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The Brunei slide: A giant submarine landslide on the North West Borneo Margin revealed by 3D seismic data

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Abstract

Three dimensional seismic data, offshore Brunei, provide evidence for a giant landslide with a volume of 1200 km^3, an area of ~5300 km^2 and an average thickness of ~240 m. It extends for over 120 km from the Baram Canyon in ~200 m water depth to the deep basin floor of the North West Borneo Trough. The landslide is a unique example of a major submarine landslide located on a steep, tectonically active margin adjacent to a large river and canyon system. The landslide is mappable using 3D seismic data, which allow detailed imaging of internal flow structures, erosional headwall and the basal sliding surface. The landslide is a complex deposit, involving a chaotic debris flow matrix, with flow structures and blocks 500 to 1000 m wide and up to 250 m thick. Imaging of the basal sliding surface reveals large striations ~30–120 km long, ~100–600 m wide, and ~10–30 m deep that show significant amounts of basal erosion. In the landslide source area we describe fluid escape structures, gas buildups and bottom simulating reflectors, which may provide a mechanism for weakening and triggering slope failure. We also report older landslides, buried several hundred meters beneath the basin floor that indicate giant landsliding is a recurrent process in the NW Borneo Trough.
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Keywords: Mass Transport Complex; landslide; 3D seismic; debris flow; triggering mechanisms; gas hydrates

1. Introduction

It is well established that large scale submarine landslides play an important role in the evolution of modern ocean margins. Individual landslides involving hundreds of cubic kilometers of material have been reported from the N Atlantic (Piper et al., 1988; Bugge et al., 1988; Laberg and Vorren, 2000; Vanneste et al., 2006) W Atlantic (Embley, 1976; Masson et al., 1993; Gee et al., 1999), E Atlantic (Popenoe et al., 1993; O'Leary, 1993), E Pacific (McAdoo et al., 2000) and Mediterranean (Lastras et al., 2002; Frey Martinez et al., 2005). Recent advances in three dimensional seismic techniques are improving our understanding of submarine landslide structure, flow mechanics and triggering mechanisms and allowing us to examine older landslides buried beneath the seafloor (see Huvenne et al., 2002; Frey Martinez et al., 2005; Gee et al., 2005).

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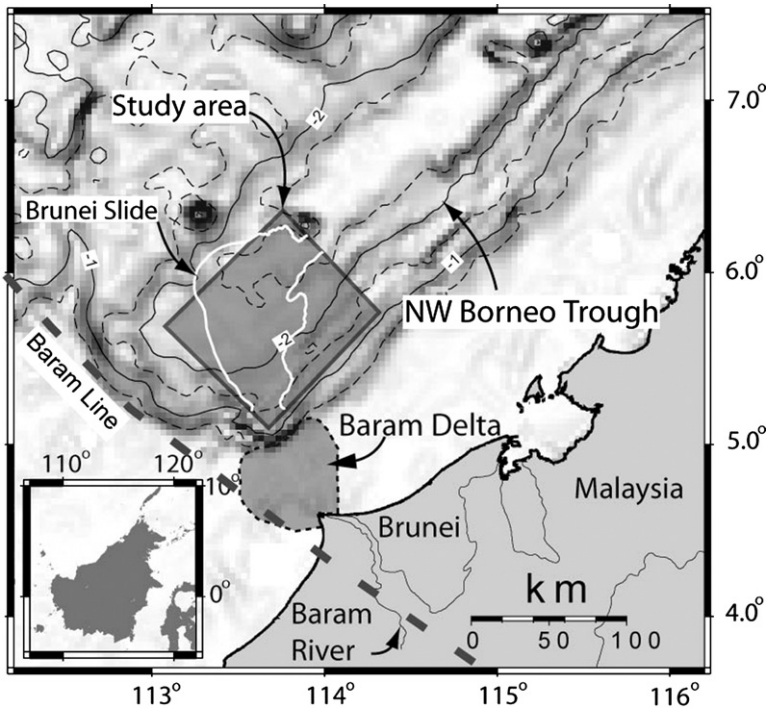


Fig. 1. Regional basemap showing the study area and Brunei Slide located in the NW Borneo Trough. Contours are drawn at 500 m intervals. Steeper slopes are shown by darker grey shades.

Evidence for submarine landsliding includes anomalous seafloor topography, basal sliding surfaces and blocks surrounded by chaotic matrix that spread for hundreds of kilometers from source.

There are several general names used to describe submarine slope failure deposits, e.g., debrite, mass transport complex, mass transport deposit. More specific names have been used to describe the failure process, e.g., slump, debris avalanche, debris flow and debris slide, where the data allow more detailed interpretation. In this paper, for simplicity, we use the name 'landslide' as a general term to describe a slope failure with no implication of specific process or geological setting.

This paper describes a newly discovered, giant submarine landslide on the deep water slope of Brunei (NW Borneo) which we name the Brunei Slide. By volume, it ranks as one of the largest slope failures on Earth, comparable with the Saharan Slide (Embley, 1976) and with the Hinlopen Slide (Vanneste et al., 2006). It is also about a third of the volume of the Storegga Slide (Bugge et al., 1988). To the best of our knowledge, the Brunei Slide is the largest submarine slope failure associated with an active delta and river system. The slide was initiated on a relatively steep slope (~2–4°) and is associated with tectonically active, shale-cored ridges (Fig. 1). According to Hampton et al. (1996) submarine slides are common in five environments: (1) fjords, (2) active river deltas, continental margins, (3) submarine canyon-fan systems, (4) open continental slope, and (5) oceanic volcanic islands. The largest non-volcanic collapse events, such and the Storegga and Saharan landslides, occur in passive margin, open slope settings away from rivers and canyon systems. The Brunei Slide is located on an active convergent margin, linked to a river delta and canyon system, which should favour the triggering of more frequent, smaller landslides (see Section 4:Discussion). The Brunei Slide presents a unique opportunity for study as over 90% of the landslide has been imaged within a 3D seismic survey, from its source in the Baram Canyon to its distal regions in the deep water part of the NW Borneo Trough.

We use 3D seismic data to show that giant landslides have played a significant role in the development of the NW Borneo Trough. Detailed analysis is presented of the most recent landslide exposed on the seafloor, the Brunei Slide, with insight into its possible triggering, flow and depositional mechanisms. Detailed time structure, amplitude and gradient maps of the seafloor and internal structure of the landslide show the headwall, basal sliding surface and blocky nature of the

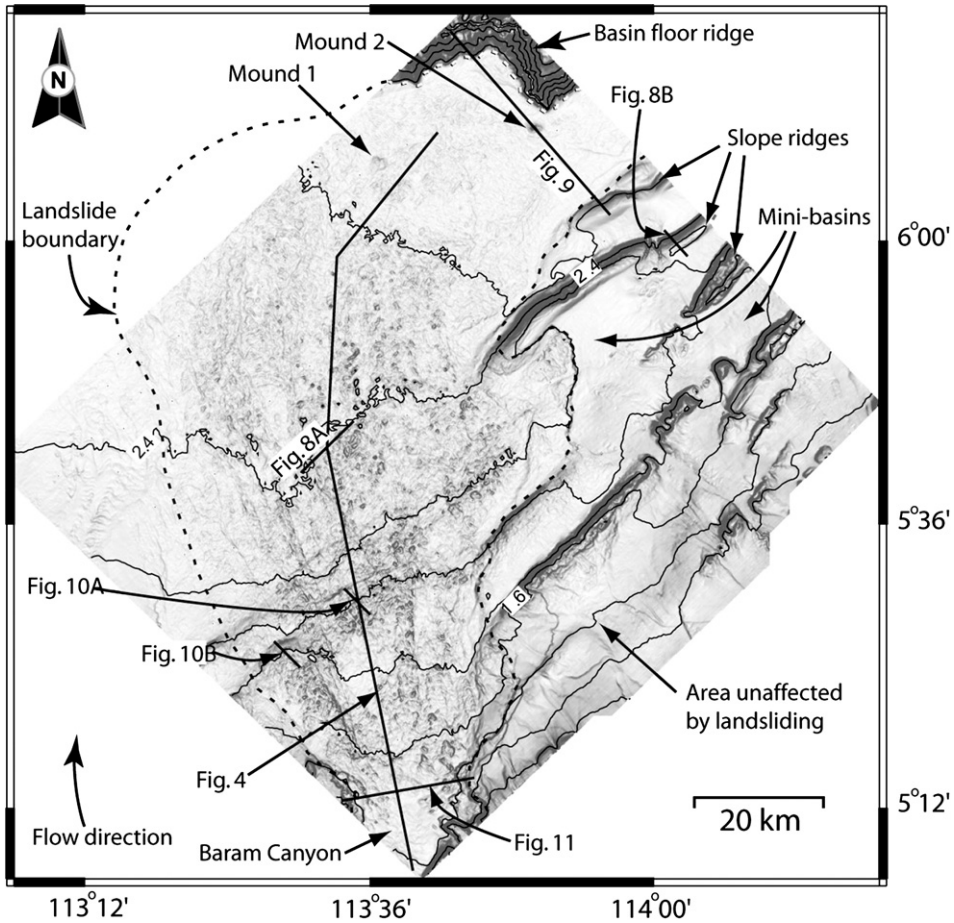


Fig. 2. Seafloor slope map of the Brunei Slide and adjacent slope mapped from 3D seismic reflection data. Darker shades show steeper slopes. Dashed line shows extent of the landslide and its characteristic rugged relief.

deposit. Bottom simulating reflectors (BSR's) and fluid escape structures are observed within the landslide headwall region and we discuss the role they may have played in the evolution of the landslide. Finally we discuss landslide processes and present a simple model for the Brunei Slide.

2. Geological background

The Northwest Borneo margin and the NW Borneo Trough are related to the opening of the South China Sea in the early Tertiary (Hinz and Schluter, 1985). During the Late Cretaceous, proto-South China Sea oceanic crust was being subducted beneath Sundaland. Subduction beneath the NW Borneo margin continued until the latest Early Miocene, when a large block of continental material called the 'Dangerous Grounds' entered the subduction trench and caused the subduction process to lock (Levell, 1987; Hazebroek and Tan, 1993; Hall, 1996). This resulted in the collision of the leading edge of the South China Sea continental realm with the Crocker–Rajang accretionary margin) of Northwest Borneo (James, 1984; Sandal, 1996). The resulting uplift and erosion of the Crocker–Rajang accretionary belt became the main source of sediment supply for this region. To the west of the NW Borneo Trough and the Baram Line, is an area of shallow seas underlain by normal continental crust (Fig. 1). A comprehensive analysis of the tectonic evolution of the southern South China Sea is provided by Hutchinson (1996).

The modern Brunei shelf is 50–70 km wide and defined by a prominent fault scarp at ~130 m water depth (Hiscott, 2001). The Baram Canyon connects the modern day Baram River and delta system to the NW Borneo Trough. The Canyon is several hundred meters deep and approximately 20 km wide (see Fig. 2). The Baram Delta is a lobate, wave-influenced, tide-dominated system (Lambiase et al., 2002). The delta has

prograded to the shelf break and head of the Baram Canyon during the last sea level rise following deglaciation. The seafloor dips steeply at an angle of 2–4° from the shelf break towards the basin floor of the NW Borneo trough in water depths of 2.7 km (Hiscott, 2001). The NW Borneo margin to the east of the Baram Line is affected by a fold and thrust belt (McGilvery and Cook, 2003). Depositional models have been developed for the Brunei slope by Demyttenaere et al. (2000), and McGilvery and Cook (2003) which describe elongate mini-basins separated by shale-cored ridges created by basin-directed thrusting. Typical deep-water elements of this slope include turbidite channels, levees, fan systems and mass transport complex or debris flow deposits. Extensive debris flow deposits were first reported offshore Brunei by Hiscott (2001), extending from the Baram Canyon in ~200 m of water towards the deep basin floor of the NW Borneo Trough.

3. Observations and interpretations

Seafloor slope maps display distinct contrasts in morphology and slope gradient. To the east, the seafloor is dominated by strike-oriented ridges up to 800 m high. The western slope and central basin floor has a distinct rugged relief and a more subdued topography where slope ridges are not observed at the seafloor (Fig. 2). The rugged relief has a typical peak to trough amplitude of 50 m and wavelength of 500 m. The area of rugged relief approximately correlates with the area mapped as the Brunei Slide. To the north of the Brunei Slide there is a large, steep-sided ridge which rises over 1 km from the basin floor. This ridge contrasts with the smoother morphology of the slope ridges to the south and east. Two mounds are identified on the seafloor in the northern and deepest part of the basin (Fig. 2). Mound 1 is ~70 m high and mound 2 is 300 m high. These

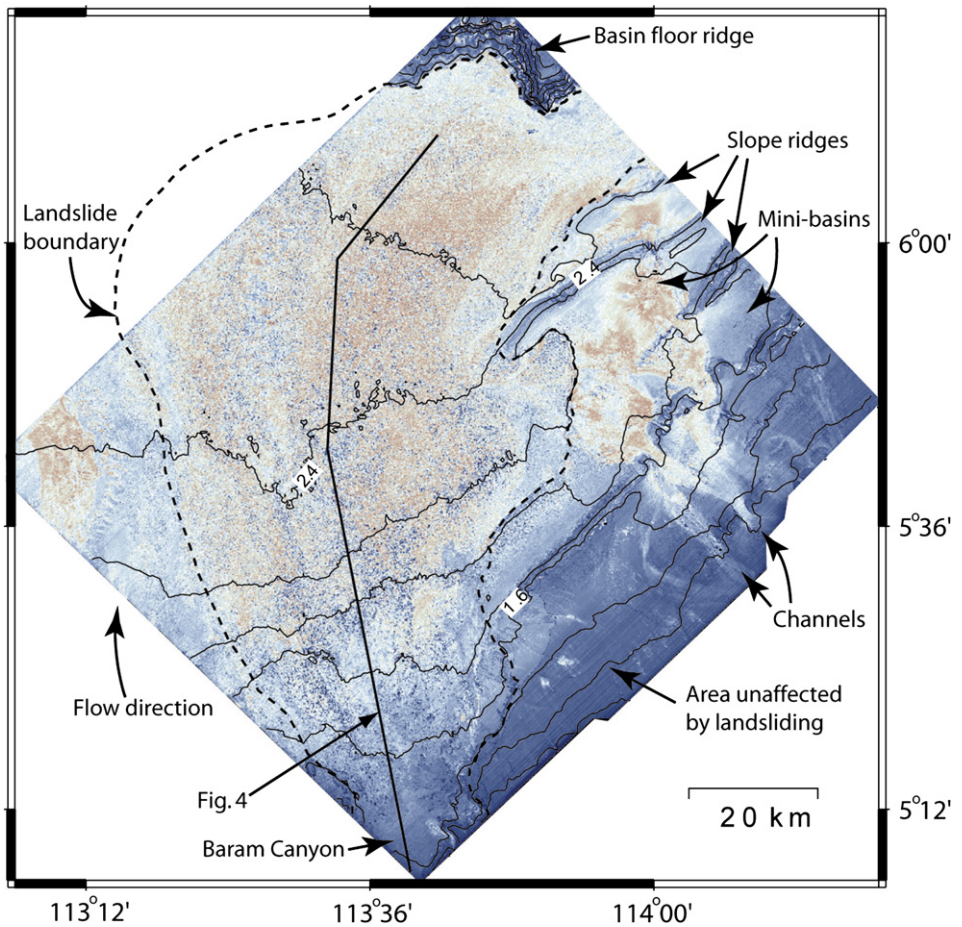


Fig. 3. RMS amplitudes mapped from 3D seismic data from a 20 ms interval at the seafloor. Blue colour represents lower amplitudes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mounds are linked to zones of seismic disturbance in the subsurface (see Figs. 8 and 9).

A 20 ms RMS amplitude extraction from the seafloor over the study area shows a relatively high amplitude, speckled pattern (Fig. 3) which correlates with the area of subdued, rugged topography shown in Fig. 2. In the eastern part of the basin, where water depths are greater than 2.4 km, the speckled pattern displays higher seismic amplitudes. This distinctive speckled pattern extends a distance of 130 km from the Baram Canyon to the basin floor and covers a total area of 5300 km^2. The steep slopes of ridges and the areas of slope unaffected by landsliding to the southeast have lower amplitude signatures, apart from some very high amplitude, linear, downslope-oriented features in the east interpreted as slope channels (McGilvery and Cook, 2003).

The Brunei Slide can be recognized from 2D seismic sections as a seismically chaotic and generally low amplitude body that extends for ~120 km from the Baram Canyon (Fig. 4). The landslide base is irregular and truncates underlying reflections. The overlying landslide deposit has an irregular thickness, which tends to thicken basinwards over lower gradient slopes. The landslide surface is characterized by a subdued topography. Beneath the landslide, the upper slope is dominated by gravity-driven, thrust folds, several of which have apparently suffered hundreds of meters of erosion of their anticline crests (Fig. 4). Slopes over the basin floor average 0.4°. Slopes over the mid-slope anticlines average 2.5°. Slopes over the upper slope average 1°. Beneath the landslide unit, mini-basins on the upper and mid-slopes are characterised by high-amplitude, layered and lens-shaped facies. In the highest level mini-basin the chaotic and low amplitude seismic facies has a thickness of almost 500 m (Fig. 4). Directly overlying the chaotic low amplitude facies is a high-amplitude, layered facies of ~50 m thick.

One of the most spectacular observations made during this study is the visualisation of the seismic reflector at the base of the landslide. A gradient map of this reflector reveals large-scale, downslope oriented striations which extend 120 km from the mid-slope to the deep basin area (Fig. 5). Individual striations are 100–600 m wide, 10–30 m deep and curve from the south towards the north-east where they decrease in width and depth. No divergence is obvious in the pattern of striations. Striations cut into the underlying substrate and provide important evidence for a catastrophic slope failure event in which sliding was the main process.

A time thickness map of the landslide deposit illustrates lineated basal structure and how it thickens downslope towards the centre of the slide area (Fig. 6). Based on typical velocity estimates of 2000 m/s for the upper basin strata, the landslide has an average thickness of ~240 m. In its distal part, the landslide thins towards the north east. It is estimated that 20% of the landslide volume has its source in the Baram Canyon, and 1–2% from the eroded anticline ridges. However, around 80% of the total landslide volume is estimated to have been mobilized from the substrate beyond the Baram Canyon by basal erosion and ploughing of the seafloor during emplacement. Estimates of mobilized material were made by reconstructing the geometry of the seabed based on adjacent undisturbed slopes. In water depths less than 2000 m the landslide basal surface becomes hard to recognize, although weakly developed striations extend upslope into the Baram Canyon (Fig. 7). These striations can be clearly observed to truncate the crests

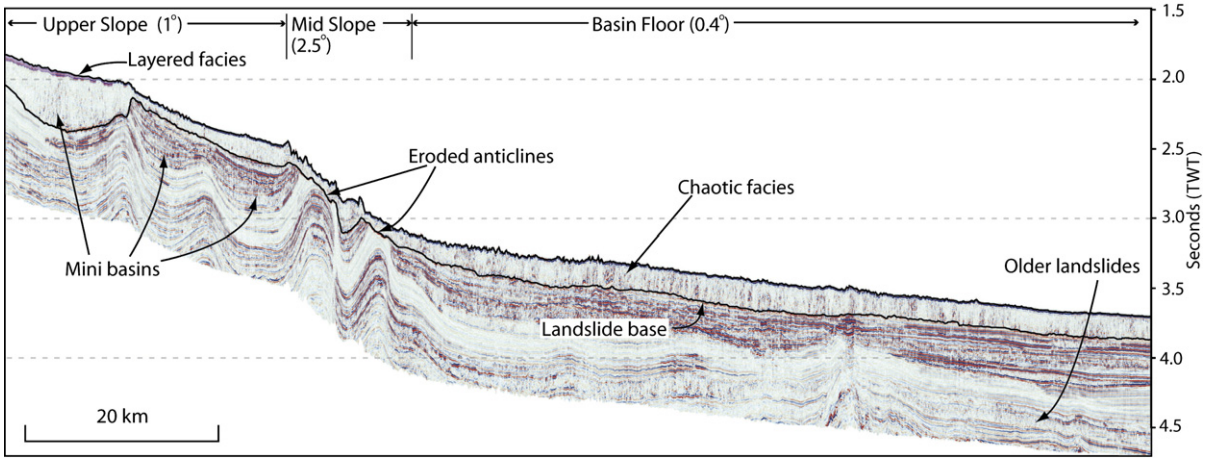


Fig. 4. Long profile seismic section across the upper and mid slopes and basin floor. See Fig. 2 for location.

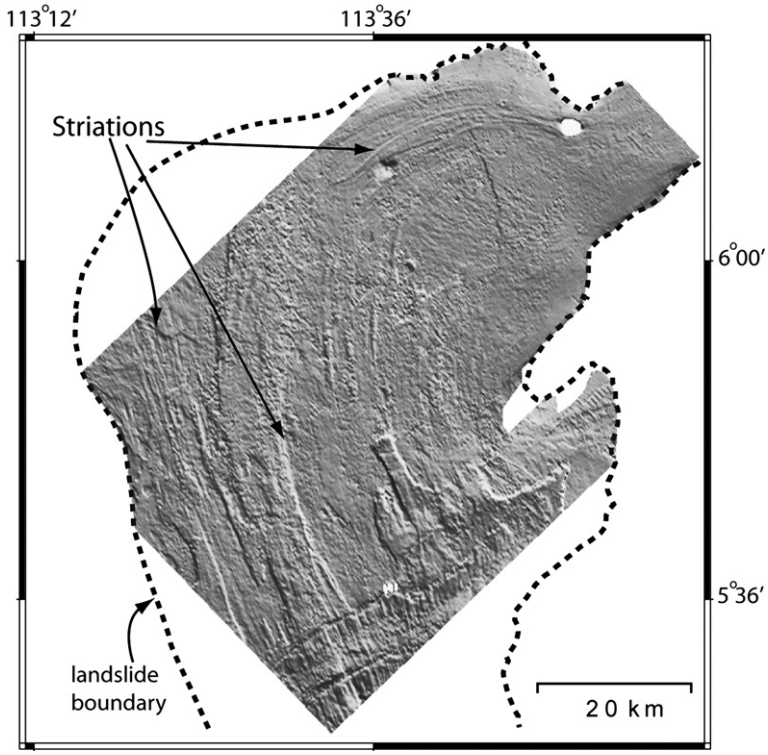


Fig. 5. Gradient map of the basal surface of the Brunei Slide showing striations extending 120 km across the slopes and basin of the NW Borneo Trough. Artificial illumination is from the north east.

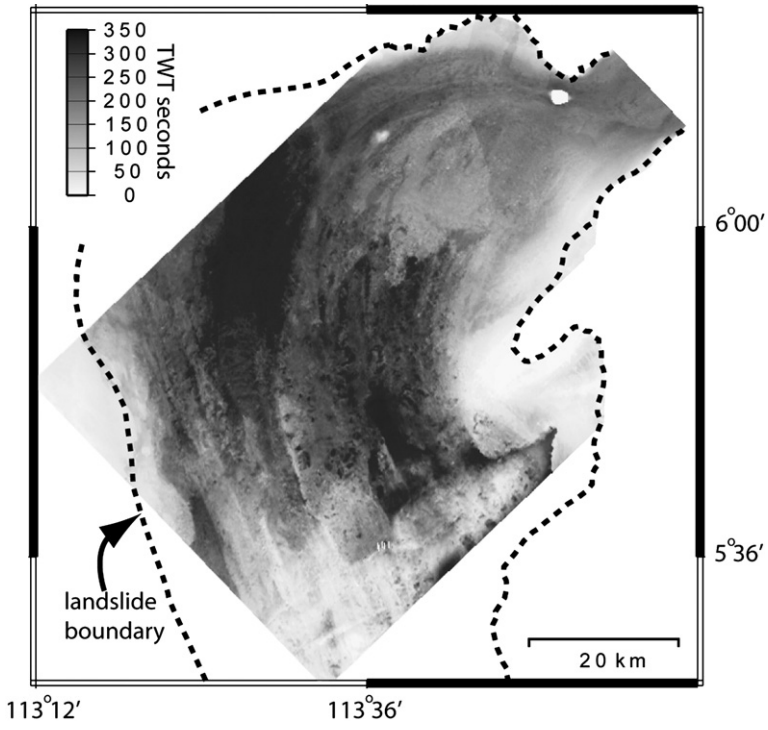


Fig. 6. Isochore map of the Brunei Slide deposit. Dark shades show landslide two way travel times up to 350 ms.

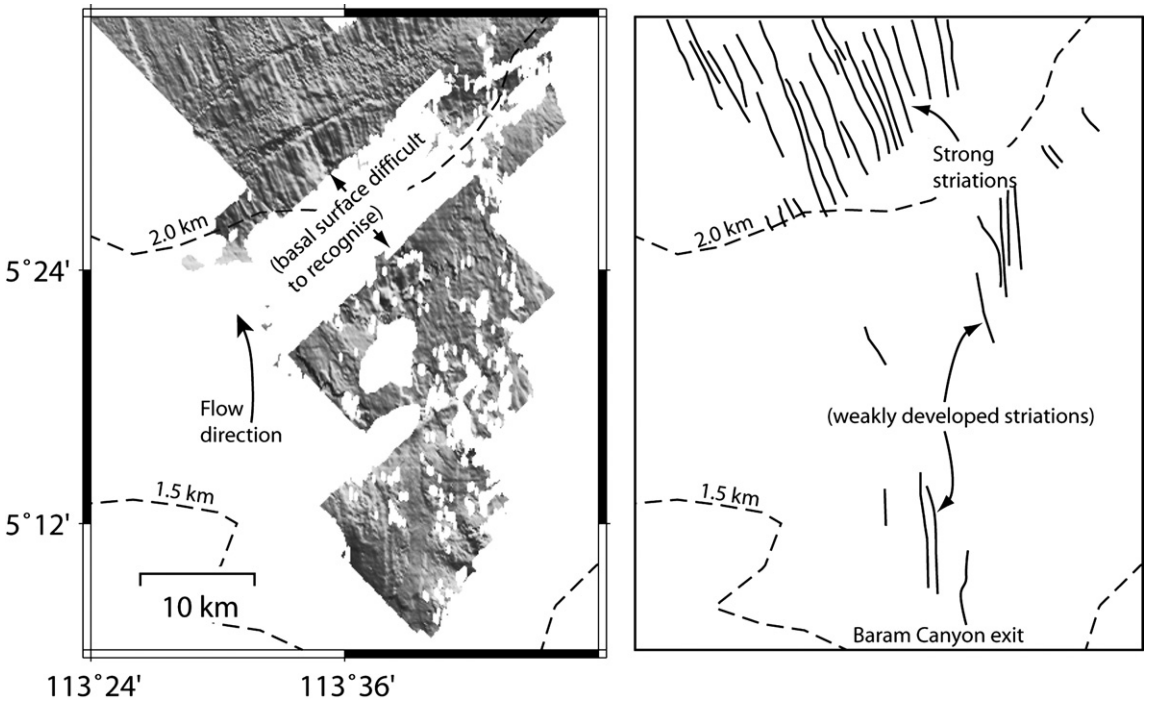


Fig. 7. Gradient map of basal sliding surface of the Brunei Slide showing weakly developed striations extending from the Baram Canyon onto the upper slope in water depths less than 2 km.

of anticline ridges immediately downslope of the Baram Canyon (Fig. 7).

The internal structure of the landslide lacks coherent and continuous reflections, although there are some high amplitude and steeply dipping events visible, which are interpreted as blocks of sediment (Fig. 8). Seismic data also show narrow, vertical zones of seismic blanking and chaotic, low amplitudes interpreted as fluid escape structures. These structures are often several hundreds of meters wide and cut across relatively horizontal and high amplitude reflections (Figs. 8, 9). There are also smaller vertical zones of seismic blanking focused within anticlines, also interpreted as fluid escapes (Fig. 8).

A seismic section between the basin floor ridge and the deepest slope ridge shows a ~100 m thick layer with chaotic low amplitudes interpreted as the landslide deposit (Fig. 9). A zone of vertical seismic disturbance cross-cuts the landslide deposit and high amplitude, sub-parallel reflectors deeper in the section to form a mound on the seafloor. Deeper in the section several chaotic, lens-shaped bodies underlying the landslide deposit occur. More lens-shaped bodies are observed to the south east of the vertical seismic disturbance. These are interpreted as smaller buried landslide deposits. Buried landslide deposits traveling along the basin floor may have been deflected north eastwards by the mound. The landslide clearly extends towards the north east beyond the survey limits.

Farther up the slope, bottom simulating reflectors (BSRs) are observed at a depth of ~200 m within eroded anticline crests (Fig. 10). They are best developed on the up-dip limbs of the anticlines. These BSRs mimic the present-day, post-landslide seafloor topography, which suggests that they may have re-equilibrated following landslide erosion of the seafloor, as has also been observed for the BSR below the Storrega Slide (see Bouriak et al., 2000; Bünz et al., 2003).

In the headwall region of the landslide, several zones of chaotic low amplitude seismic facies and small seafloor mounds are observed along the western part of the Baram Canyon (Fig. 11). In the absence of data to show mud out-flows and structure, we suggest tentatively that they may be related to fluid escape and have built mud volcanoes on the sea floor. The seismic section (Fig. 11) shows ~400 m of seismically chaotic facies overlain by a thin (50 m), high amplitude, and layered facies. This is interpreted as post-landslide turbidite deposition from the Baram Canyon. The eastern canyon wall appears to have experienced some

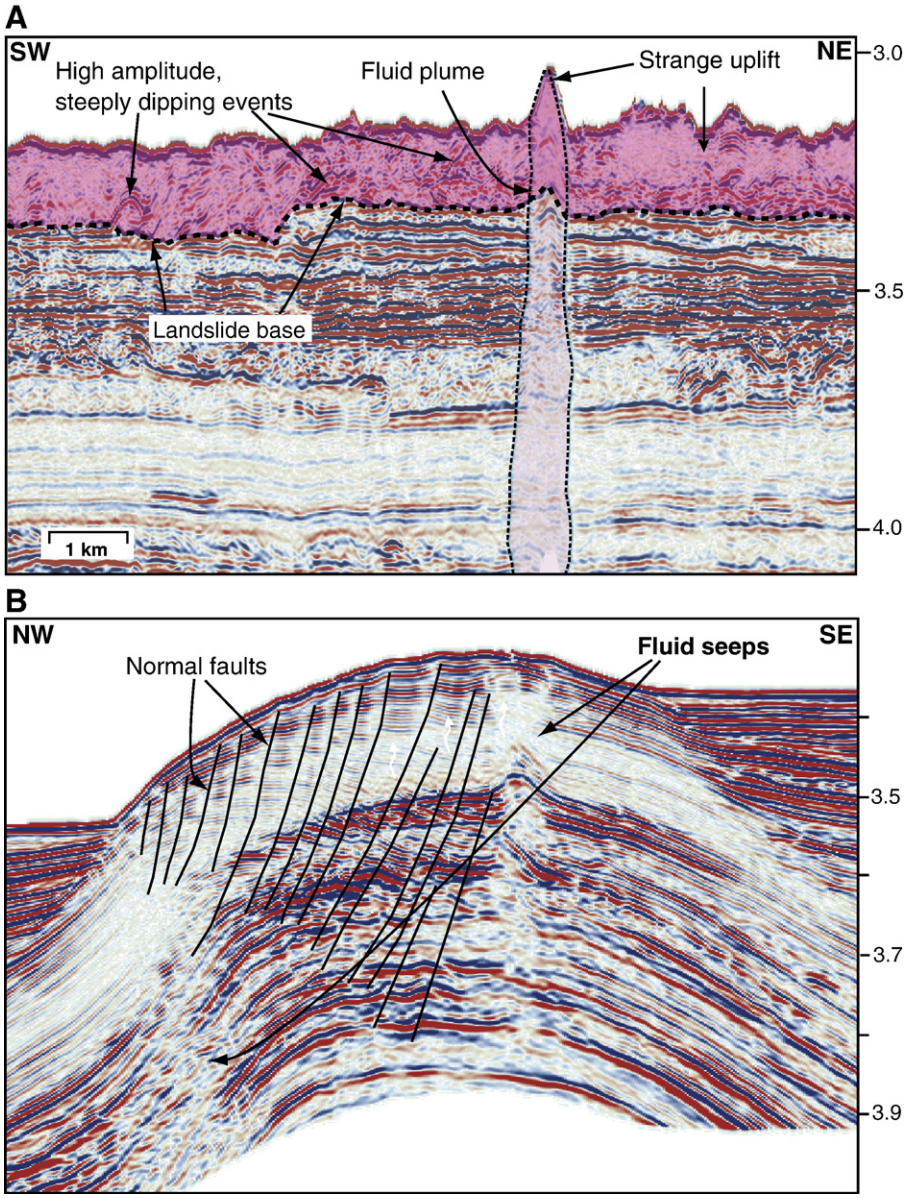


Fig. 8. Two seismic sections showing fluid escape structures in the study area. Section A shows a large fluid plume up to 1 km wide and a mud volcano. The landslide unit is characterised by high amplitude, steeply dipping events interpreted as landslide blocks. Section B shows smaller fluid seeps focussed in the crest of a slope anticline. For location, see Fig. 2.

retrogressive failure in the form of rotated fault blocks that have slipped towards the canyon (Fig. 11).

4. Discussion

Giant, 120 m long, erosional striations, extending continuously from the lower slope anticlines across the low gradients of the basin floor, indicate a catastrophic landslide failure process. The extent and erosional nature of the striations suggests the landslide ploughed and scraped the seafloor instead of sliding efficiently over a low friction basal shearing layer. The presence of striations on the eroded crests of anticline ridges is evidence that the anticlines were eroded during landslide emplacement. Intense erosion probably resulted from large cohesive blocks lodged in the base of the flow.

The size and extent of basal striations associated with the Brunei Slide is unprecedented, covering an area of almost 4000 km^3. The abrupt appearance of numerous

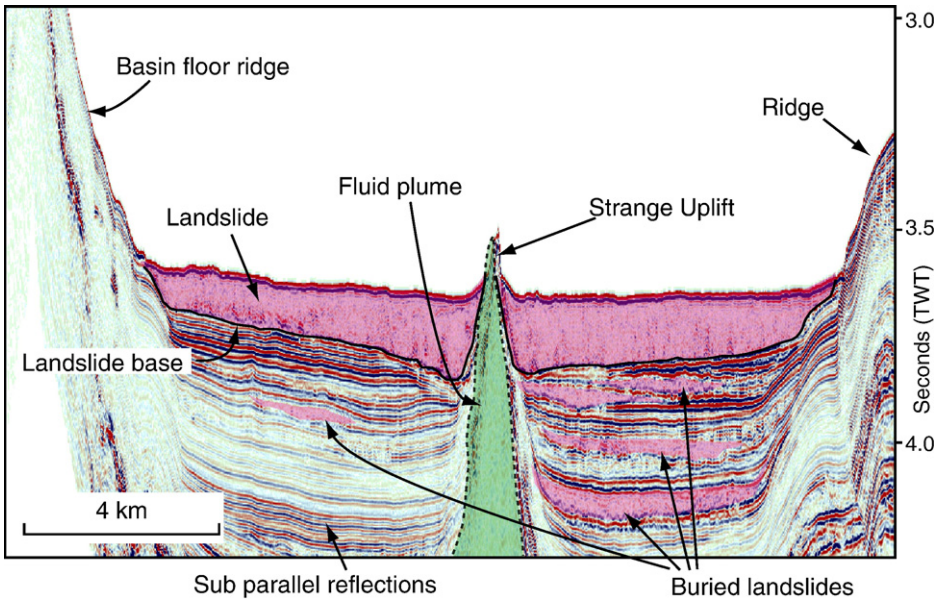


Fig. 9. Seismic section across the distal part of the basin, illustrating a major fluid plume and mud volcano. Note the Brunei Slide unit at the highest stratigraphic level and a number of smaller buried landslide units. For location, see Fig. 2.

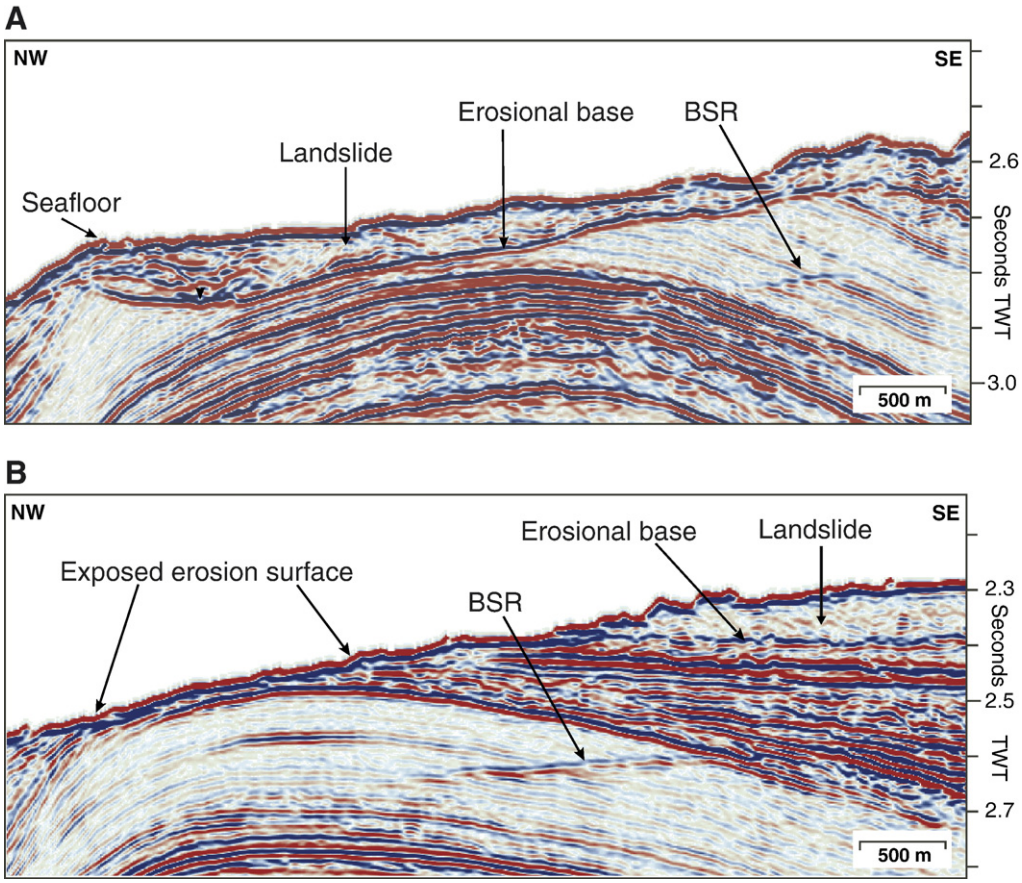
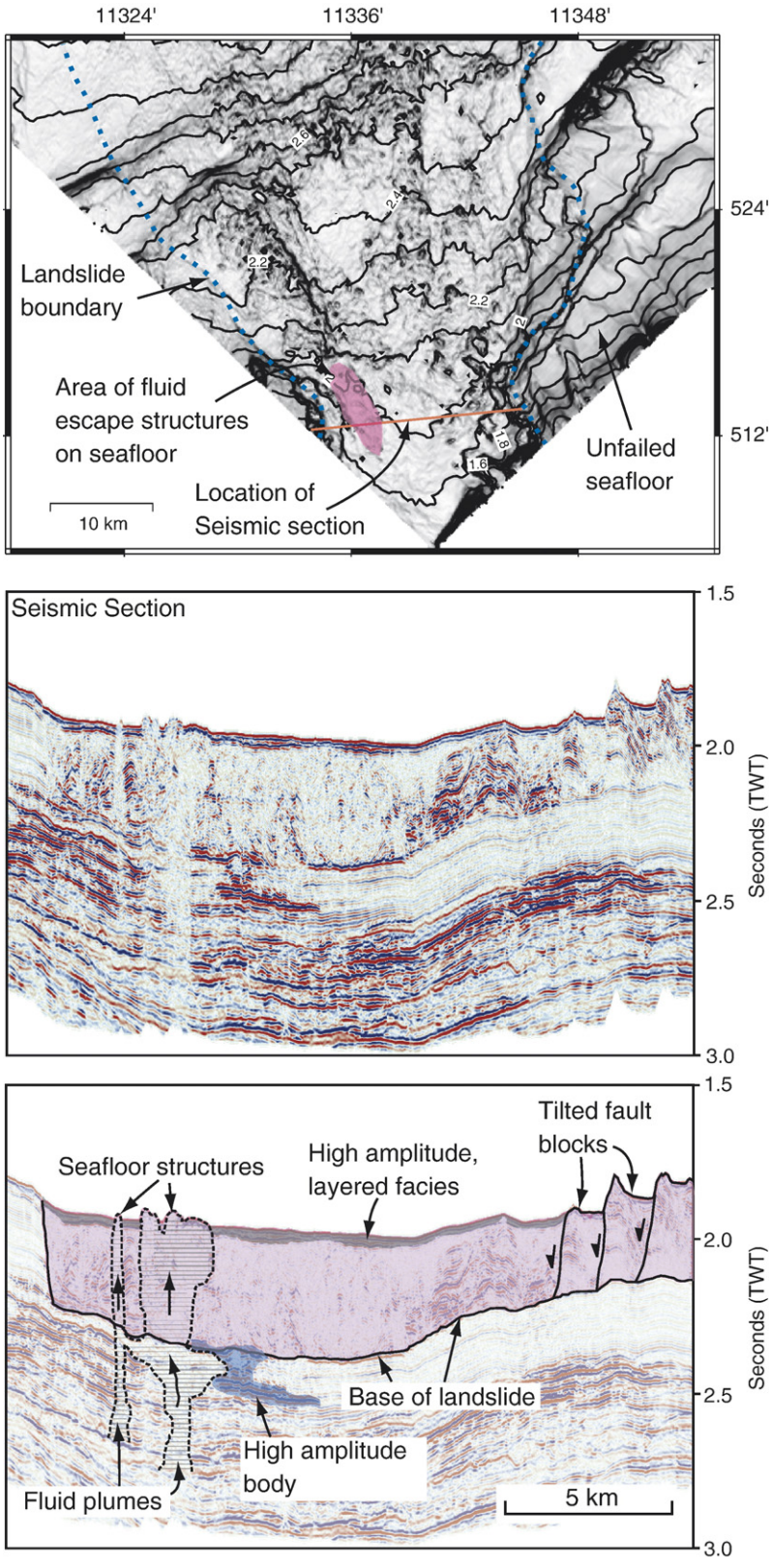


Fig. 10. Seismic sections A and B show eroded anticline crests and BSRs in the subsurface. For location, see Fig. 2.


11324'
11336'
11348'
524'
512'
Landslide boundary
Area of fluid escape structures on seafloor
Location of Seismic section
Unfailed seafloor
10 km
Seismic Section
1.5
2.0
2.5
3.0
Seconds (TWT)
Seafloor structures
High amplitude, layered facies
Tilted fault blocks
Base of landslide
High amplitude body
Fluid plumes
5 km

striations in water depths of ~1800 m where the seafloor steepens, indicates the location of the main castastrophic failure phase. Where the landslide encountered steeper slopes in water depths of ~2000 m, basal erosion may have increased significantly. Alternatively, stronger striations downslope might indicate a multi-phase failure process where initial sliding occurred in the upper slope region restricted by the anticlines. Weaker basal striations observed upslope, in water depths less than 2000 m might be related to lower gradients on the landslide sliding surface. We speculate that slope failure was related to collapse of an anticline ridge due in part to lateral forces due to the build-up of debris upslope, and the weakening of the anticline by increased pore fluid pressure related to BSR formation. The subsequent failure may have triggered a major landslide onto the upper slope and basin floor. In some areas, such as in the vicinity of the canyon, up to 40 m of post-landslide drape indicate a landslide age of between 2000 and 7000 years, based on typical sedimentation rates of between 20 and 6 cm per thousand years (Lambiase 2004 pers. com.).

Similar striated surfaces have been reported from other large submarine slope failure events. In the deepwater Makassar Straits, a striated surface 70 km^2 in area was described from the base of a debris flow deposit (Posamentier and Kolla, 2003). Another example from offshore Angola (Gee et al., 2005) showed a larger area of landslide failure surface (430 km^2) characterized by erosional striations up to 9 km long. Striations from Angola were observed to terminate abruptly upslope against a major fault, indicating the landslide source area and a fault-related triggering mechanism. Striations described from the base of the Brunei Slide are remarkably similar to those of the Angola landslide, although they are 120 km long and underlie a landslide volume fifty times larger.

The 'speckled' amplitude character of the landslide surface may indicate blocks transported and supported by the landslide material. Internal seismic geometry suggests the presence of large kilometer scale blocks carried within the landslide mass. Lastras et al. (2002) demonstrated the presence of large tabular blocks, several kilometers across transported by a large submarine landslide. The blocks within the Brunei Slide are smaller, less tabular in shape and appear to have experienced some rotation relative to their original positions, as opposed to being transported by simple sliding. It is also plausible that such blocks, when lodged at the base of the landslide have caused the erosional striations seen at the landslide base.

The landslide evolution is described by a simple three stage model that shows the build-up of debris flow deposits on the upper slope and subsequent catastrophic failure of slope anticlines to form the 1200 km^3 Brunei landslide (Fig. 12). Stages 1 and 2 represent reconstructions of the landslide evolution and the underlying folded strata. Stage 3 of the model is based on direct observation of seismic data. The anticline ridges may have stood several hundred meters above the present seafloor before slope failure (stage 1). However, it is not clear what role the ridges played in the development of the landslide. The seafloor between the ridges may also have been considerably higher, before erosion by the landslide. Upward moving fluid focused into anticlines may have acted as weak layers within the anticline crests prior to failure. During stage 2, debris flows from the Baram Canyon erode the seafloor and build up behind ridge number 2 to form deposits ~500 m thick, directly downslope of the canyon. In stage 3, catastrophic failure of ridge 2 occurs, releasing landslide material which travels over 120 km across the basin floor. The formation of basal striations indicates that during stage 3 of landsliding, intense erosion of the seafloor occurred, estimated to have removed several hundred meters of the seafloor sediments.

The landslide volume (1200 km^3) by far exceeds the total volume of the Baram Canyon. Therefore, the landslide either formed as a series of slope failures on the upper slopes, or the landslide eroded a considerable amount of the substrate during transport. As newly eroded material is accreted to the landslide base the basal sliding horizon migrates deeper into the substrate. This has implications for the efficiency of the landslide as the increased landslide mass would result in a greater runout potential (Gee et al., 1999).

One of the largest submarine landslides known to date is the Storegga Slide, located off the Norwegian Margin. It was originally interpreted to consist of three failure events, the first and largest of which had a volume of 3880 km^3 (Bugge et al., 1988). Recent work by Haflidason et al. (2004) in the headwall region has shown the landslide event to consist of numerous individual failure events. The Brunei Slide is of comparable volume, being at least a third of the size of the largest failure event within the Storegga Slide.

Fig. 11. Slope map and seismic section of the landslide headwall. Fluid escapes are observed at the seafloor as small mud volcanoes. Note thick landslide unit, tilted fault blocks to the east. The fluid plume appears to have spread out beneath the landslide. The high amplitude body indicates gas charged sediments related to the fluid plumes. A thin (50 m) layered, high amplitude facies overlies the landslide deposit.

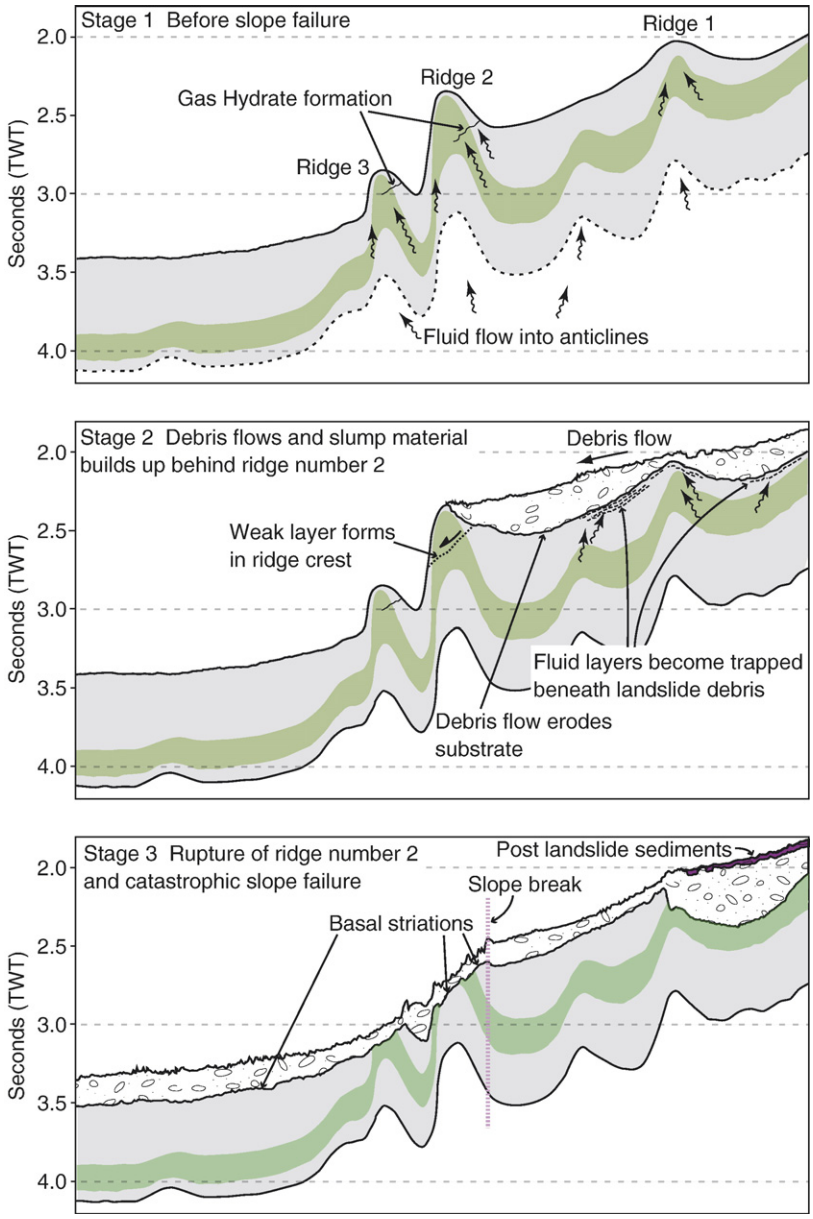


Fig. 12. A schematic model of the landslide which describes a two stage failure event involving the weakening and catastrophic failure of Ridge 2 to release a large landslide into the basin.

However, the Brunei Slide has a much smaller area than the Storegga, perhaps partly due to the bowl-like topography of the NW Borneo Trough. The Brunei Slide also contains similar kilometer scale blocks as observed within the Storegga Slide (see Haflidason et al., 2004). The main difference between the two landslides is that the Brunei Slide appears to have been a more simple failure event, lacking the numerous flow phases observed within the Storegga Slide headwall area. The Brunei Slide appears to have relatively simple headwall geometry without the extensive retrogressive erosion interpreted for the Storegga Slide. Whereas we consider the landslide to have formed during a single catastrophic event, some faulting and slumping of the Baram Canyon walls along the eastern margin (e.g., Fig. 10), indicates retrogressive and perhaps creep processes operating after the main failure.

Similar to the Brunei Slide, the headwall region of the Storegga Slide contains fluid-escape structures and BSRs (Bouriak et al., 2000; Bünz et al., 2003). Bouriak

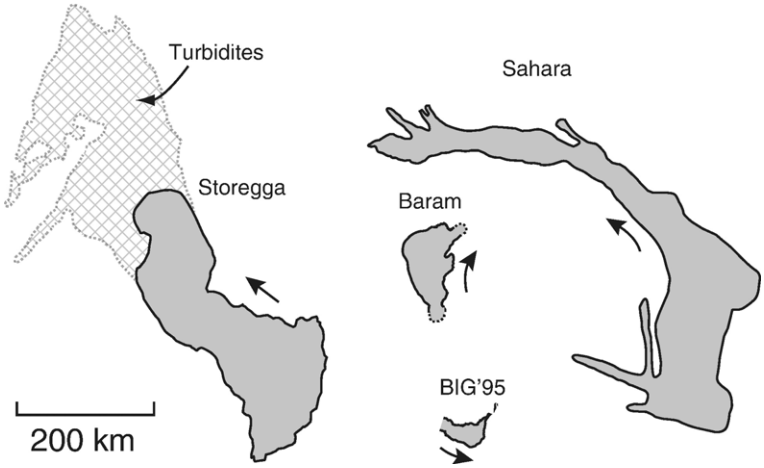


Fig. 13. Comparison of four giant submarine landslides from different geolocial settings.

et al. (2000) developed a model that describes the development of BSRs after slope failure and their link with clay diapirs and fluid-escape pock marks on the seafloor. They also speculated on the link between BSRs, subsurface fluid buildups and slope instability. The model presented by Bouriak et al. (2000) provides a mechanism for weakening slope sediments and forming a glide plane upon which the landslide evolves. The disassociation of gas hydrates has been previously cited as a potential landslide triggering mechanism (Carpenter, 1981; Hampton et al., 1996). Hydrates require high pressures and low temperatures (Kvenvolden, 1993), therefore in order to cause disassociation, either the hydrate pressure must release or the temperature increase, or some combination of the two. The influences of gas hydrate destabilization on sliding and vise versa have been eloquently discussed by Bouriak et al. (2000). Destabilisation can be triggered by varying combinations of sea level change, earthquake activity and slope failure. However, given the presence of considerable hydrocarbon reserves and fluid escape structures offshore northern Borneo, we

Table 1
Summary of four giant landslides, showing geological setting, volume, area, emplacement process and speculated trigger mechanism

Landslide	Geological setting	Volume (km^3)	Area (km^2)	A/V ($^{2/3}$)	Emplacement process	Speculated trigger mechanism
Storegga (Canals et al., 2004)	Passive margin, sediment input to upper slope by ice sheets during cold periods	~3000	44,000	211	Wide range of processes from avalanche and block gliding to debris flow and mud flow	Earthquake activity associated with postglacial isostatic rebound. Presence of gas and gas hydrates.
Sahara (Embley, 1976; Masson et al., 1993)	Passive margin, minimal terrigenous input. Highly productive surface waters	1100	30,000	283	Dominant process appears to be debris flow, plus rafted tabular blocks with a basal shearing layer	Unknown
Brunei (this study)	Active convergent margin with steep upper slopes (>4°). Baram Canyon and Baram River directly feed sediments to upper slope of landslide	1200	5300	46	Debris flow, km scale, rafted landslide blocks. Widespread basal sliding and erosion observed	Sediment loading from Baram River and Canyon. Sediment column weakened by upward moving fluids, possible anticline collapse. Presence of gas and gas hydrates.
BIG'95 (Canals et al., 2004)	Passive margin, wide continental shelf. Failure is not directly connected but occurred adjacent to the 900 km long Ebro River	26	2000	228	Large km scale tabular landslide blocks and debris flow matrix	Earthquake activity likely

speculate that warm upward moving fluids from deeper, perhaps hydrocarbon reservoirs, may provide an additional mechanism for hydrate disassociation and subsequent landsliding.

A comparison between four large non-volcanic submarine landslides is given in Fig. 13 and Table 1. Of the four landslides shown, only the Brunei and BIG'95 are or have recently been connected with a river system supplying sediment ,and the volume of the Brunei (1200 km^3) exceeds that of the BIG'95 by an order of magnitude. The relative efficiency of the landslides can be understood by comparing the ratio of area to volume. Using the parameter $A/(V^{2/3})$ (from Dade and Huppert, 1998) where A is area and V is volume, the Brunei Slide appears relatively inefficient (see Table 1), reflecting the bowl-like basin that has confined the landslide deposit.

Giant landslides such as the Saharan Slide, with a volume estimated to be in the region of 1100 km^3 (Embley, 1976; Embley, 1982) occur on margins starved of terrigenous, river-fed or glacial fed material where slopes are apparently more stable. The stable slope conditions may explain why slope failures are so large. River and glacial systems, on the other hand can deliver large volumes of sediment rapidly to the slope, resulting in rapid sedimentation and unstable accumulations that may lead to more frequent and smaller slope failures unless there is some mechanism for preventing smaller slope failures such as the development of slope ridges. The presence of older landslides buried beneath the Brunei Slide indicates that landsliding is a recurrent process in the NW Borneo Trough (Fig. 9).

We do not mean to imply that anticline collapse is the only control on the triggering and emplacement of submarine landslides in the NW Borneo Trough. Clearly, other factors, such as sea level, sediment supply and the climate, are important. The integration of the 3D seismic data with other data relating to sediment supply systems from upslope and the acquisition of core samples from the recent Brunei Landslide are likely to offer the best chances for answering this question in the future.

5. Conclusions

Based on this study of 3D seismic data from the NW Borneo Trough, the following conclusions can be made:

1. A giant landslide covers an area of at least 5300 km^2 of the slope and basin floor in the NW Borneo Trough. The landslide can be traced upslope into the Baram Canyon. It has an estimated length of 120 km, a width of up to 63 km, an average thickness of 240 m and a volume ~1200 km^3.
2. The landslide is underlain by a distinctive basal surface characterized by striations measuring ~30–120 km long, ~100–600 m wide and ~10–30 m deep which suggest significant erosion of the substrate by the landslide.
3. The extensive and continuous nature of the basal striations suggests a single landslide.
4. The presence of older landslide deposits buried several hundred meters beneath the present seafloor, suggests that giant landsliding is a common resedimentation process in the NW Borneo Trough.
5. The observation of fluid plumes and fluid seeps in the headwall region of the landslide indicates the presence of active fluid venting which we suggest played a part in the weakening and triggering of the most recent Brunei Slide.
6. Reconstruction of the pre-Brunei Slide slope topography suggests that the anticlines presented barriers to sediments passing downslope several hundred meters high, and may have played a key role in the build-up and failure of the Brunei Slide.

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