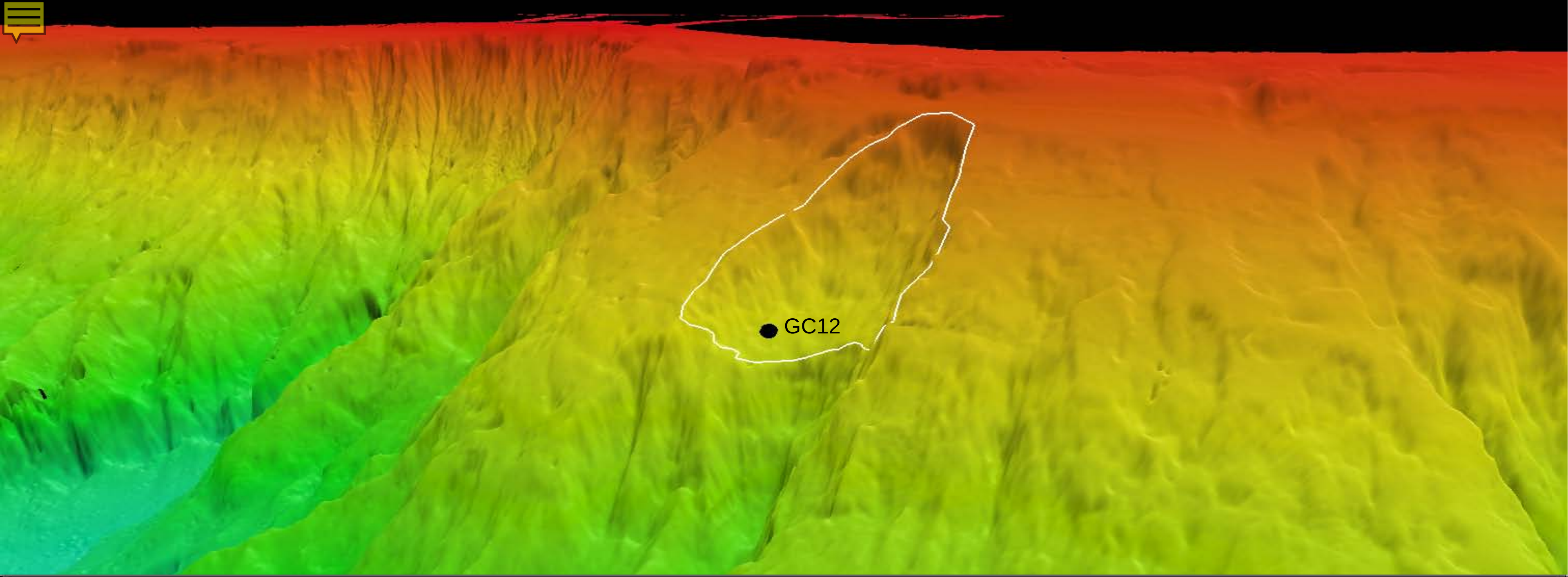
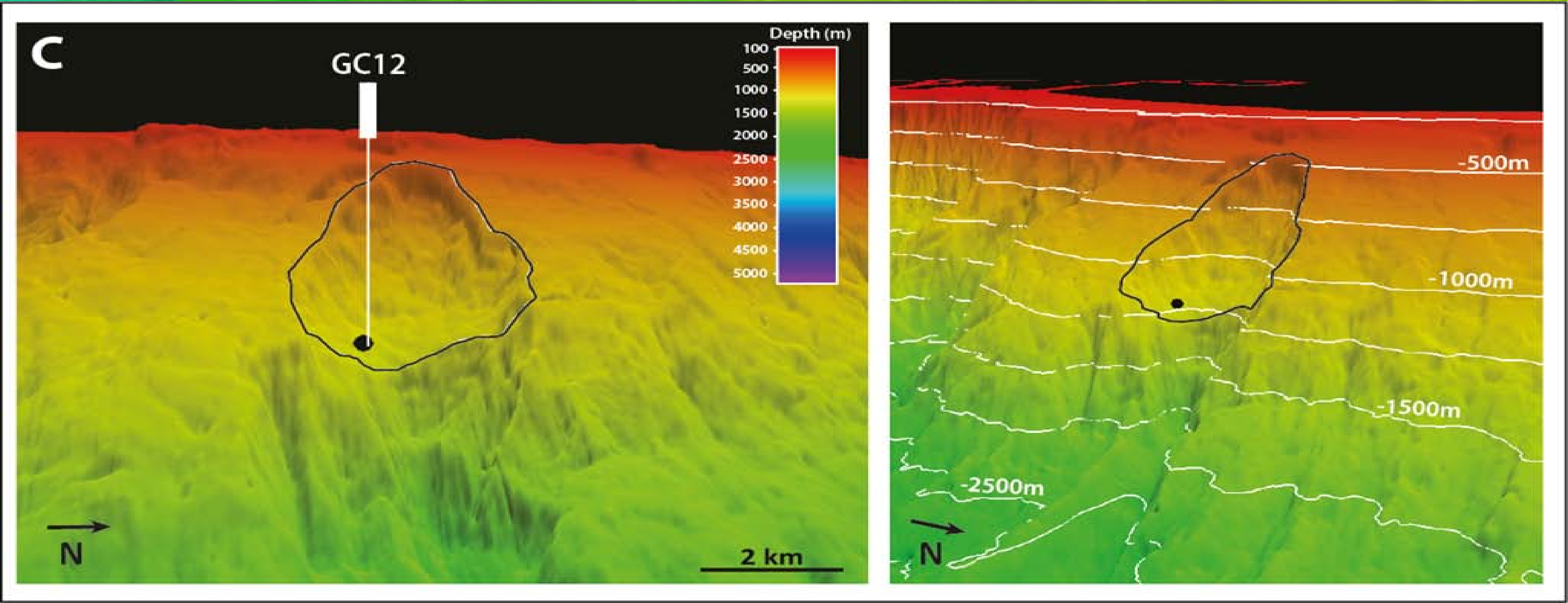
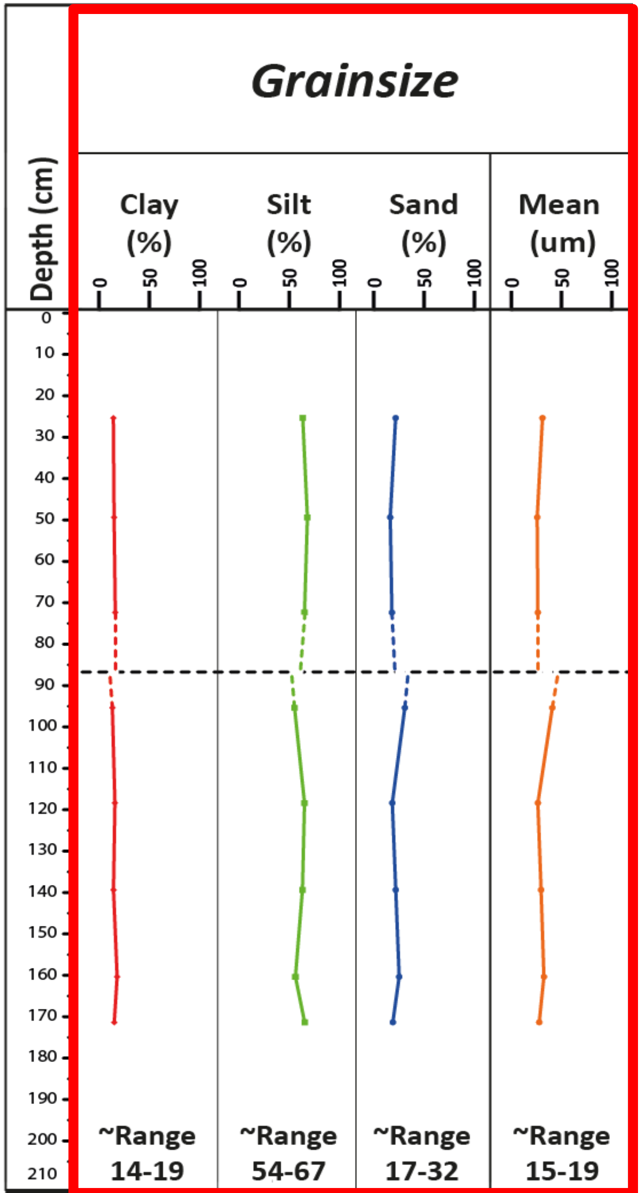

GC12


C
GC12
Depth (m)
100
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
N
2 km
-500m
-1000m
-1500m
-2500m
N

SEDIMENT PROPERTIES

GRAINSIZE

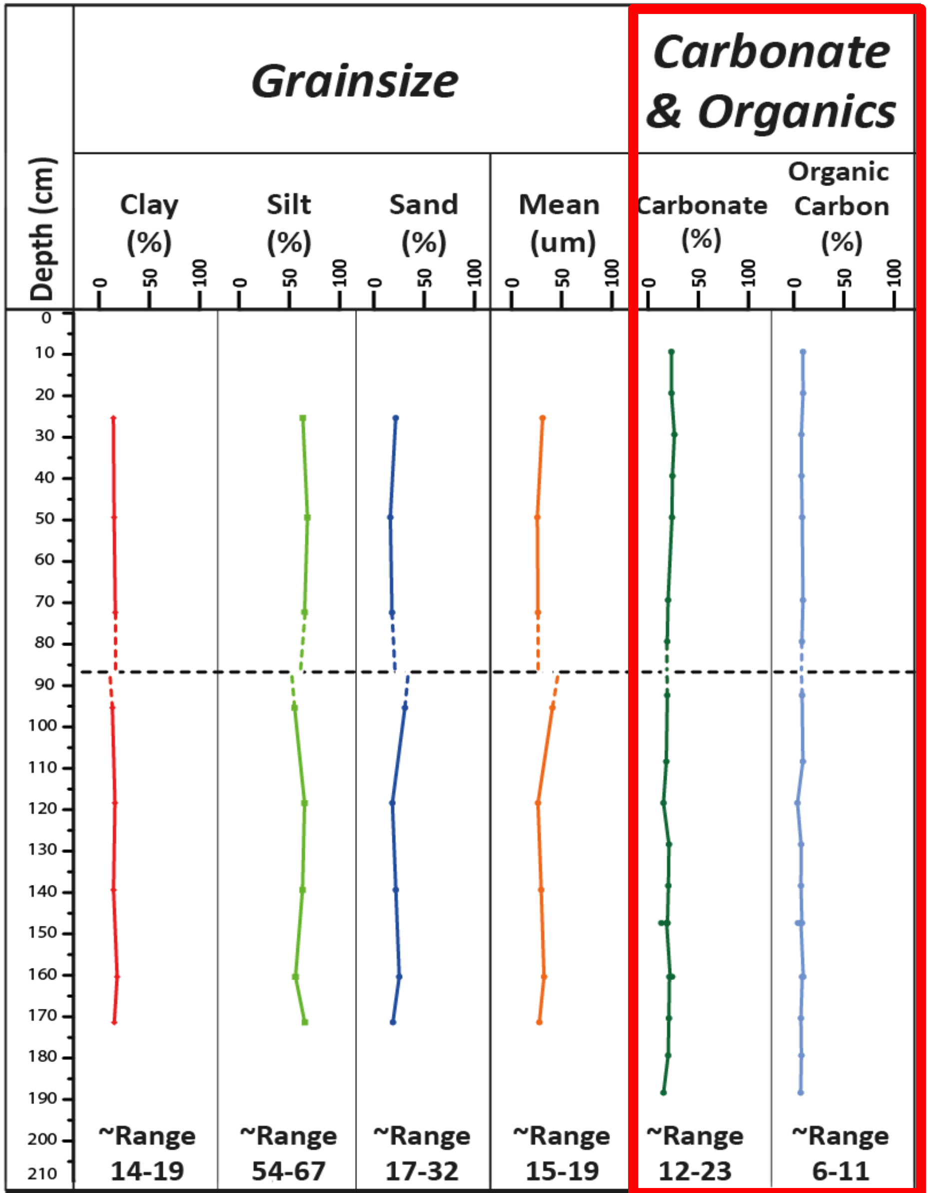
- No significant change



SEDIMENT PROPERTIES

CARBONATE & ORGANIC CARBON

- No significant change



GEOTEC
PROPER

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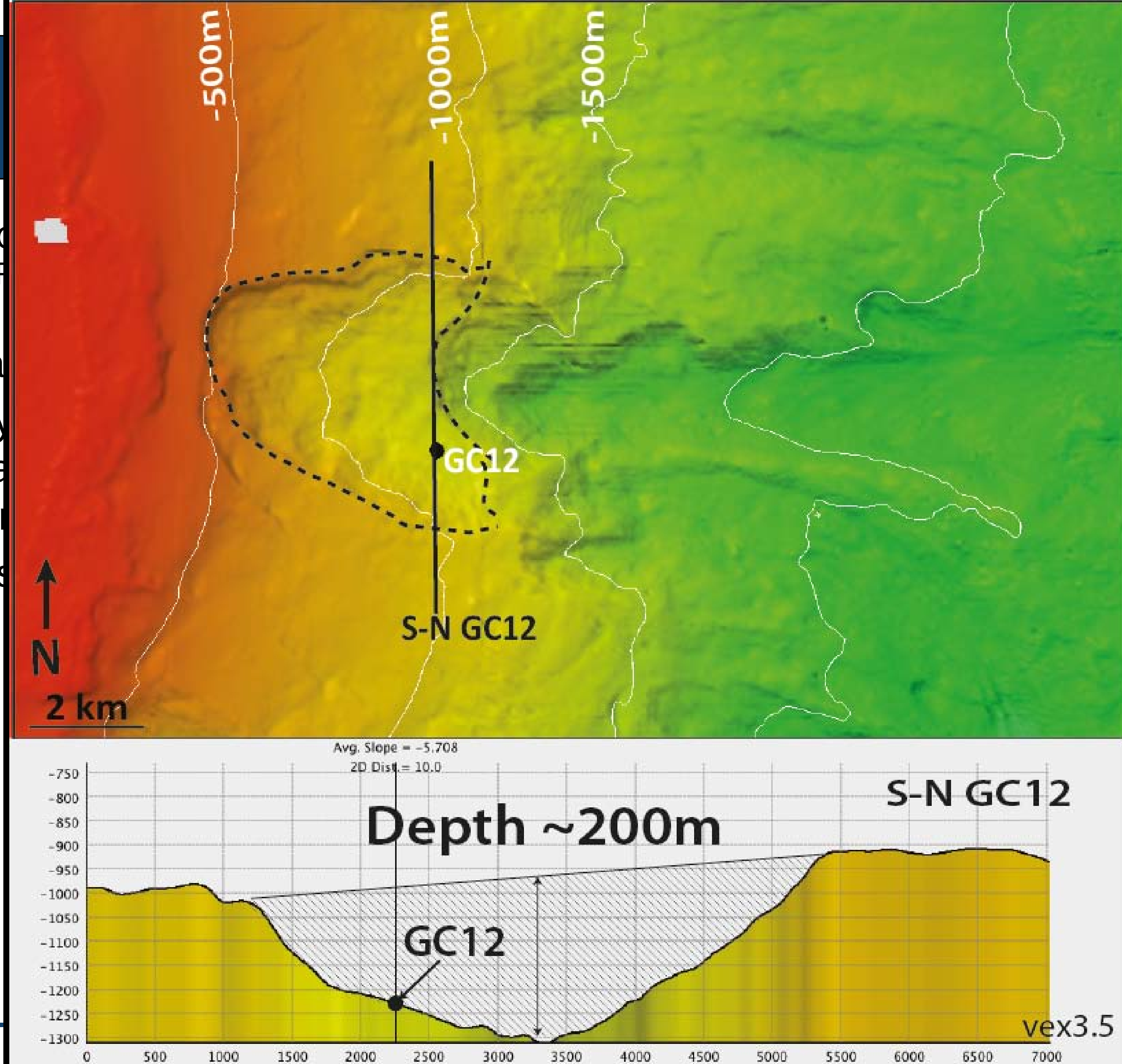
- 2 dis



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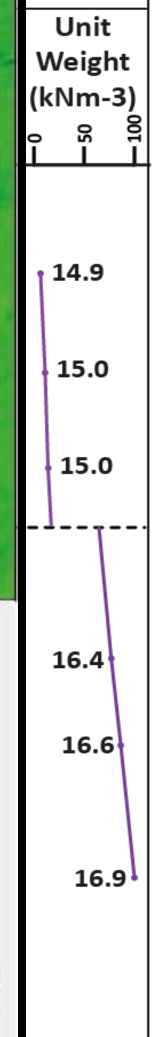

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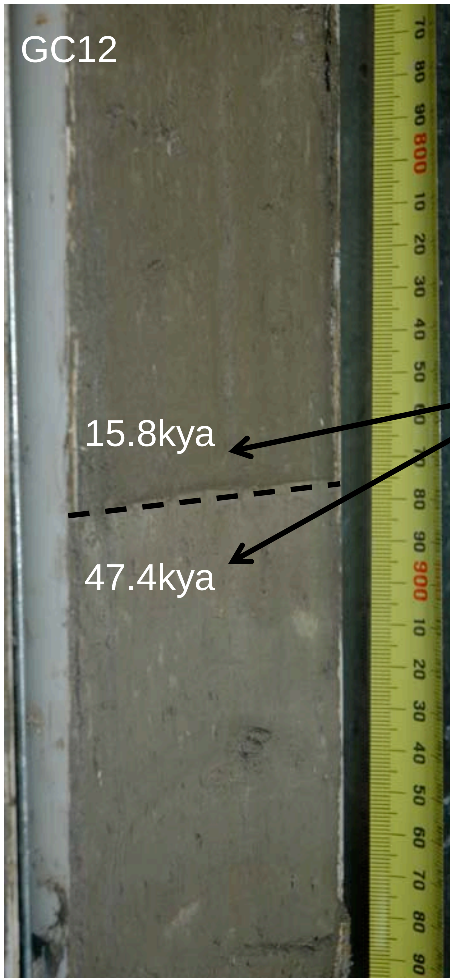
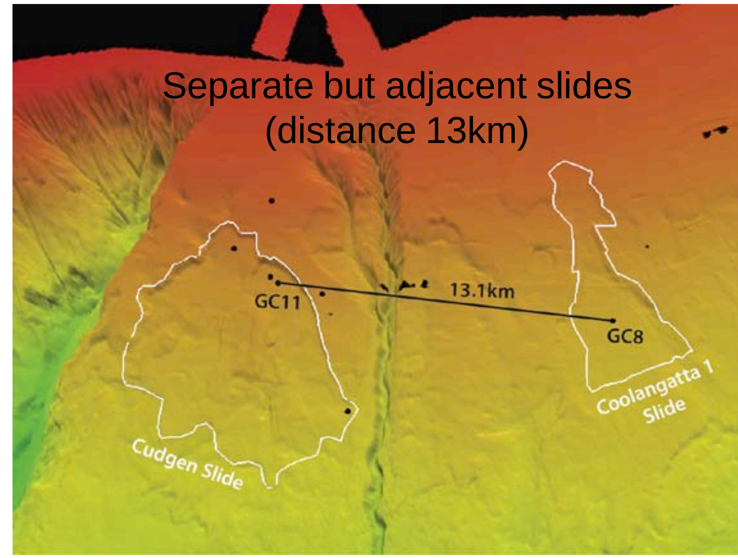
FAILURES ON THE CONTINENTAL SLOPE

Radiocarbon Dating



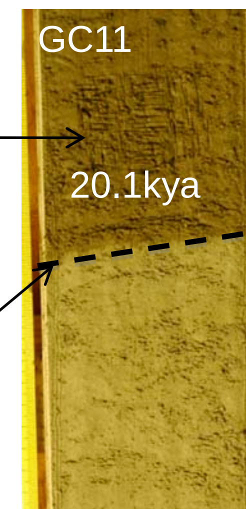
» Establish minimum age constraints on the timing of the slide surface

Significant time gap across the boundary



basal homogenous silt layers

boundary feature (slide plane?)



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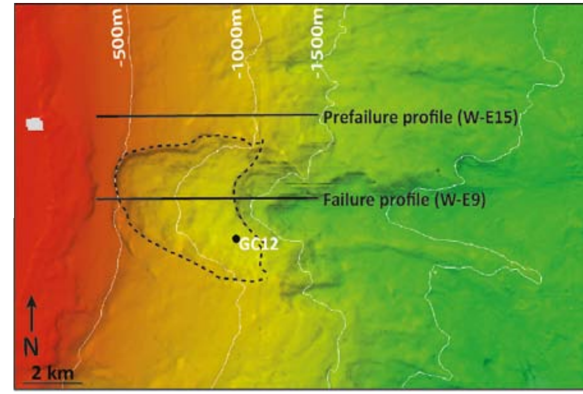
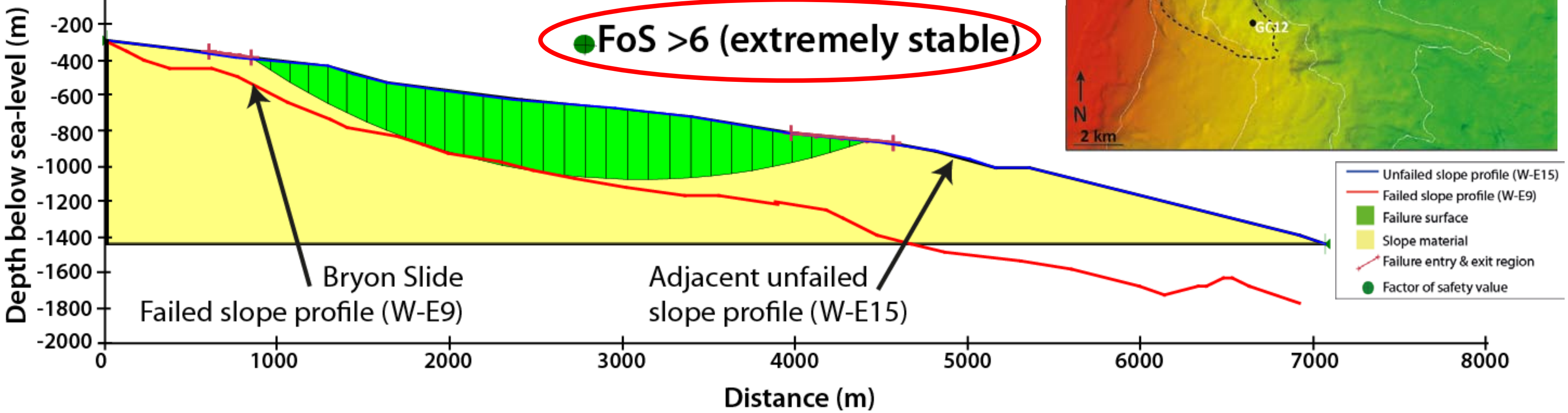
Slope Stability Analysis

FoS	Stability
<1	Unstable
1	Critically Stable
>1	Stable
>2	Extremely Stable





- Conventional slope stability analysis suggests high FoS
- Inconsistent with widespread slope failures

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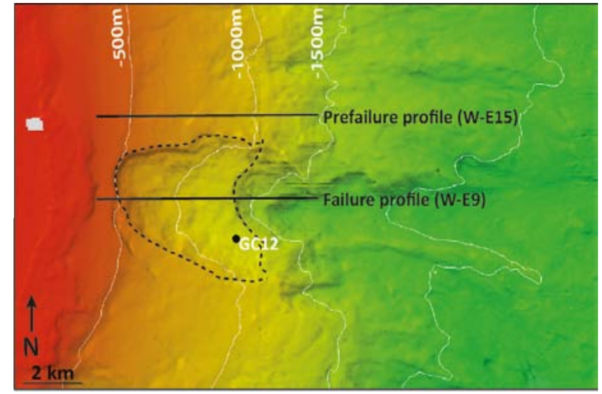

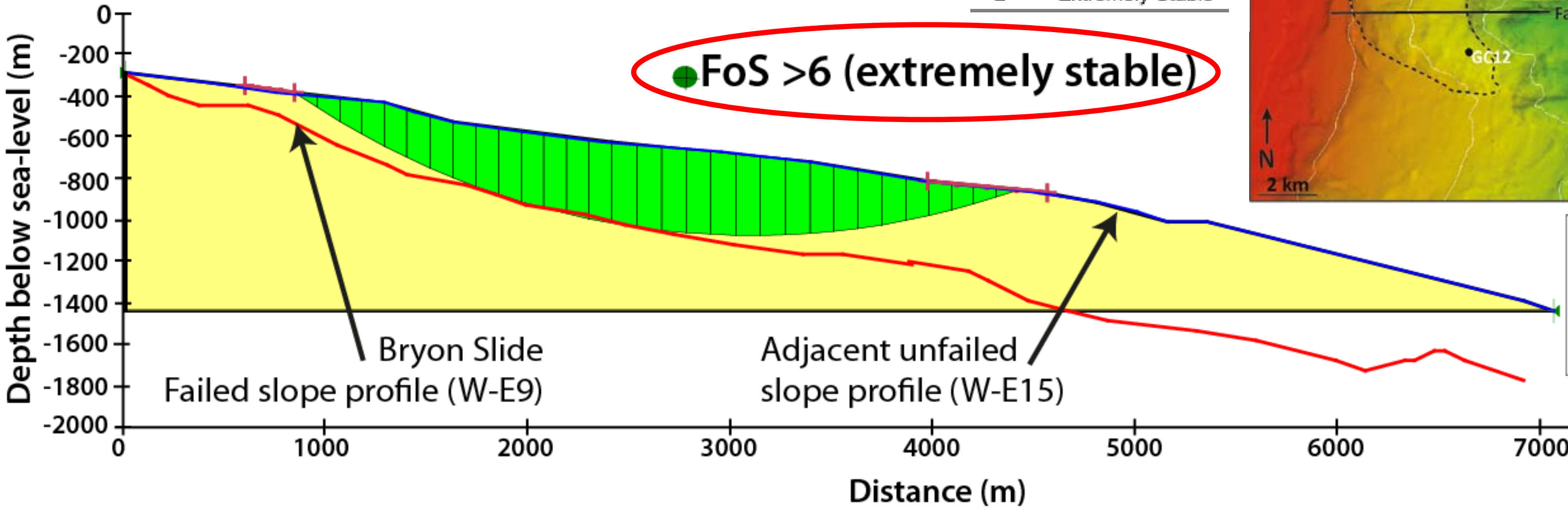

- Conventional slope stability analysis suggests high FoS
- Inconsistent with widespread slope failures
- Pseudo-static analysis including factors for seismic loading require a = 0.3g to reduce FoS to 1

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1. **SLIDE PLANE BOUNDARY SAMPLED**

2 units - distinct difference in burial signature

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2. **YOUNG**

Sediment <21 ka directly above the 3 inferred failure surfaces

CONCLUSIONS

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3. **BIG & EVERYWHERE**

Widespread slide features suggest slides are geologically frequent

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Conventional slope stability analysis suggests the upper slope should be stable

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Conventional slope stability analysis suggests the upper slope should be stable

→ THEREFORE…PROCESS WE DON'T UNDERSTAND (YET)

External process causing slopes to failure

CONCLUSIONS

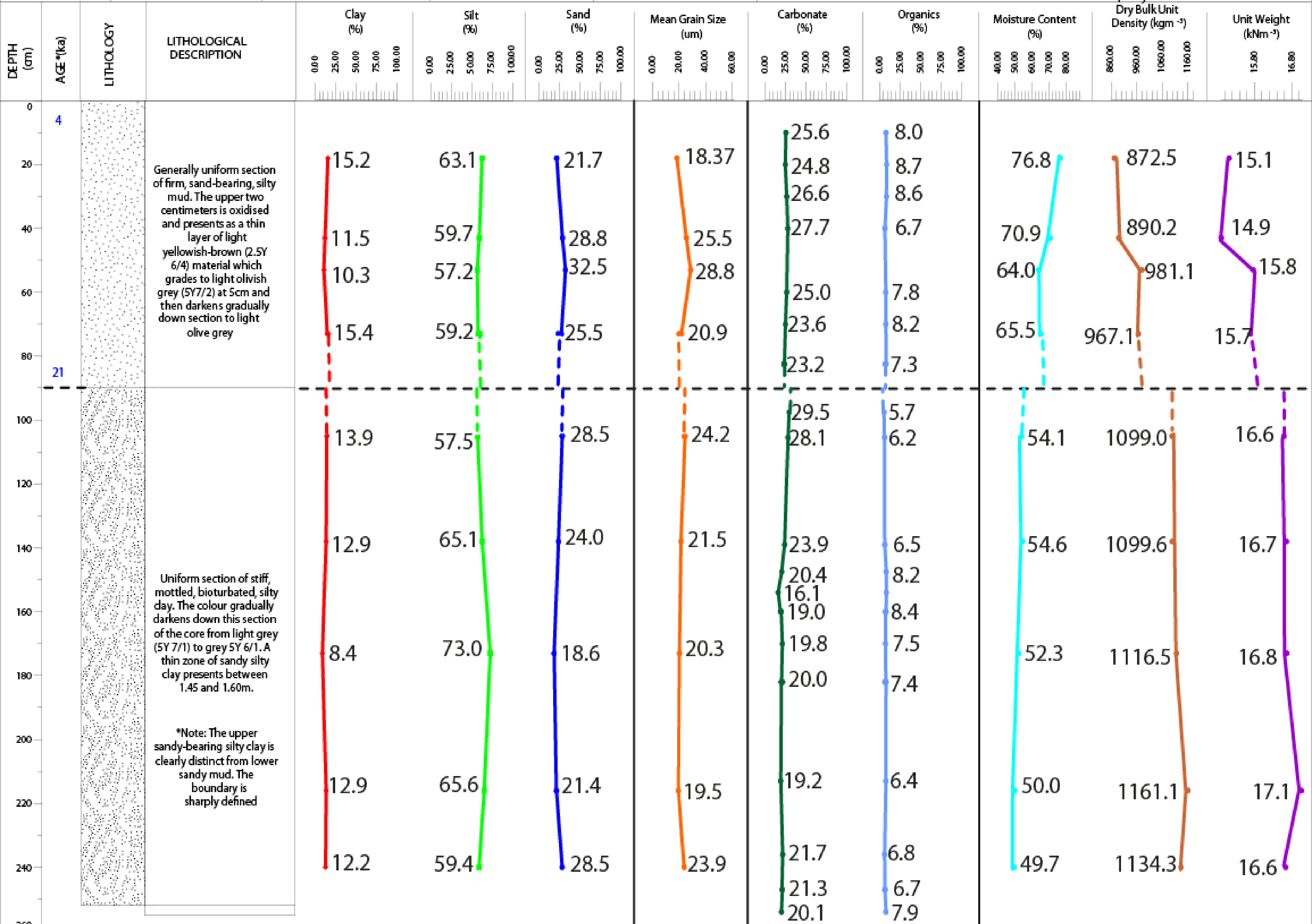
THANK YOU
for you support!

34TH INTERNATIONAL GEOLOGICAL CONGRESS
5-10 August 2012 – BRISBANE, AUSTRALIA
www.34igc.org

QUESTIONS?

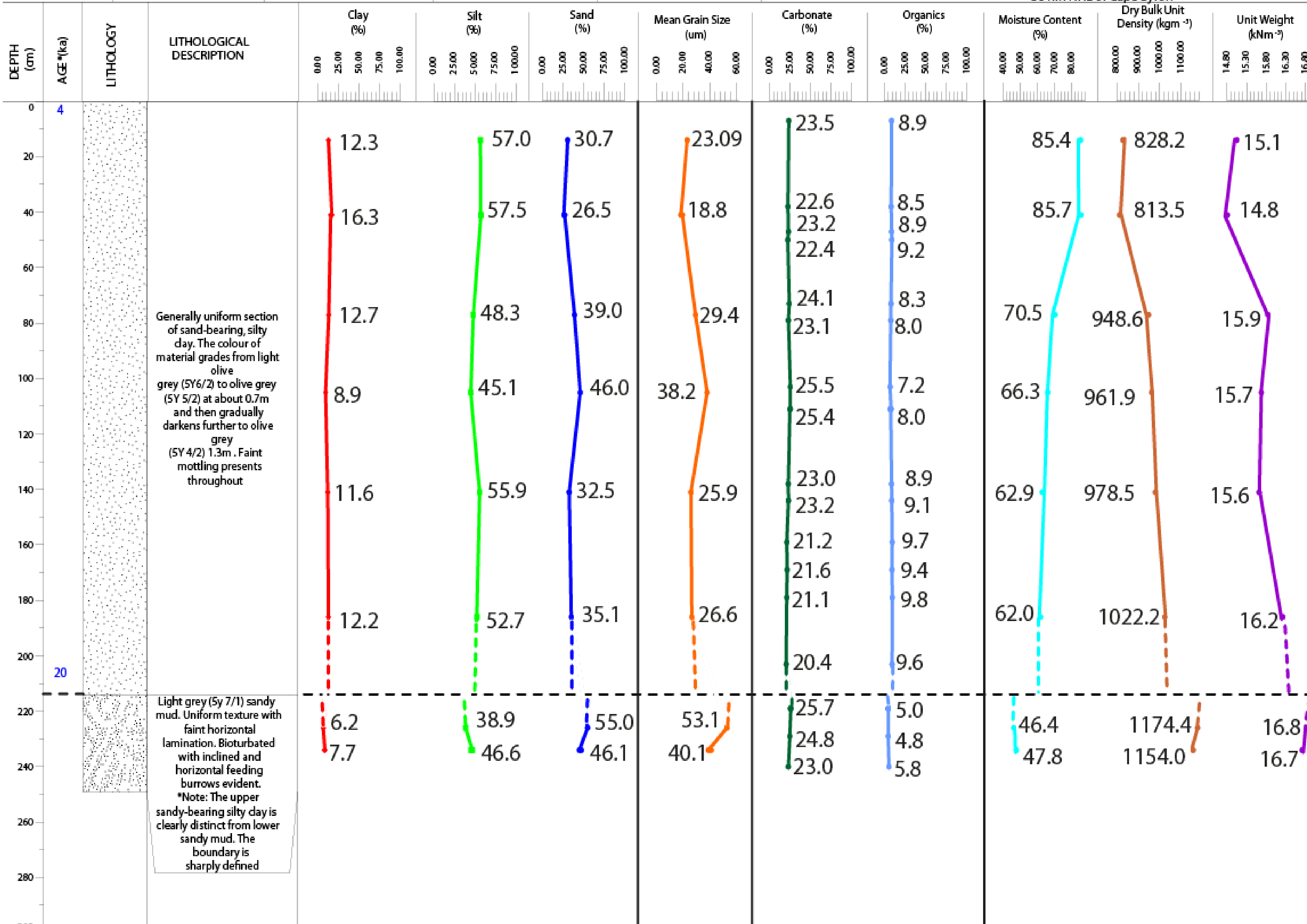
1. Dramatically reduces the strength of the sediment
2. Causes a long-term modification of the slope-geometry in order to promote slope failure OR
3. Seismic events which is large enough to trigger sediment collapse

CORE: GC8	LATITUDE: -28°07.263'	LONGITUDE: 154°02.752'	WATER DEPTH (m): 929	CORE LENGTH (m): 2.52	LOCATION DESCRIPTION: Northern New South Wales Margin ~30 nm NNE of Cape Byron



LOGGED BY: Tom Hubble & Samantha Clarke | DATE LOGGED: Nov-08 | *Thousand calandar years before present (BP)

CORE: GC11 | LATITUDE: -28°13.491' | LONGITUDE: 153°58.960' | WATER DEPTH (m): 755 | CORE LENGTH (m): 2.49 | LOCATION DESCRIPTION: Northern New South Wales Margin ~30 nm NNE of Cape Byron



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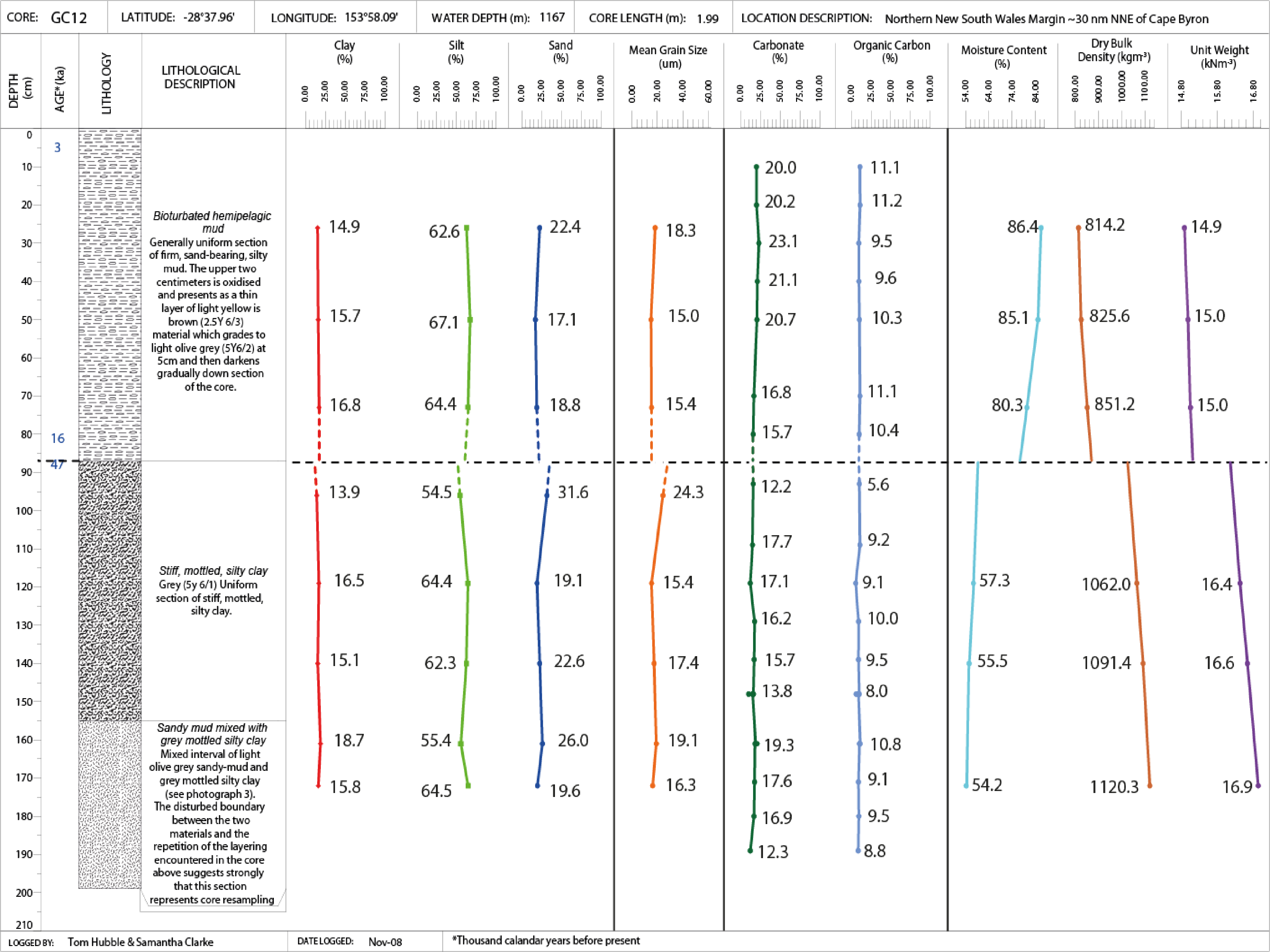


CORE: GC12
LATITUDE: -28°37.96'
LONGITUDE: 153°58.09'
WATER DEPTH (m): 1167
CORE LENGTH (m): 1.99
LOCATION DESCRIPTION: Northern New South Wales Margin ~30 nm NNE of Cape Byron
DEPTH (cm)
AGE* (ka)
LITHOLOGY
LITHOLOGICAL DESCRIPTION
Clay (%)
Silt (%)
Sand (%)
Mean Grain Size (um)
Carbonate (%)
Organic Carbon (%)
Moisture Content (%)
Dry Bulk Density (kgm⁻³)
Unit Weight (kNm⁻³)
3
16
47
Bioturbated hemipelagic mud
Generally uniform section of firm, sand-bearing, silty mud. The upper two centimeters is oxidised and presents as a thin layer of light yellow is brown (2.5Y 6/3) material which grades to light olive grey (5Y6/2) at 5cm and then darkens gradually down section of the core.
Stiff, mottled, silty clay
Grey (5y 6/1) Uniform section of stiff, mottled, silty clay.
Sandy mud mixed with grey mottled silty clay
Mixed interval of light olive grey sandy-mud and grey mottled silty clay (see photograph 3). The disturbed boundary between the two materials and the repetition of the layering encountered in the core above suggests strongly that this section represents core resampling
Clay: 14.9, 15.7, 16.8, 13.9, 16.5, 15.1, 18.7, 15.8
Silt: 62.6, 67.1, 64.4, 54.5, 64.4, 62.3, 55.4, 64.5
Sand: 22.4, 17.1, 18.8, 31.6, 19.1, 22.6, 26.0, 19.6
Mean Grain Size: 18.3, 15.0, 15.4, 24.3, 15.4, 17.4, 19.1, 16.3
Carbonate: 20.0, 20.2, 23.1, 21.1, 20.7, 16.8, 15.7, 12.2, 17.7, 17.1, 16.2, 15.7, 13.8, 19.3, 17.6, 16.9, 12.3
Organic Carbon: 11.1, 11.2, 9.5, 9.6, 10.3, 11.1, 10.4, 5.6, 9.2, 9.1, 10.0, 9.5, 8.0, 10.8, 9.1, 9.5, 8.8
Moisture Content: 86.4, 85.1, 80.3, 57.3, 55.5, 54.2
Dry Bulk Density: 814.2, 825.6, 851.2, 1062.0, 1091.4, 1120.3
Unit Weight: 14.9, 15.0, 15.0, 16.4, 16.6, 16.9
LOGGED BY: Tom Hubble & Samantha Clarke
DATE LOGGED: Nov-08
*Thousand calandar years before present

PRELIMINARY RESULTS AND IMPLICATIONS

RADIOCARBON DATING

Table 1 ^{14}C dating results of bulk sedimentary organic carbon samples. All samples were taken from above the inferred slide plane boundary except for sample SS2008-12/GC12/1B-88.

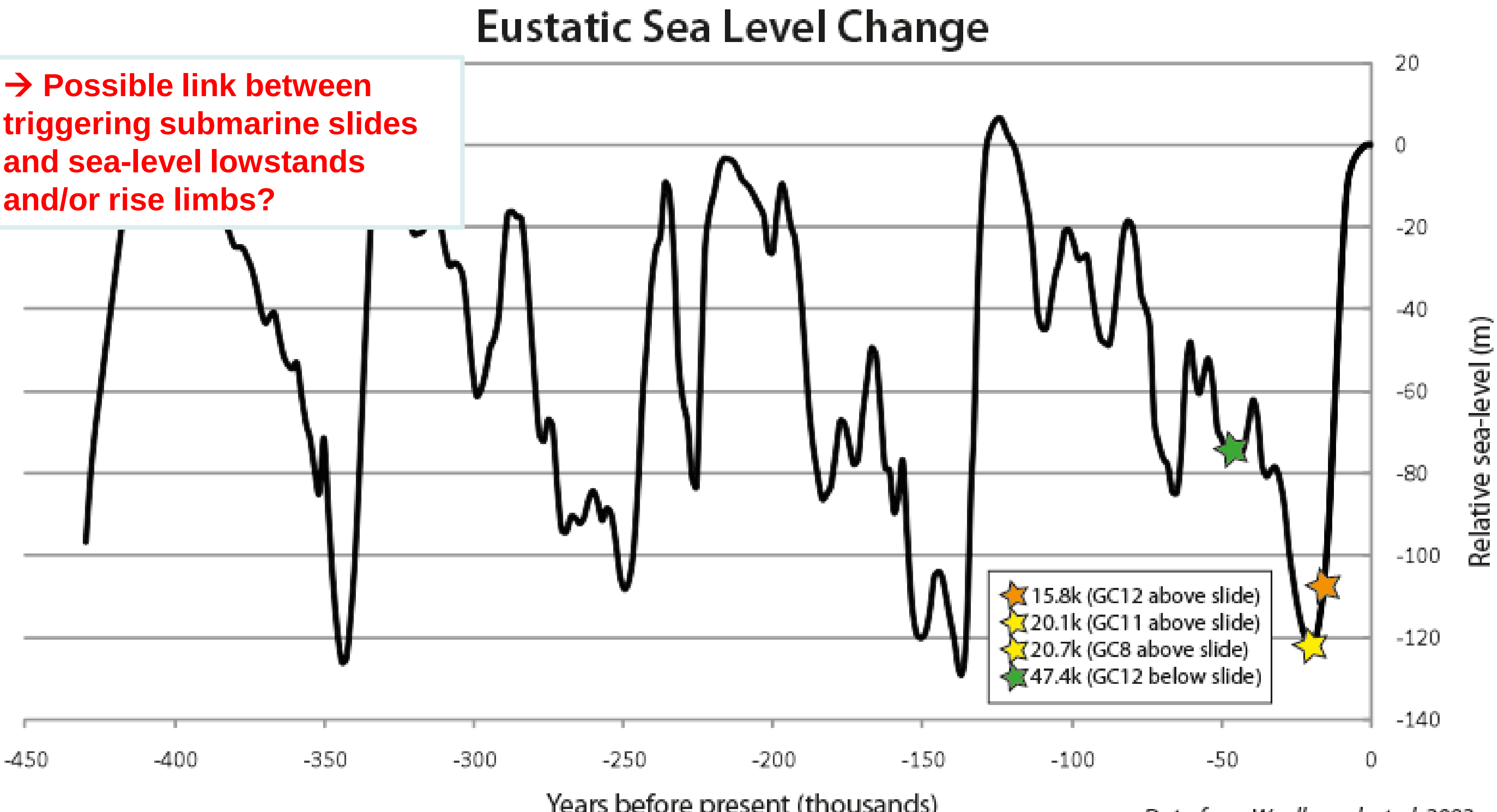
Lab Code	**Core**	**Depth (cm)**	**Conventional ^{14}C age (BP)**	**^{14}C error***	**Median calibrated age (2σ) (BP)**	**2σ calibrated age range (95.4% probability) (BP)**
SS2008-12/GC8/1C-6/D	GC8	6	4,157	±45	4,229.5	4,079.5 – 4,379.5
SS2008-12/GC8/2B-85/D	GC8	85	17,732	±95	20,699.5	20,249.5 – 21,149.5
SS2008-12/GC11/1C-3	GC11	3	3,763	±44	3,699.5	3,569.5 – 3,829.5
SS2008-12/GC11/3A-206	GC11	206	17,417	±91	20,149.5	19,849.5 – 20,449.5
SS2008-12/GC12/1B-5	GC12	5	3,207	±51	3,024.5	2,859.5 – 3,189.5
SS2008-12/GC12/1B-81	GC12	81	13,463	±77	15,799.5	15,149.5 – 16,449.5
SS2008-12/GC12/1B-88	GC12	88	44,288	±1205	47,399.5	45,149.5 – 49,649.5

**Quoted errors are 1 standard deviation*

PRELIMINARY RESULTS AND IMPLICATIONS

RADIOCARBON DATING

→ **Possible link between triggering submarine slides and sea-level lowstands and/or rise limbs?**



Data from Waelbroeck et al. 2002

PRELINIMARY RESULTS AND IMPLICATIONS

MODELLING INPUT DATA AND BACK ANALYSIS RESULTS

Table 1 Numerical input parameters used for modeling the slides with GEO-SLOPE/W. The friction angle (Φ) represents the friction component of the soil strength and the apparent cohesion (c') represents the cohesive component of the soil strength.

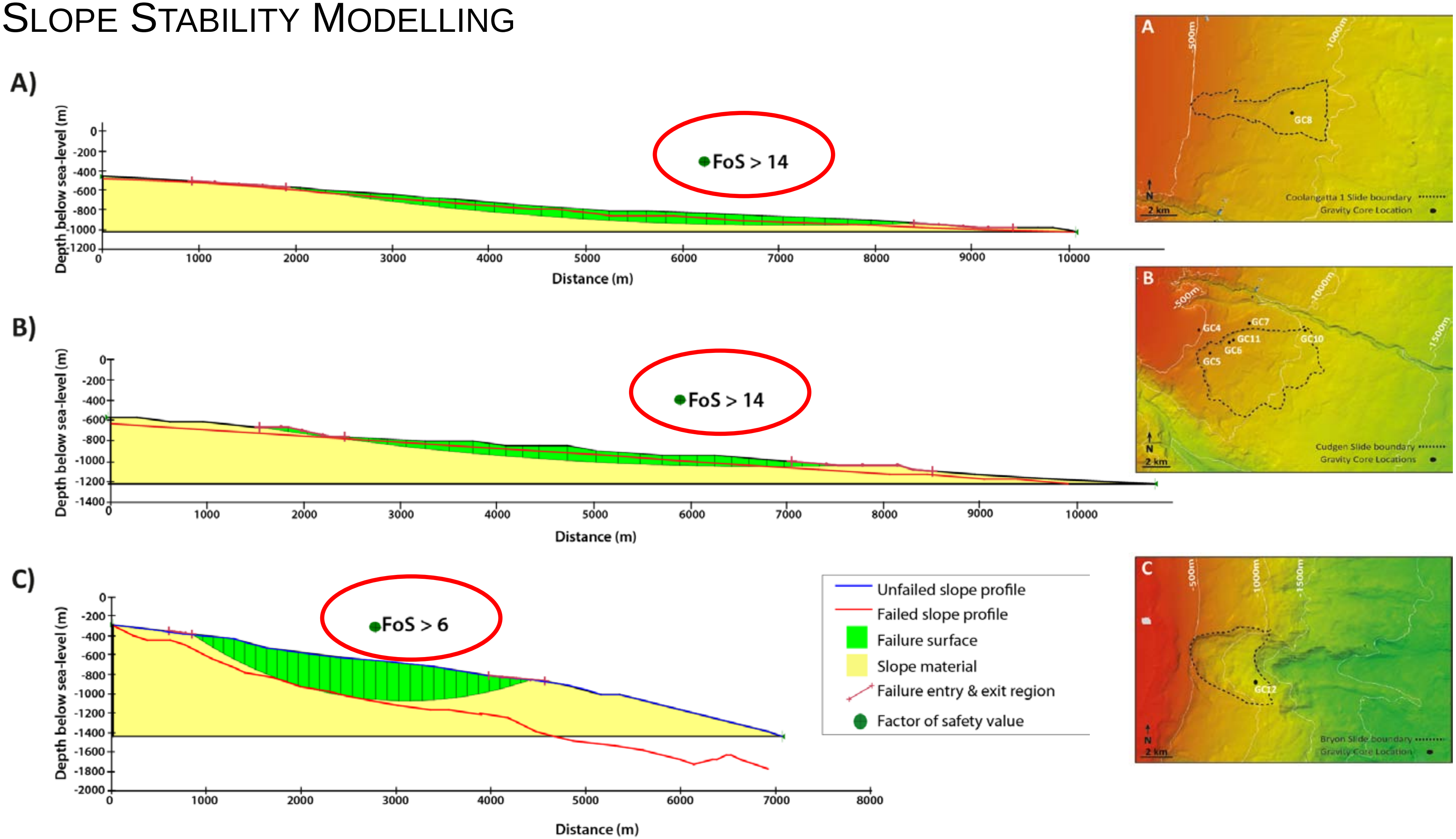
Parameter	Unit	Input value range
Unit weight (γ)	kN/m^3	15 - 17
Apparent cohesion (c')	kPa	0 - 22
Friction angle (Φ)	°	0 - 40

Table 2 Back analysis GeoSlope outputs: a summary of the factors of safety (FoS) for the Byron slide arising from reducing c and Φ is shown in Table 2. Critical FoS are underlined. The Coolangatta1 and Cudgen slides follow the same trends.

Site	Scenario description	Cohesion (kPa)	Friction angle (°)	FoS (lowest)
Byron Slide	Residual cohesion, decreasing friction angle	0	40	6.19
			30	4.26
			15	1.98
			7.5	<u>0.97</u>
			3.75	<u>0.48</u>
	Peak friction angle, decreasing cohesion	11	40	8.8
		5.5		7.8
		2.75		7.28
		1.375		6.98

PRELIMINARY RESULTS AND IMPLICATIONS

Slope Stability Modelling



STUDY AREA

- Widespread erosional features
- SE Australian margin has relatively little sediment
- Slowly increasing slope due to abyssal plain subsidence
- Sedimentation rates: 0.3-1.2m/10,000years
- Retrogressive gravity driven failures (Glenn et al, 2010)

SUMMARY

Numerous large landslides have been detected on the SE Australian continental slope.

- Slopes average 1^{o} to 9^{o}
- Friction angles 37^{o} to 40^{o}, no evidence of weak clay layers
- Factors of Safety should be high
- Triaxial tests indicate brittle material response
- Largest failures (20 km^3) could generate significant tsunami
- Most recent failures at time of last glaciation, at sea level minimum