Int J Earth Sci (Geol Rundsch) (2007) 96:451–472
DOI 10.1007/s00531-006-0112-8

ORIGINAL PAPER

Mauritania Slide Complex: morphology, seismic characterisation and processes of formation

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Received: 24 October 2005 / Accepted: 12 June 2006 / Published online: 5 August 2006

Abstract Recently acquired Parasound and high resolution multi-channel seismic reflection data have afforded a more detailed investigation of the Mauritania Slide Complex. The slide is more complex than previously reported, and has affected an area in the order of 34,000 km^2 between ~ 600 and > 3,500 m water depths. The ovate-shaped slide displays a long run-out distance > 300 km. Slide formation was pre-conditioned mainly by uninterrupted deposition of upwelling-induced organic-rich sediment in an open slope environment which gave rise to rapid accumulation of poorly consolidated bedded sediment intercalated with thin weak layers. The stages of slide development were characterised by multiple failure events probably occurring mainly as retrogressive sliding which exploited widespread weak layers as glide planes. The study suggests excess pore pressures as being the most important trigger mechanism for slide formation. Earthquakes associated with nearby Cape Verde Islands may have played a mostly complementary or, at one time, a leading role in triggering sediment failures. Diapiric growths have locally triggered minor instability events which resulted in remobilizing of pre-existing debris flows as well as translational sliding. The combined activities of all these triggering factors are the most like cause of the complex morphology of the Mauritania Slide Complex.

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Keywords Submarine slide · Diapirs · Contourites · Retrogressive sliding · Weak layers

Introduction

Over the last couple of decades, sustained research efforts, driven by improved geophysical mapping methods, are gradually establishing that submarine slides occur globally and affect all types of continental margins including passive, e.g., the eastern Scotian margin (Piper and Ingram 2003), the New Jersey continental margin (McHugh et al. 2002) and the Norwegian-Greenland Sea continental margins (Bugge 1983; Vorren et al. 1998) as well as active margins, e.g., NE Mediterranean Sea (Lykousis et al. 2002) and Japan Sea (Lee et al. 1996) and also on the flanks of large submarine volcanic edifices, e.g., the Haiwaiian Ridge (Moore et al. 1989). Along the eastern Atlantic continental margins, submarine slides have been recognised in various dimensions ranging from relatively smaller slides < 1,000 km^2, e.g., the Afen Slide off northwest of Shetlands Islands (Wilson et al. 2004) and the Gebra Slide off the Trinity Peninsula margin, Antarctica (Imbo et al. 2003) to giant slides affecting areas > 10,000 km^2, e.g., the Canary Slide (Canals et al. 2004) and the Storegga Slide off western Norway (Bugge 1983; Haflidason et al. 2004; Canals et al. 2004).

Submarine slides constitute one of the most important mechanisms for mass sediment movement from shallow- to deep-water marine environments and also for shaping continental margins (Hampton et al. 1996; McAdoo 2000; Casas et al. 2003). Because of their widespread and often episodic nature, mass sediment movement events are perceived as being important components of the modern stratigraphic record, and have been studied in connection with global climatic cycles, including sea level changes (e.g., McHugh et al. 2002). In recent years, the importance of submarine slides has become very crucial in geo-hazard assessment studies for engineering and environmental projects connected with offshore economic resource exploitation and installations, especially as interest of the oil industry moves further into the deep sea (Baraza et al. 1999; Piper and Ingram 2003). In addition, the oil industry finds further motivation in studying submarine slides because slides are capable of modifying the architectural and, hence, sedimentological characteristics of submarine channel systems and channel–levee complexes which are often connected with potential deep sea hydrocarbon reservoirs. Furthermore, being large-scale mass sediment failure events, submarine slides are capable of displacing large volumes of water and hence have, in recent years, been studied towards evaluating their tsunami generation risks to coastal communities (e.g., Dawson 1999; Fryer et al. 2003; Trifunac et al. 2003; Fine et al. 2005).

Several studies have suggested that continental margins which receive high rates of sediment accumulation are especially prone to mass sediment failures, e.g., the Uruguayan continental margin (Klaus and Ledbetter 1988). The rapid sediment build-up gives rise to huge volumes of undercompacted sediment packages which may be rendered highly unstable by the presence of increased pore pressure from entrapped water and/or shallow gas generated from decaying buried organic matter. In addition, changes in sedimentation rates and types of sediment resulting from climatic controls may lead to the formation of lithologically weak sediment layers which facilitate sediment failure by serving as glide planes e.g., as reported in the Barents Sea (Laberg and Vorren 1996) and the Aegean Sea (Lykousis et al. 2002). Furthermore, the often resulting slope oversteepening may also contribute to sediment instability (Hampton et al. 1996; Canals et al. 2004), though submarine slide events, quite unlike aerial slides, are known to occur along slope gradients as low as $< 1°$ (Hampton et al. 1996). In addition to excess pore pressures and slope oversteepening, other factors commonly cited as the immediate trigger mechanism for the mass sediment failure events include earthquakes, decay of gas hydrates, diapirism and tectonic movements, or a combination of two or more of them (e.g., Bugge 1983; Laberg and Vorren 1996; Haflidason et al. 2004; Canals et al. 2004).

A number of large mass sediment movement events have been documented along the continental margin off NW Africa (e.g., Jacobi and Hayes 1982; Gee et al. 2001; Wynn et al. 2000). However, only a few of them, notably, the Sahara Debris Flow (Gee et al. 2001) and the numerous slides on the flanks of the Canary Islands (Krastel et al. 2001; Masson et al. 1998) have been mapped and studied in detail. The Mauritania Slide Complex was previously mapped and described by Jacobi (1976) following its discovery offshore Mauritania by Seibold and Hinz (1974). Based primarily on 3.5 kHz profiles, Jacobi (1976) estimated that the Mauritania Slide Complex covered an area of ~ 34,300 km^2. This areal dimension of the Mauritania Slide Complex places it as one of the largest submarine failure events ever mapped along the NE Atlantic margin, perhaps next in size only to the Storegga Slide, 95,000 km^2 (Bugge 1983; Haflidason et al. 2004), the Saharan Debris flow, 48,000 km^2 (Jacobi and Hayes 1982) and the Canary Slide, 40,000 km^2 (Masson et al. 1998). Jacobi and Hayes (1982) provided a general overview of seafloor reflectivity characteristics of the margin between 3N and 23N, which included the area offshore Mauritania. Since these previous studies of the Mauritania Slide Complex were based on sparsely distributed data, and in connection with more regionally based investigations, important questions regarding, among others, the internal architecture of the slide, slide dynamics and trigger mechanisms as well as origin and age of slide formation have not been properly resolved.

The main objective of RV Meteor Cruise M 58/1 expedition in April/May 2003 (Fig. 1) was to study upwelling and sedimentation processes off NW Africa (Schulz et al. 2003). During the cruise, new Parasound echosounder profiling as well as high resolution multi-channel seismic reflection (MCS) data were collected over the Mauritania Slide Complex to provide a better framework for studying the slide. In this study, we use primarily the newly acquired Parasound and MCS data to describe and analyse in detail the main morphological components of the slide. In addition, the study intends to evaluate the scale of destabilization caused by the slide and also identify or suggest possible slide release mechanisms. The study also investigates the relationships between slide development and regional sedimentation processes as well as the influence from structural features of the margin, including the Cape Verde Rise, canyon systems and diapirism.

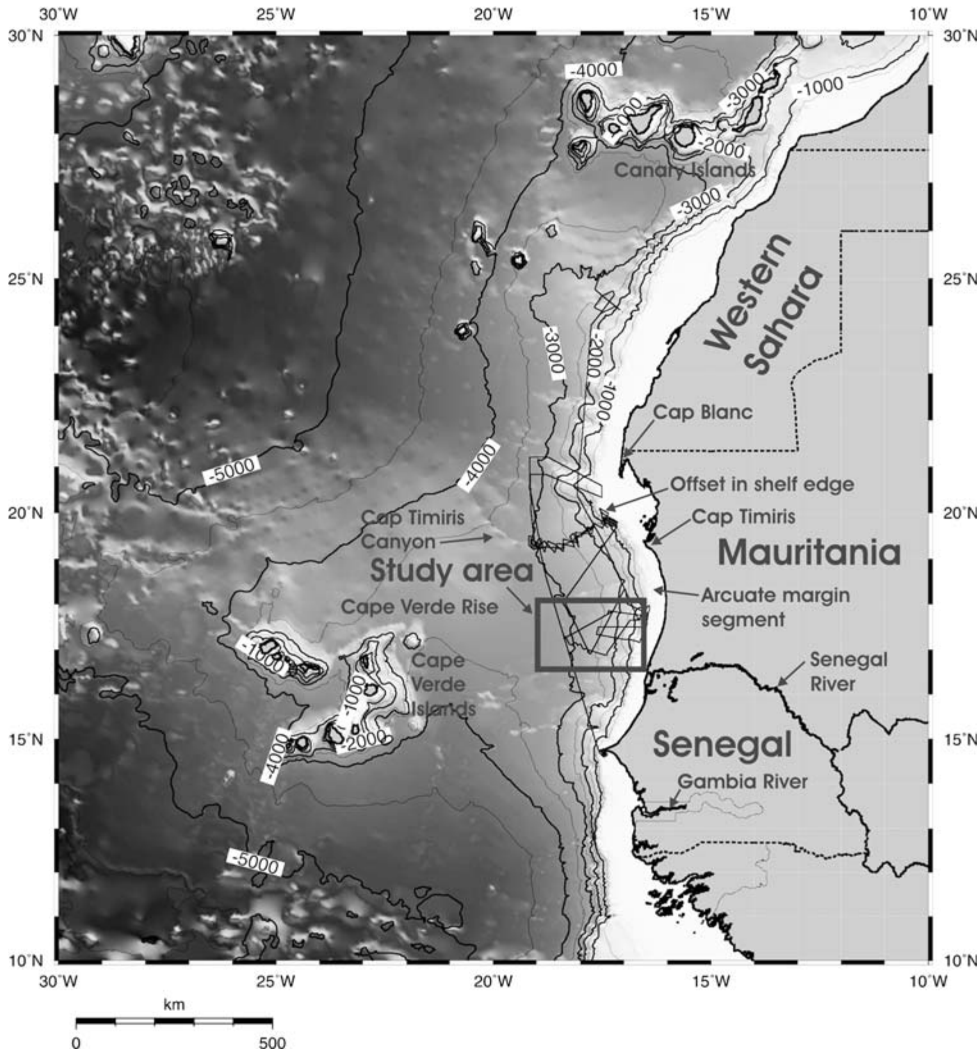


Fig. 1 General bathymetry of NW African continental margin (GEBCO 2003) showing the location of the study area (in *box*). Contours are at 500 m intervals. RV Meteor Cruise M58/1 track lines are shown in *solid black lines*. The study area is located off a giant arcuate segment of the Mauritanian margin

Geological setting and oceanography

Margin physiography

The Mauritania Slide Complex lies between latitudes 16°40′N and 18°20′N, and is centrally located off the giant arcuate segment of the Mauritanian coastline which extends from Cap Timiris in the north to offshore northern Senegal in the south (Fig. 1). The shelf break in this segment occurs at a water depth of 50–80 m. The shelf is relatively narrow within the arcuate segment, typically between ~ 25 and 40 km wide, but widens up to ~ 100 km just north off Cap Timiris following an abrupt seaward offset in the shelf break. The continental slope displays gradients which vary between 1° and 3°. The shelf and slope areas to the immediate north of the Mauritania Slide Complex are deeply incised by a system of canyons and gullies including the Tiolit Canyon (Wissmann 1982) and farther to the north, the Cap Timiris Canyon, a prominent canyon system recently discovered off the latitude of Cap Timiris (Schulz et al. 2003; Krastel et al. 2004). The entire continental rise off Mauritania is very broad, and occurs at water depths of between 2,000 and 2,500 m where slope angles are typically < 1°. Off the arcuate segment, however, the rise is dominated by the extensive Cape Verde Rise which gradually elevates into the Cape Verde Islands further seawards. The northern and southern boundaries of this group of volcanic islands possibly trace directly into major fracture zone extensions (Jacobi and Hayes 1982).

Structural setting

Structurally, the Mauritania Slide Complex is located within the depocenter of the large Senegal Mauritania Basin, one of the series of marginal basins emplaced along the NW African margin in response to the

Mesozoic opening of the Atlantic ocean (Jansa and Wiedemann 1982; Wissmann 1982). Initial opening of the basin was accompanied by evaporite deposition within a narrow elongate zone between 16N and 19N. The basin is filled by a thick succession of Mesozoic-Cenozoic terrigenous to shallow marine sediment which is known to attain maximum depths of more than 10 km below the lower continental slope off Mauritania (Wissmann 1982). Earliest indications of mass wasting processes along the slope are provided by the presence of slumps and turbidites observed in early Miocene deposits. After a prevalent tropical climate along the margin during the middle Eocene, a more arid condition began to emerge during the end of Eocene and within Oligocene time. Following the end of a Tertiary humid climate, a long period of arid quaternary sedimentation known as the 'continental terminal' formation emerged (Jansa and Wiedemann 1982; Wissmann 1982).

Sources of sediment supply to the margin

During the last 20,000 years, the margin has been fed with huge quantities of offshore wind-blown sediment from the adjacent Sahara Desert (Sarnthein et al. 1982). Currently, offshore wind-transported sediment remains the main source of terrigenous sediment input into the margin, and is estimated to supply about 50×10^6 tons of eolian sediment per year over a 1,000 km broad zone (Koopman 1981). In addition, the margin is the site of rapid sediment accumulation resulting from upwelling-induced high productivity.

Though the margin receives no significant fluvial sediment supply at present, a study of potential paleodrainage patterns off NW Africa by Vörösmarty et al. (2002) indicates that the Cap Timiris area once constituted the estuary of a major ancient river system which is now extinct, hence suggesting that part of the margin may have previously received significant fluvial sediment supplies. Furthermore, the Senegal River is believed to have entered the coast near 18°30′N during Miocene/Pliocene time, thereby supplying large quantities of sediment which are thought to have triggered salt halokinesis in the area (Wissmann 1982). The area of salt diapirs lies between 16N and 19N (Wissman 1982) and includes the location of the Mauritania Slide Complex (Figs. 2, 3). Currently, the Senegal River enters the coast in the south near latitude 16°05′N, i.e., slightly to the south of the slide area, and its sediment discharges are swept southwards by nearshore currents (Seibold and Hinz 1974). Hence, the river is at present unlikely to contribute any significant sediment inputs into the slide area.

Oceanography

Along the outer shelf and slope areas of the Mauritanian margin, i.e., < 200 m water depth, the current regime is controlled by the southward-flowing Canary Current which splits up into two on reaching Cap Blanc. From here, the dominant fraction is diverted away from the coast to the southwest, whilst the minor fraction continues further southwards where it is transformed into the Guinea Current (Sarnthein et al. 1982). Below the Canary Current, i.e., between ~ 150 and 400 m, the current regime is controlled by the northward-flowing South Atlantic Central Water (SACW) which in turn is underlain by the southward-flowing North Atlantic Central Water (NACW) operating down to ~ 600–700 m water depths. The deeper waters are dominated by the southward-flowing North Atlantic Deep Water (NADW), which operates down to ~ 3,500–4,000 m water depths, and the underlying northward-flowing Antarctic Bottom Water (AABW). Present current velocities of the deep waters are thought to be generally weak, i.e., < 5 cm/s, but this may increase significantly up to ~ 20 cm/s in areas where the current circulation is focussed by seafloor morphology (Lonsdale 1982).

Data and methods

The Parasound and MCS data used for this study were simultaneously acquired during R/V Meteor Cruise M58/1 in April 2003 as part of a larger marine geophysical survey (Fig. 1) undertaken by the Research Center Ocean Margins (RCOM) of the University of Bremen in order to study upwelling and sedimentation processes offshore northwest Africa. Data coverage over the Mauritania Slide Complex analysed for this study include more than 1,200 km of Parasound profiles and ~ 900 km of MCS profiles. The areas covered comprised the outer shelf and the headwall region in the slope areas down to the continental rise and ranged from 200 m to > 3,500 m water depths.

The Parasound system

The Parasound system (Grant and Schreiber 1990) is a hull-mounted high frequency sediment echosounder that utilizes the so-called parametric effect to generate an operational signal of 4 kHz which is focused within a cone of opening angle of 4°. This results in a footprint diameter of ~ 7% of the water depth, which affords better horizontal resolution than conventional

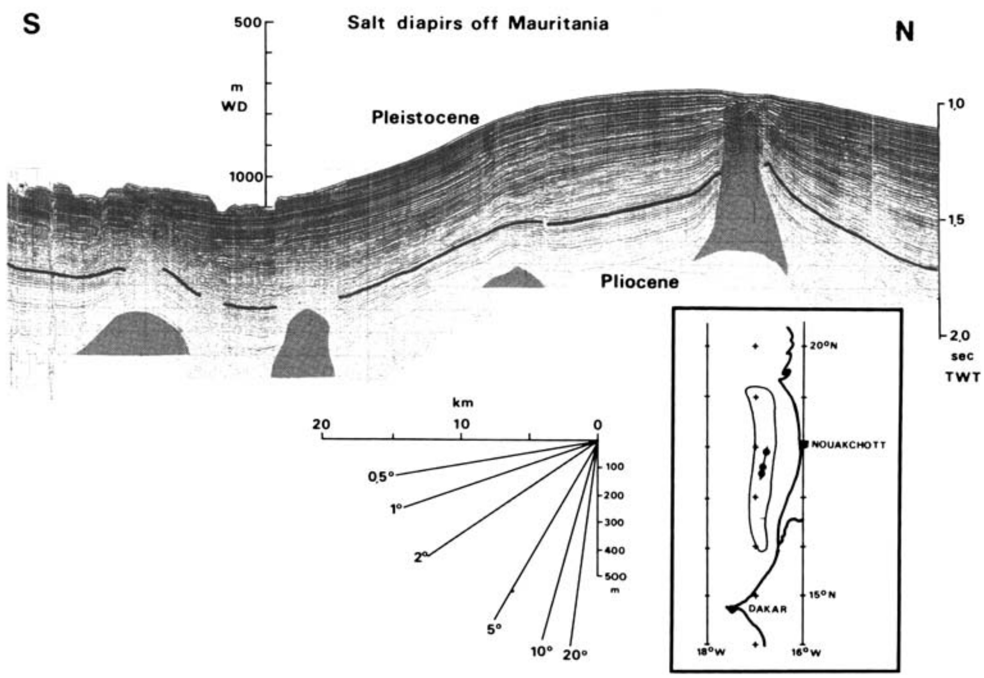


Fig. 2 Seismic reflection profile METEOR 25-E 2 in the elongate zone of salt diapirs off Mauritania. *Thickened* reflector is interpreted to separate Pliocene from Pleistocene sediment (after Wissman 1982). Location of profile is indicated in Fig. 3 as well

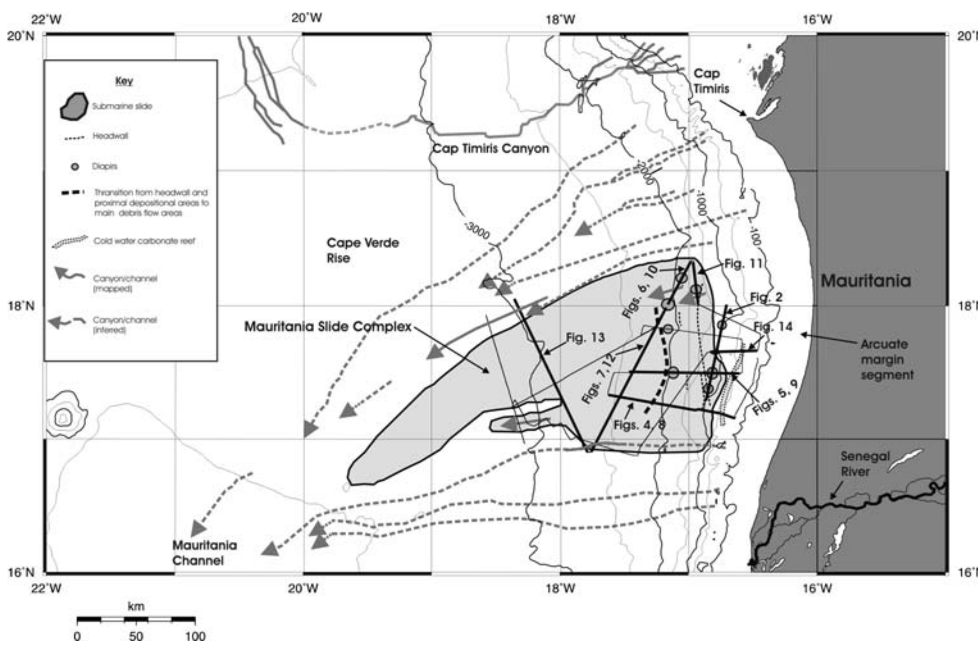


Fig. 3 Detailed bathymetry of the Mauritanian margin (GEBCO 2003) showing the seafloor map of the Mauritania Slide Complex derived mainly from Parasound data from RV Meteor Cruise M58/1. Map of features outside the parasound data coverage area was compiled from published data (i.e., Jacobi 1976; Jacobi and Hayes 1982). Parasound and MCS survey lines analysed for the study are shown in *solid black straight lines*. Locations of Parasound and MCS profiles presented in the study are shown in *thick solid black lines*

3.5 kHz systems. In addition, the broader signal bandwith gives a better vertical resolution, which is in the order of a few decimeters. Depending on the type of sediment and attenuation, depth penetration may vary between 0 and 200 m. The ParaDigMA system (Spiess 1993) was used to digitally record and store the data in a compressed SEGY format. A band pass frequency filter of 2.0–6.0 kHz was applied before display.

The high-resolution MCS system

The MCS data were acquired using a GI-Gun seismic source which was shot at a distance of ~ 30 m. The standard GI-Gun, with normal chamber volume (i.e., 2 × 1.7 l), was operated with a high pressure air of 150 bar (2,150 PSI). A 450 m-long Syntron streamer, equipped with separately programmable hydrophone subgroups, was used to record the data with 36 groups of 6.25 m length at a group distance of 12.5 m were used. Digital recording of the data was carried out at a sampling rate of 4 kHz over 3 s. Positioning was based on Global positioning system (GPS). The MCS data were processed using a combination of 'in-house' and the 'Vista' (Seismic Image Software Ltd.) softwares, and standard procedures including trace editing, CDP sorting, static and delay corrections, velocity analysis, normal moveout corrections, bandpass frequency filtering (frequency content: 55/110–600/800), stack and time-migration were used. A CMP spacing of 10 m was applied throughout.

Echosounder characteristics and seafloor morphology of the Mauritania Slide Complex

Echosounder characteristics

The Parasound data allow us to describe the main architectural elements of the slide under two major morphological divisions based primarily on a major change in seafloor slope gradient accompanied by a downslope variation in seafloor acoustic characteristics. The divisions are: (i) the headwall and the proximal slide areas, and (ii) the main debris flow depositional area.

The headwall and proximal depositional areas

Parasound dip-profiles (e.g., Figs. 4, 5) which reach out from the outer shelf and upper slope areas downslope into the main slide area, show that sediment layers shallower than 600 m have generally not been affected by sliding. The unaffected layers are acoustically characterised by sharp prolonged flat, but locally undulating, seafloor reflections. The dip profiles (e.g., Figs. 4, 5) display a feature acoustically imaged as a sharp rise in seafloor relief to narrow isolated transparent peaks, up to 75 m high occurring between 450 and 550 m water depths. These peaks have been confirmed by gravity coring to consist of carbonate mounds inhabited by fresh water corals (Schulz et al. 2003; Colman et al. 2004). No sliding activity is observed upslope of the feature.

In most parts of the slide, headwall scars are imaged as a series of distinct steps in morphology with heights

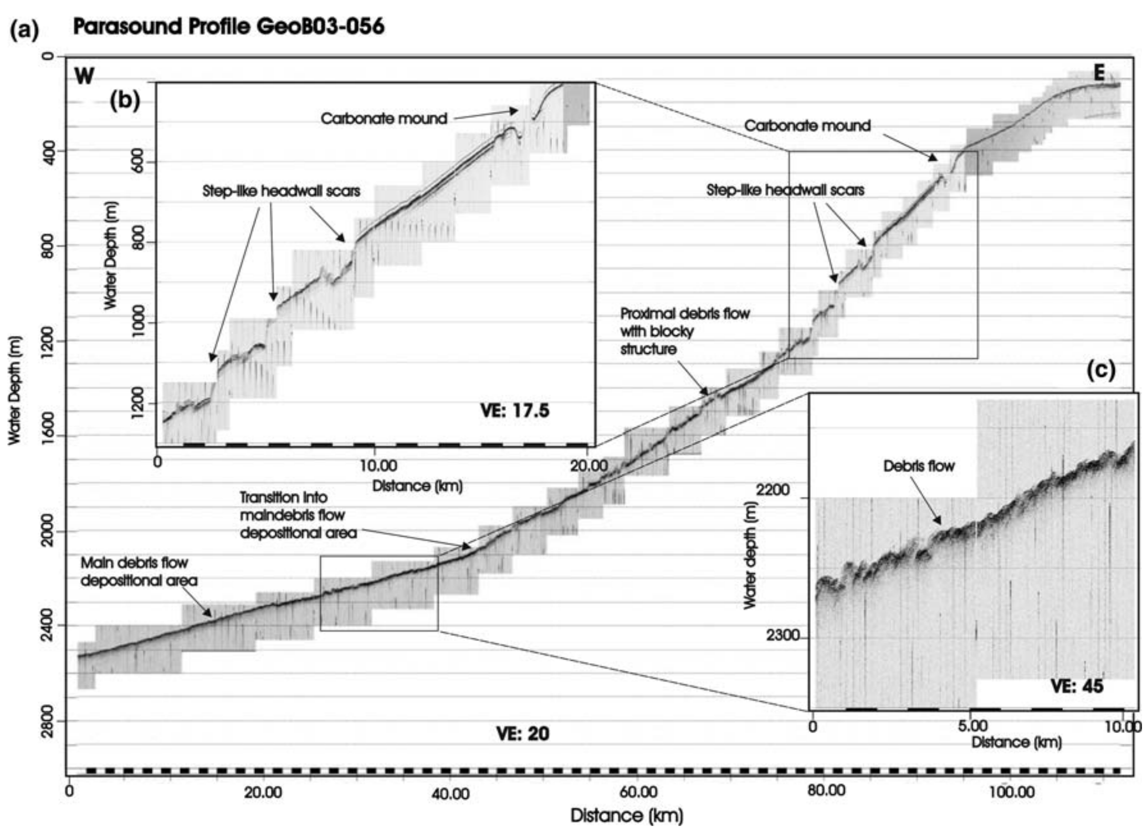


Fig. 4 **a** Parasound dip-profile GeoB03-056 recorded across the southern part of Mauritania Slide Complex. The profile cuts across the headwall and proximal depositional areas as well as the transition into the main debris flow depositional area. Location of the profile is shown in Fig. 3. **b** Close-up of slope area showing headwall scars and immediate vicinity. **c** Close-up showing debris flow in main depositional area

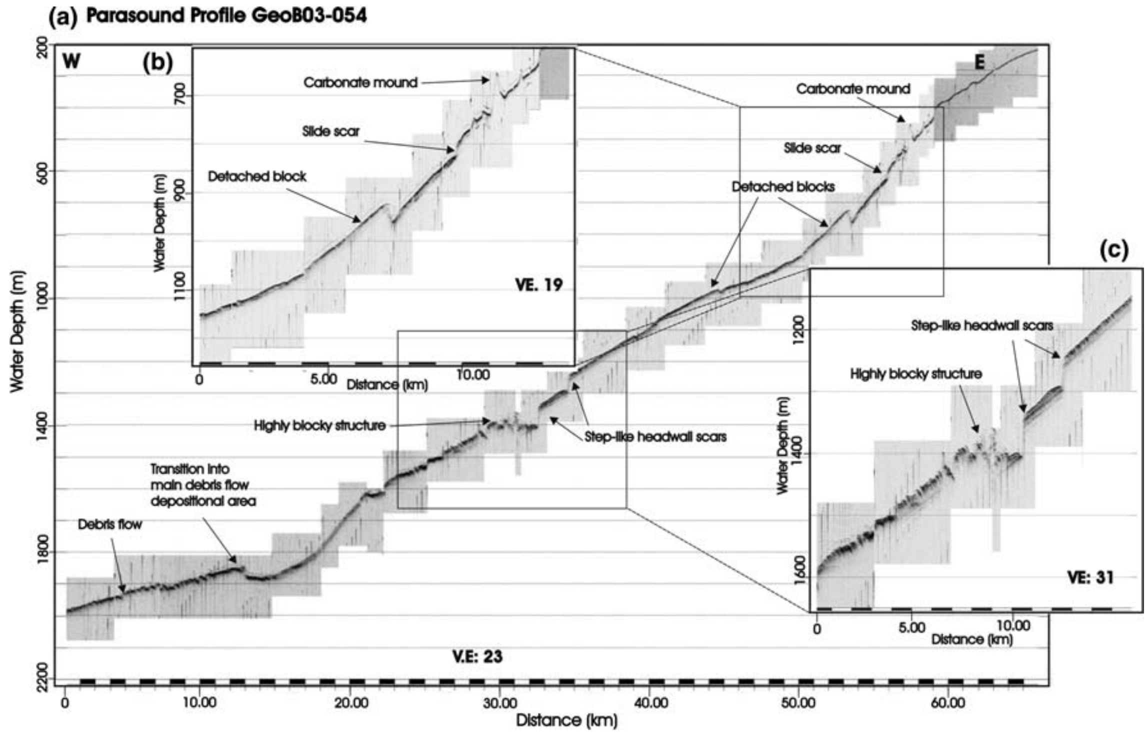


Fig. 5 **a** Parasound dip-profile GeoB03-054 recorded across the middle part of Mauritania Slide Complex. The profile cuts across the headwall and proximal depositional areas as well as the transition into the main debris flow depositional area. Detached blocks are seen in the *upper* and *middle* slope areas. Location of the profile is shown in Fig. 3. **b** Close-up of the upper slope area showing slide scar and detached block. **c** Close-up showing headwall scars

ranging from < 25 m to 100 m above the seafloor. This is especially the case in the southern parts (e.g., Fig. 4), where the scars occur between 800 and 1,150 m water depths. However, in the middle part of the slide, the uppermost headwalls appear to be associated with a number of detached blocks, up to 40 m thick and some with widths > 4 km, between 600 and 1,400 m water depths (Fig. 5). The seafloor reflections of these blocks are acoustically characterised by very sharp prolonged returns, with very faint or no clear sub-bottom reflectors. The lower headwall scars are step-like, and occur between 1,200 and 1,400 m water depths (Fig. 5).

In the northern parts of the slide, especially towards its northeastern boundary, the headwall area is dominated by several canyons and gullies which have given rise to a number of isolated sediment blocks (Fig. 6). Some of these blocks show layered internal structure while others are acoustically transparent. The largest of the canyons attain depths up to 100 m or more and widths up to 3 km (Fig. 6). In general, the canyon floors do not show any significant debris flow infill. In the uppermost slope area, towards the northern end of Parasound Profile GeoB03-046a (Fig. 6), a sidewall scar, ~ 40 m high which is associated upslope with undisturbed sediment, is seen near 1,775 m water depth. The profile also shows a distal scar occurring near 2,100 m water depth close to the southern end, but this clearly cuts across a pre-existing debris flow deposit which is ~ 40 m thick.

In most of the profiles (e.g., Figs. 4, 5, 6) the deposits occurring immediately beneath the headwall scars show highly blocky structure, and are acoustically characterised by irregular hyperbolae of weak to strong surface reflections with vertices often attaining relief up to 30 m high (Fig. 4b). These proximal debris flows are commonly underlain by clearly visible prolonged strong to weak sub-bottom reflectors (Fig. 6). The thickness of these deposits is usually < 25 m but may gradually increase downslope up to ~ 40 m or more. The headwalls commonly occur between 600 and 1,400 m water depths where slope gradients are typically up to ~ 2.5° (Figs. 4, 5). However, the headwall scars themselves may attain gradients up to ~ 8°. The proximal depositional areas extend downslope to between ~ 2,100 and 2,150 m water depths (Figs. 4, 6), so that the overall average slope gradient for the headwall and proximal depositional areas, is typically ~ 1.9°.

Main debris flow depositional area

Downslope ~ 2,100–2,150 m water depths, the slope gradient is drastically reduced from the average of

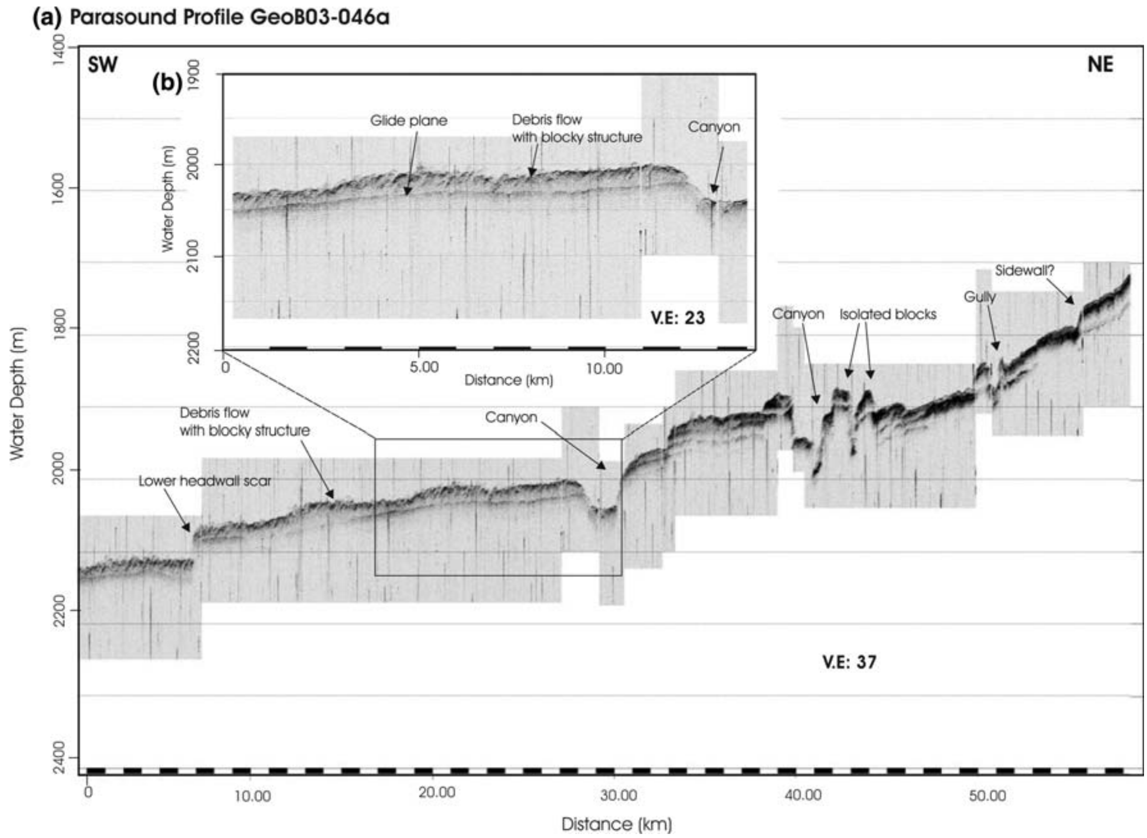


Fig. 6 **a** Parasound profile GeoB03-046a recorded in the NE–SW direction across the northern headwall region of Mauritania Slide Complex which is dominated by canyon and gully incisions. Location of the profile is shown in Fig. 3. **b** Close-up showing glide plane and blocky debris flow structure

~ 1.9° observed in the headwall and depositional proximal areas, to < 1°. No scars are seen deeper than this depth but rather debris flow deposition becomes laterally extensive (Figs. 4, 5, 6, 7). The deposits are characterised mostly by prolonged seafloor reflections which may, however, locally appear blocky (Fig. 7). This major reduction in slope gradient, which is accompanied by a change in acoustic character, marks the transition into a dominantly debris flow depositional regime which characterises the main depositional area of the slide in most of our profiles (e.g., Figs. 4, 5, 6, 7).

Profile GeoB03-046b (Fig. 7) which cuts across the main depositional area in the NE–SW direction, shows that debris flow deposition extends from the northeast more than 120 km across the length of the profile, and is only delimited in the southwestern end by a small channel–levee system. In places, the debris flow deposits are underlain by prolonged sub-bottom reflectors which grow weaker downslope and eventually fade out. The debris flow deposits display widths from < 25 m up to ~ 45 m. They appear to be composed of several units which lie side by side and commonly onlap one another, especially within the northeastern half of the profile (Fig. 7). Towards the distal parts of the slide, the seafloor reflections become more prolonged, and no sub-bottom reflectors are clearly visible, except in the vicinity of the channel–levee system that bounds the debris flows in the southwestern end of the profile. The presence of debris flow facies at the floor of the channel indicates that some of the slide material has travelled down the channel. However, the particularly well-stratified southern levee facies show that slide material has not moved further southward beyond the channel–levee system.

Seafloor morphology of the Mauritania Slide Complex

We present a newly compiled map of the seafloor morphology of the Mauritania Slide Complex (Fig. 3), based on the mapping of slide features identified in the Parasound data. However, the most distal part of the slide that was not covered by our Parasound profiling, has been incorporated from published data by Jacobi (1976) and Jacob and Hayes (1982) into the map. The

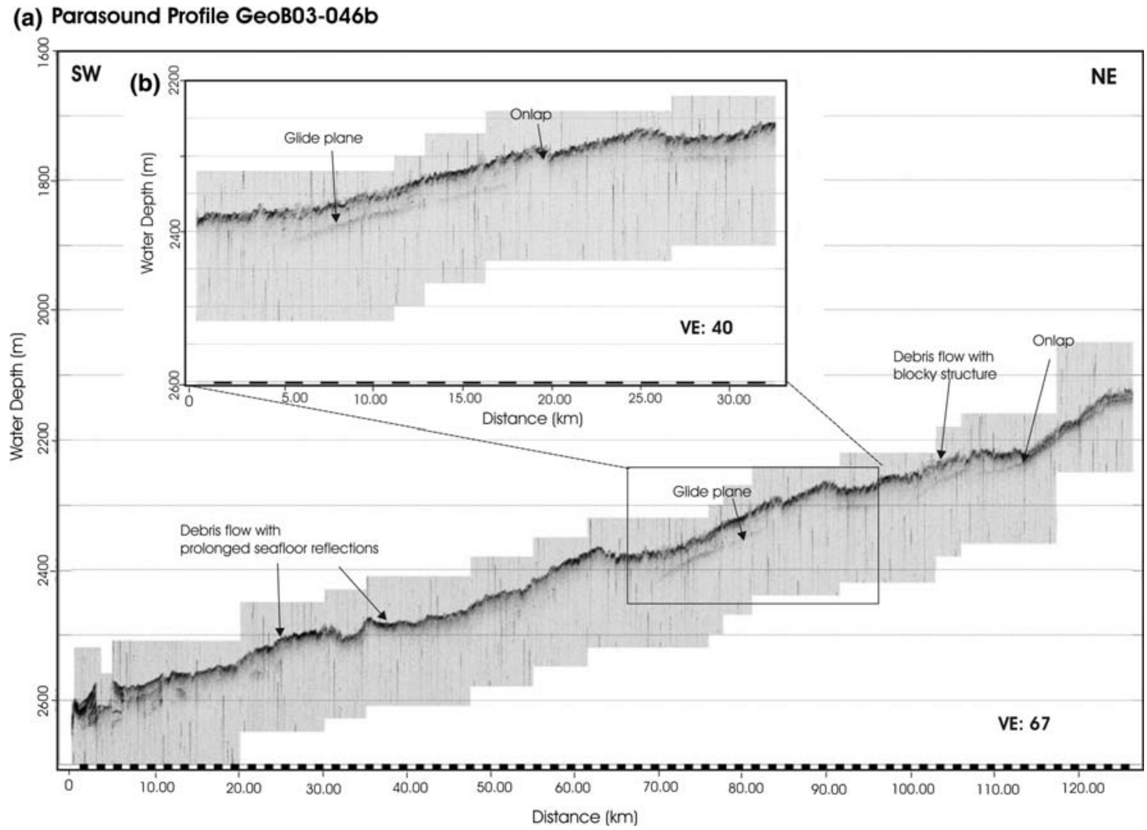


Fig. 7 a Parasound profile GeoB03-046b which is the SW continuation of Parasound profile GeoB03-046a, extending across the main debris flow depositional area to the southern boundary of Mauritania Slide Complex. The profile shows extensive debris flow deposition. Location of the profile is shown in Fig. 3. **b** Close-up showing glide plane and debris flow onlap

map shows that the slide has affected an area in the order of 34,000 km^2, which is generally in agreement with that previously reported by Jacobi (1976). The affected area includes the upper slope area, from water depths ~ 600 m, down to the rise at water depths > 3,500 m.

The seafloor map shows that the slide is delimited in the upper slope area by a slightly arched to sub-linear headwall boundary, ~ 150 km long and located below 600 m water depth, which trends sub-parallel to the shelf edge bathymetric contour (i.e., 100 m contour) and opens seaward to the west. Immediately west of this headwall boundary, the failed sediment assumes a general westward flow direction forming a complex, more or less, ovate-shaped body which extends seawards into the continental rise. From 2,750 m water depth, however, the northern part of the sediment flow suddenly emerges into an elongated distal body whose flow direction is gradually diverted to the southwest by a system of canyons and the Cape Verde Rise which bound the slide in the north and northwestern parts. The distal slide body eventually tapers off further seawards near 3,500 m water depth. The total run-out distance of the slide from the uppermost headwall boundary to the most distal slide tongue is > 300 km. In the southern part of the slide, a relatively much smaller sediment flow also emerges from ~ 2,750 m water depth from where it flows within a westward flowing channel. The southern slide boundary is effectively delimited by a system of westward flowing canyons. Just beyond the apex of the most distal part of the slide, i.e., near 3,500 m water depth, the southwest and westward flowing bounding canyon systems appear to coalesce to constitute a single major canyon system. In the upper slope area, the cold water carbonate mound reef is mapped as a linear topographic feature located immediately between the headwall boundary and the shelf edge.

Seismic characteristics

Our MCS profiles have generally afforded a very good resolution of sedimentary features within the upper 600 m (800 ms TWT) of the seafloor cover, and hence provide additional valuable information about the

Mauritania Slide Complex which is otherwise lacking in the Parasound echosounder data. Consequently, the seismic profiles have allowed a detailed visualisation of the internal structure of the Mauritania Slide Complex as well as its basal sliding surfaces and headwall features. Quite as in the case with the Parasound profiles, we distinguish between the source region and the main depositional area of the slide based primarily on changes in the seafloor reflection characteristics and slope gradient.

Headwall and proximal depositional areas

The seismic data (e.g., Figs. 8, 9, 10, 11) reveal that the headwall areas of the Mauritania Slide Complex are strongly characterised by a complexity of seafloor morphologies comprising of slide scars, detached slide blocks as well as, locally, canyons and erosional gullies and their associated isolated blocks. In addition the debris flow deposits occurring on the seafloor immediately beneath the headwall scars display highly blocky and strongly hyperbolic seismic reflections.

Seismic dip-oriented profile, Profile GeoB03-056 (Fig. 8) which crosses the southern part of the Mauritania Slide Complex from the upper slope to the rise, shows a headwall area characterised by a series of step-like slide scars which truncate well-layered reflectors on the seafloor between 800 and 1,150 m water depths. Upslope the uppermost headwall, i.e., at Shot Point 8900, the profile displays an isolated sharp peak ~ 50 m high characterised by chaotic to transparent seismic signature which we ascribe to the presence of the cold water carbonate mound (observed earlier in the Parasound data)

Within the middle parts of the slide, the seismic data show that the upper slope headwall area is characterised by large detached blocks measuring up to 4 km wide, and some with thickness exceeding 40 ms TWT (Fig. 9). The blocks show preserved mostly

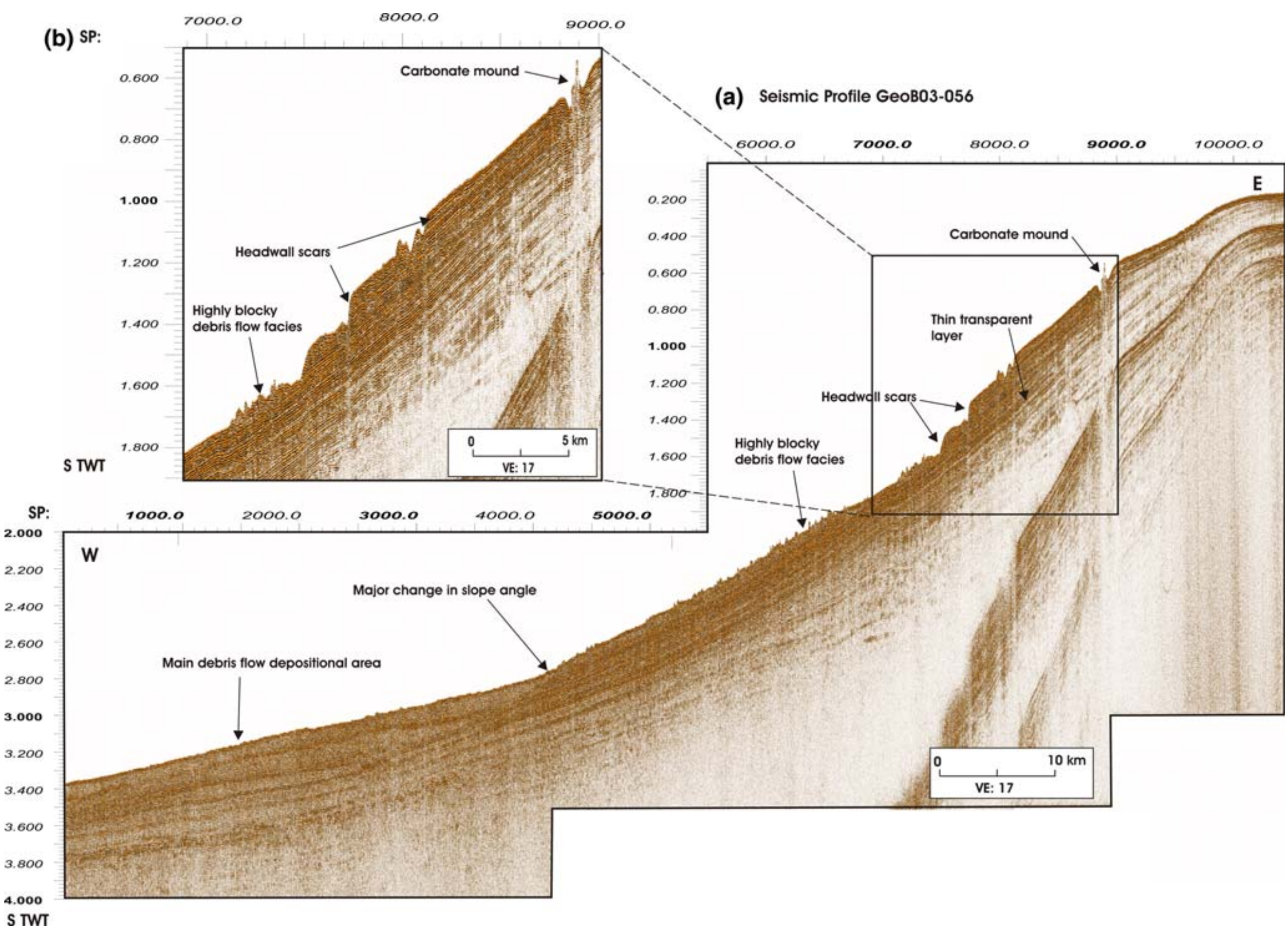


Fig. 8 **a** Seismic dip profile GeoB03-056 recorded across the southern part of Mauritania Slide Complex. The profile cuts across the headwall and proximal depositional areas as well as the transition to the main debris flow depositional area. Location of the profile is shown in Fig. 3. **b** Close-up of slope area showing headwall scars and immediate vicinity

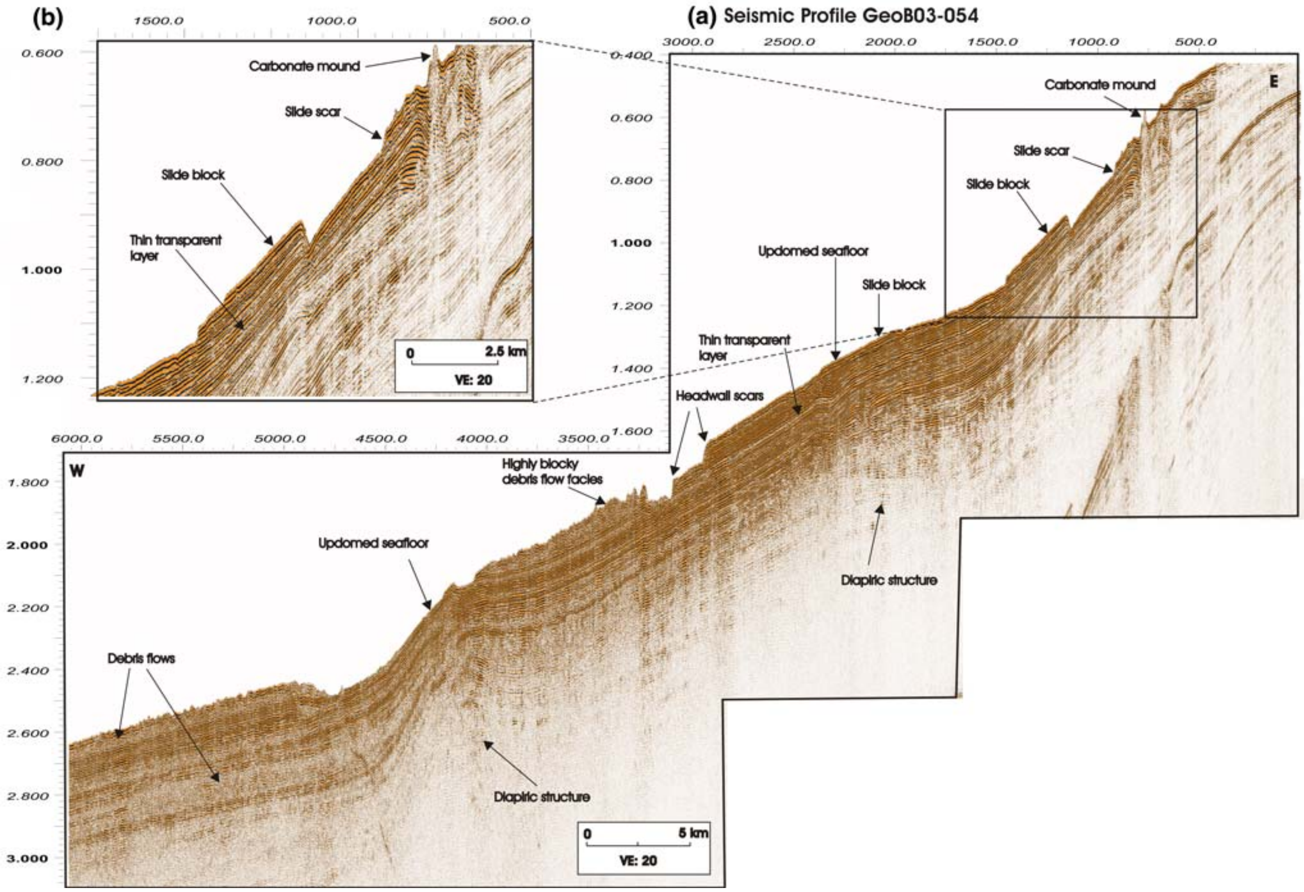
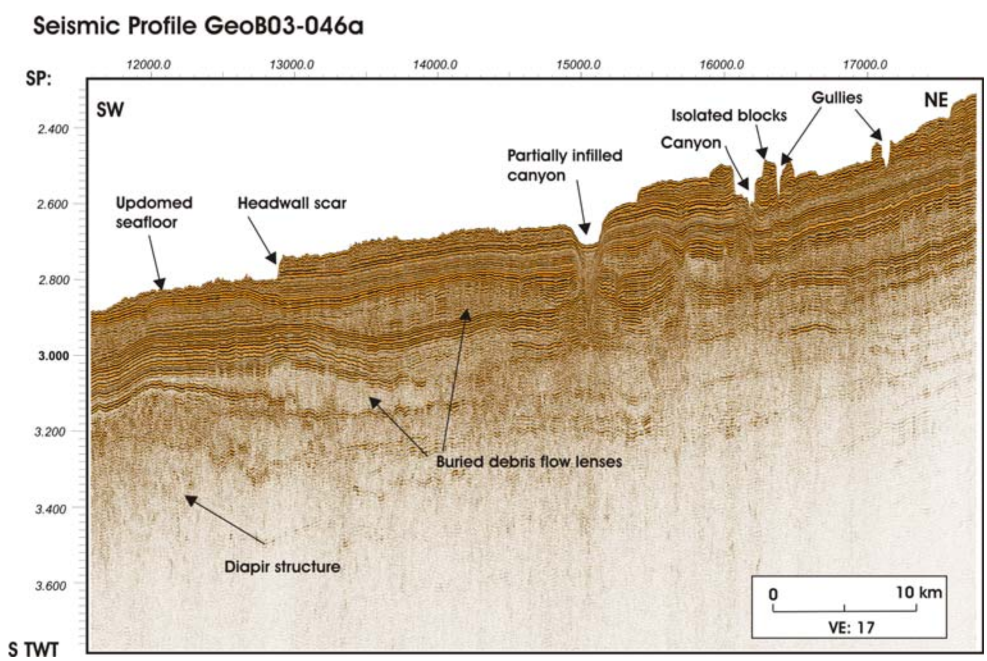


Fig. 9 **a** Seismic dip profile GeoB03-054 recorded across the middle part of Mauritania Slide Complex. The profile cuts across the headwall and proximal depositional areas as well as the transition to the main debris flow depositional area. Discrete slide blocks are seen in the upper and middle slope areas. Also, the seafloor is updomed in two places by underlying diapiric structures. Location of the profile is shown in Fig. 3. **b** Close-up of the upper slope area showing slide scar and slide block

Fig. 10 Seismic profile GeoB03-046a recorded in the NE-SW direction across the northern headwall region of Mauritania Slide Complex. The headwall area in the northern part of the profile is dominated by canyon and gully incisions. The seafloor at the southern end of the profile appears to be gently updomed by diapiric structure. Location of the profile is shown in Fig. 3



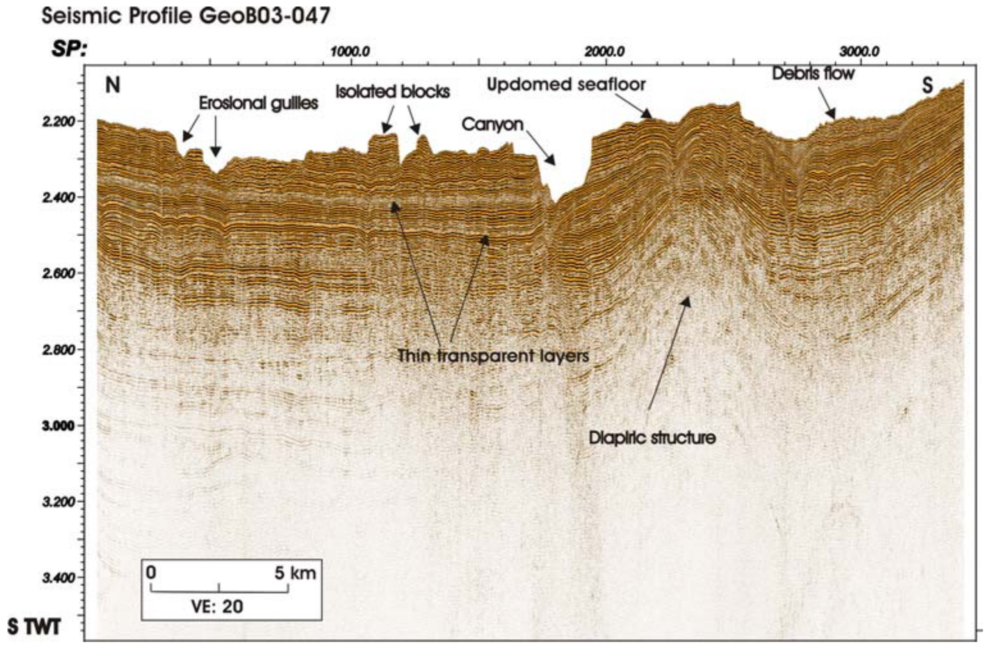


Fig. 11 Seismic profile GeoB03-047 recorded in the N–S direction across the northern headwall region of Mauritania Slide Complex. Again, the headwall area is dominated by canyon and gully incisions. The seafloor towards the northern end of the profile is updomed by diapiric structure. Location of the profile is shown in Fig. 3

well-layered internal reflectors, and rest conformably over undisturbed generally continuous and well-stratified reflectors parallel to the general slope stratigraphy. In places, the base of the blocks appears to be associated with very thin transparent layers which are intercalated within the well-layered sediment packages. Between 1,250 and 1,350 m water depths, the lower parts of the blocks are truncated by seaward facing scars which define the lower headwalls. The sediment packages in the slope area have been gently updomed by two underlying diapiric structures occurring near Shot Points 2250 and 4250. A large section of the blocky debris flow deposit located near the downslope flank of the lower updomed seafloor appears to be missing. The presence of the carbonate mounds in the middle parts of the slide, is again observed as a chaotic to transparent piercement structure with a sharp rise in seafloor relief up to 50 m high.

Most of the headwall area in the northern parts of the slide is dominated by intense erosion and gully incision of well-layered sediment packages giving rise to a number of canyons and several isolated sediment blocks on the seafloor (Figs. 10, 11). The well-layered sediment packages are intercalated with thin acoustically transparent layers, commonly < 20 ms TWT, which may locally pass into lens-shaped debris flow bodies. The overlying sediment has in places been deformed and updomed by sub-surface sediment remobilization (Fig. 10) and upward diapiric growths (Fig. 11). In Profile GeoB03-046b (Fig. 10), located close to the northern boundary, an isolated headwall scar ~ 40 m high is seen to truncate the seafloor debris flow layer near Shot Point 1280. The seafloor topography towards the northeast is highly irregular, and several gullies and a number of canyons, up to 4 km wide and 100 m deep, are observed to incise within the surrounding topographic low areas of this intensely eroded headwall area. The isolated blocks display mostly blocky structure with well-layered to chaotic internal reflections (Figs. 10, 11).

Main debris flow depositional area

Downslope-oriented profiles (e.g., Figs. 8, 9) show that the transition from the headwall area to the main body of the slide is generally characterised by a major change in seafloor gradient from ~ 1.9° to < 1° as already observed in corresponding Parasound profiles. These seismic profiles, together with others which cut obliquely across the main body of the Mauritania Slide Complex (e.g., Fig. 12), reveal that the main depositional area of the slide occurs immediately downslope of the major slope gradient transition. In the main slide depositional area, the slide is dominated by a complex stack of sheet-like and lens-shaped debris flow deposits, seismically imaged as laterally extensive zones of transparent to chaotic reflections, separated by well-stratified, generally continuous strong amplitude reflection packages (Figs. 12, 13). In general, the uppermost debris flow deposits within the main depositional area show less blocky seismic facies on the seafloor, and towards the distal parts of the slide they commonly display a more or less smooth surface.

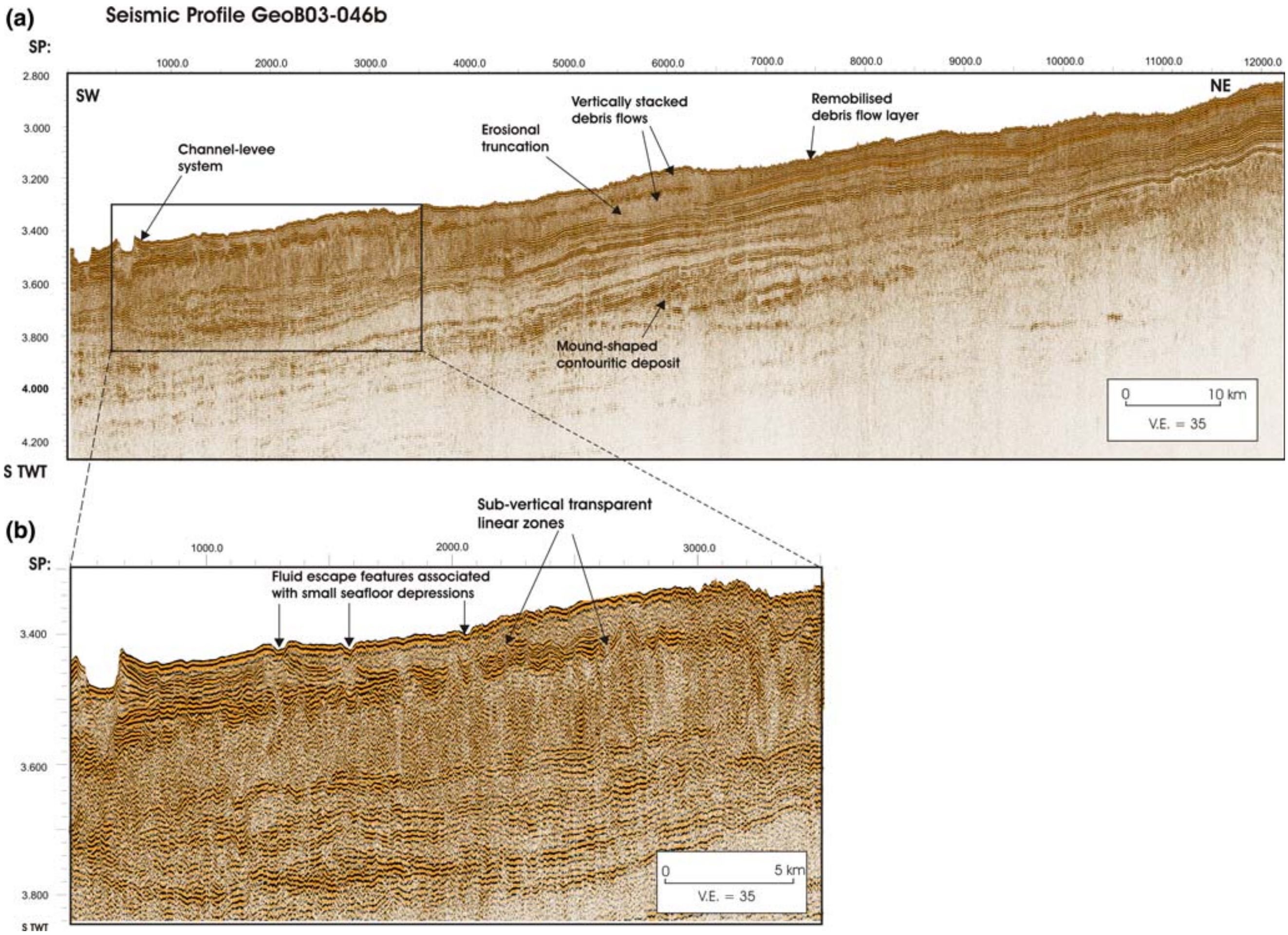


Fig. 12 a Seismic profile GeoB03-046b which is the SW continuation of profile GeoB03-046a, extending across the main debris flow depositional area to the southern boundary of Mauritania Slide Complex. The profile shows extensive debris flow deposition separated by stratified contouritic sediment intervals. Location of the profile is shown in Fig. 3. **b** Close-up of the southern part of the profile showing pervasive and widespread fluid escape features

In Seismic Profile GeoB03-045 (Fig. 13), a large buried debris flow deposit > 90 km wide and up to 80 ms TWT thick is seen to lie below 4.200 s TWT and extends from Shot Point 9000 to the northwestern end of the profile. The overlying sediment body between Shot Points 2500 and 8000, which also infills the erosional depression, is characterised by well-layered strong amplitude reflection packages intercalated by thin, i.e., < 20 ms TWT thick, acoustically transparent layers. This sediment body is up to 150 ms TWT thick and has a mound-shaped geometry. Towards the southwest the well-layered interval is seen to locally display smaller mound-shaped forms. At the northwestern part of the profile, i.e., between Shot Points 1000 and 5200, the overlying debris flow deposit, is about 80 ms TWT thick and shows mound forms on the seafloor. At its northwestern end, this debris flow deposit locally displays very blocky facies, though it appears less blocky in most parts. At Shot Point 5200, the deposit is sharply bounded by two relatively thin, generally < 50 ms TWT, vertically stacked debris flow sheets which extend up to the southwestern end of the profile. In Profile GeoB03-046b (Fig. 12), the well-layered sediment intervals show mound-shaped forms in places, especially where they infill pre-existing topographic lows, e.g., between Shot Point 5000 and 8000 and below 3.500 s TWT. Quite like in the previous profile, the uppermost debris flow layer at the northeastern part of the profile is seen to sharply bound two vertically stacked debris flow layers near Shot Point 7500. The channel–levee system seen in the previous profile, is again observed to bound the uppermost debris flow layers at the southwest end of the profile. Large sections of both profiles, show very pervasive acoustically transparent sub-vertical linear zones originating from the sub-surface which cut up-

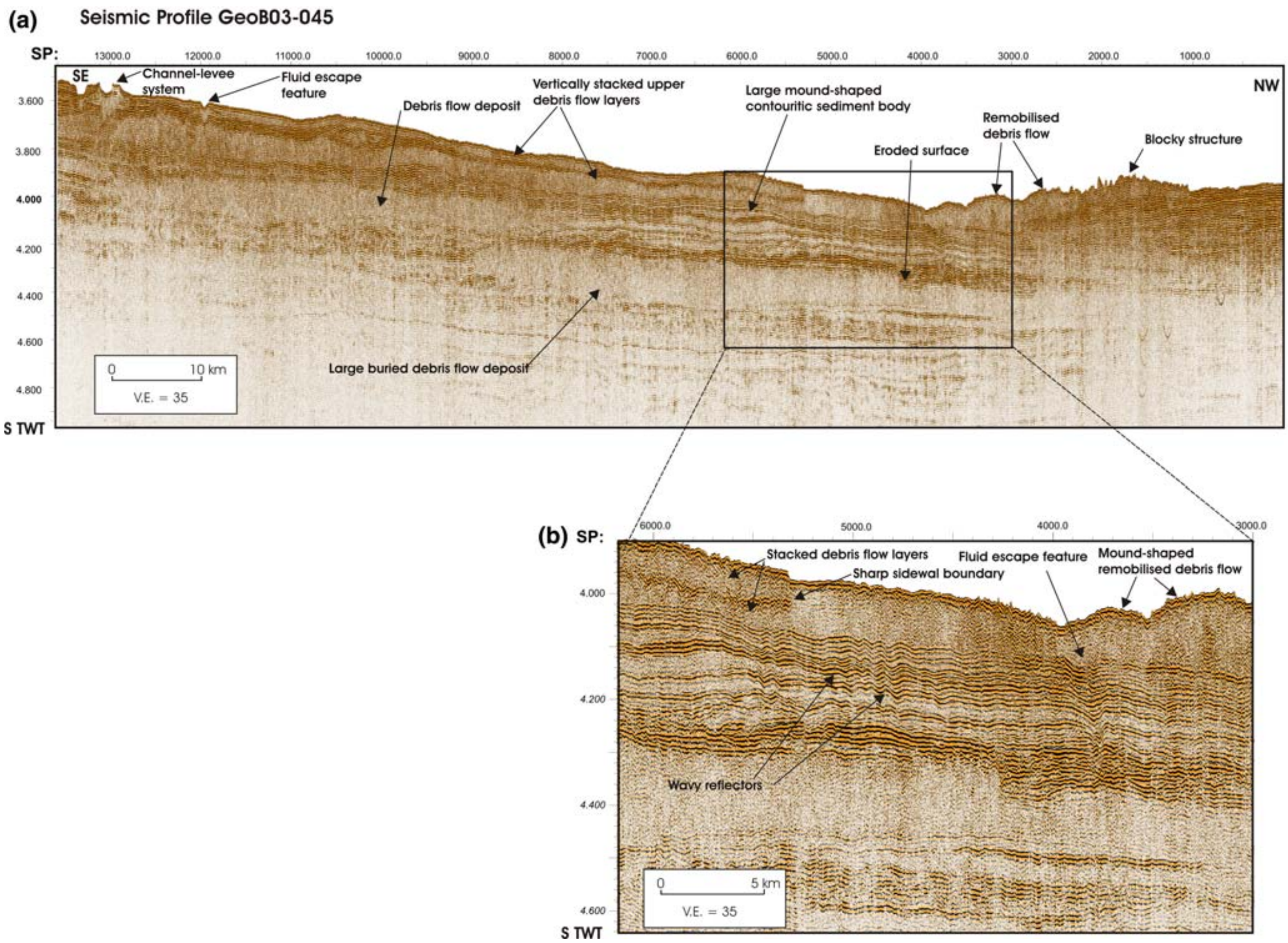


Fig. 13 **a** Seismic profile GeoB03-045 recorded in the NW-SE direction across the main debris flow depositional area of Mauritania Slide Complex. The profile shows extensive debris flow deposition separated by stratified contouritic sediment intervals. Location of the profile is shown in Fig. 3. **b** Close-up of the northwestern part of the profile showing different seafloor debris flow deposits lying side by side as well as fluid escape features

wards through both overlying debris flow layers and the well-layered sediment intervals. In some parts, these sub-vertical features give rise to wavy and often disjointed reflectors within the well-layered intervals, and where they emerge on the seafloor, especially towards the southern parts of the profiles, the features are associated with small depressions (Figs. 12, 13).

Discussions

Controls on slide geometry and mobility

We note from the seafloor map of the Mauritania Slide Complex (Fig. 3) that whereas the morphology of the main depositional area displays an ovate-like shape, its distal part is exceptionally elongated, giving the slide complex a long run-out distance of more than 300 km. Our data interpretation suggests that several factors may have contributed in determining this peculiar geometry of the Mauritania Slide Complex. These factors include controls exerted by the Cape Verde Rise and the bounding canyon systems, the rheology of slide material and the presence of diapiric structures.

The Cape Verde Rise acts as a major topographic diversion for downslope mass sediment movements along the Mauritanian margin (e.g., Wynn et al. 2000). Our seafloor map of the Mauritania Slide Complex shows that the southwestern flow direction of the northern part of the slide has clearly been induced by the flow direction of the system of canyons that controls the northwestern boundary of the slide complex. The general course of these canyons may have been pre-determined by the Cape Verde Rise, as noted for the flow direction of the north-lying distal Cap Timiris Canyon (Antobreh and Krastel 2006).

By acting as a topographic diversion for the canyons and debris flows in the northern parts of the slide, the Cape Verde Rise may have contributed in focussing the mass sediment flows. In addition, the predominance of canyons and gullies within headwall areas north of the slide would have focused flow energy so as to facilitate more rapid downslope evacuation of the failed sediment. Consequently, flows close to the northern boundary are likely to remain more fluidised and energised than those in the southern parts, and hence should have greater ability to travel much longer distance. As a similar example, the development of an erosional channel within the central scar of the Storegga Slide is thought to have enabled channelized flow and increased velocity of the debris flows in that part of the slide (Bryn et al. 2005b).

Our seismic profiles (Figs. 10, 11) suggest that in the head region of the northern parts of the slide most of the upper sediment bodies have been destabilized by underlying diapiric uplifts and sub-surface sediment remobilization. The resulting sediment destabilization has led to the remobilization of pre-existing debris flows and also the disintegration of overlying sediment, thus providing more mobility to the slide material for further downslope transport.

The seismic data (e.g., Figs. 12, 13) show the presence of mound-shaped sediment units with well-layered internal reflectors which we interpret as contouritic deposits. Contourite drifts in large slide environments have been found to be more sensitive and brittle than surrounding coarse grained sediment, e.g., as observed for the Storegga Slide (Bryn et. al. 2005a) and the Traenadjupet slide (Laberg and Vorren 2000). In a similar vein, we speculate that contouritic deposits which appear to be more widespread in the northern parts of the slide (Fig. 12), should favour an easier sediment disintegration in the area, and hence give rise to more mobile sediment flows. In contrast, the predominance of intact tabular slide blocks (Figs. 5, 9) as well as highly irregular and blocky debris flow facies (Figs. 4, 8) in the headwall areas of the southern parts of the slide suggests that pre-slide sediment in those areas have experienced less disintegration than sediment in the north therefore rendering the resulting southern slide materials stiffer and less mobile.

The two canyon systems that delimit the northern and southern boundaries of the slide complex are seen to merge immediately downslope near the apex of the distal slide to constitute a major single channel system, the Mauritania Channel (Fig. 3). As turbidity flows are presumed to generate at the leading edge of debris flows (Middleton and Hampton 1973; McHugh et al. 2002), we expect the distal debris flows to potentially evolve into a major turbidity flow system which is likely to feed this major channel system for enhanced mass sediment evacuation into the deeper sea.

Sedimentary environments and pre-conditioning for slide development

Our seismic data (Fig. 14) reveal that sediment layers in the vicinity of the northern parts of the slide that are unaffected by sliding, display contouritic deposition characterised by mounded morphology. In addition, we note that several of the well-layered sediment that separate debris flow deposits within the main depositional area, especially those which infill pre-existing topographic lows, show contouritic characteristics (e.g., Fig. 12). These observations suggest that a large amount of the failed sediment, particularly in the northern parts of the slide, were probably of contouritic origin. The nearby Cape Verde Rise may have aided in focusing bottom current, i.e., the south-flowing NADW, circulation in the area. Consequently, the increased bottom current speed would have actively interacted with sediment depositional processes in the area, arising mainly from upwelling-induced and wind-blown aeolian sediment sources, thereby enhancing contouritic deposition.

Contouritic deposits characterised by sand-rich sediment which are intercalated by fine-grained layers are known to be especially prone to sediment instability (Bryn et al. 2005a). In this case, the fine grained layers often serve as suitable planes of weakness for promoting mass sediment failures. Weak layers facilitate the destabilization of sediment and the formation of slides. Most weak layers are probably much too thin to be resolved by the seismic system but the occurrence of very thin acoustically transparent layers within the unfailed sediment (Figs. 10, 11) in the northern parts suggests that lithologically weak layers probably exist in this area and may have facilitated the slide process within the mostly contouritic deposits. Though contourite deposition becomes less widespread in the southern parts of the slide, the unfailed well-stratified sediment in the area are also intercalated with very thin acoustically transparent layers (Figs. 8, 9) which should serve to promote gravity-driven downslope sediment movement, as similarly observed on the Aegean Sea margin (Lykousis et al. 2002) and offshore Norway (Laberg and Vorren 2000).

Lack of canyons within the arcuate segment of the margin favoured uninterrupted rapid build-up of sediment piles over relatively long time intervals in a sheltered open slope setting. This is in sharp contrast to

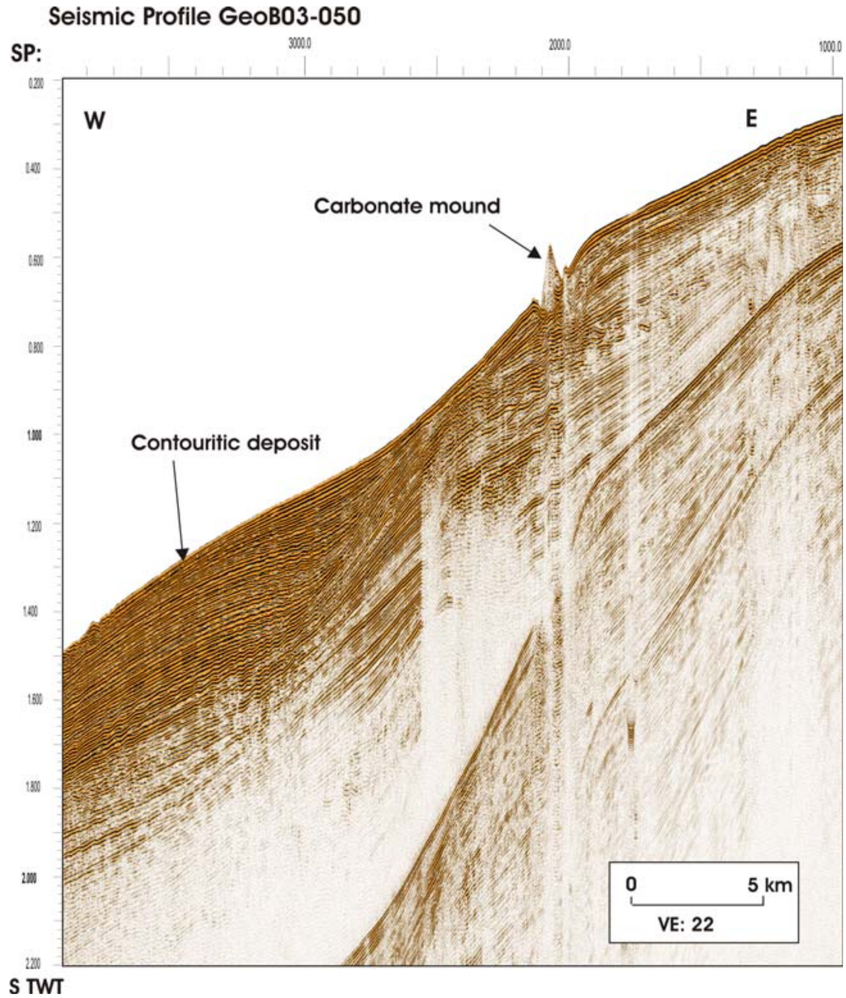


Fig. 14 Seismic dip profile GeoB03-050 recorded upslope of Mauritania Slide Complex showing mound-shaped contouritic sediment, unaffected by sliding, as well as a carbonate mound feature. Location of the profile is shown in Fig. 3

the adjacent north and south bounding areas of the margin where high concentration of canyons and gullies must have effectively evacuated any sediment supplies through channelised sediment transport, and therefore precluded any significant pile-up of sediment in those areas. The high rates of sediment accumulation, especially in the presence of upwelling-induced organic-rich sedimentation, would have given rise to underconsolidated sediment charged with excess pore pressure, thus making the sediment highly prone to instability, and hence pre-conditioned for slide development.

Timing of slide events and failure mechanism

The seismic data reveal that the main depositional area of the Mauritania Slide Complex is composed of several stacks of debris flow deposits separated by well-stratified sediment. In addition we note in both the seismic and Parasound data, that the uppermost debris flow deposits are made up of several lens-shaped units lying side by side or onlapping each other in places (Figs. 7, 10). We also note in both data sets the presence of multiple headwall scars in the source areas (e.g., Figs. 4, 5, 8, 9).

These observations suggest that the stages of development of the slide complex have been characterised by several recurrent mass sediment failure events, which may be grouped into major and relatively minor failure events. We speculate that the termination of each major debris flow depositional event was generally followed by a period of 'normal' sedimentation during which the intervening well-layered sediment was deposited. Also during this period, pre-existing headwall scars as well as seafloor topographic lows, created by sub-surface sediment mobilization or diapiric growths and probably erosional removal, were infilled by 'normal' sediment. That some of the well-layered sediment between 700 and 2,500 m water depths (Figs. 12, 14) display mounded contouritic characteristics, is indicative of the prevalent increased bottom current activity, i.e., under the regime of North

Atlantic Deep Water, which characterised the sedimentation process.

Many young submarine slides on deep continental margins which exhibit complex and multi-staged behaviour are thought to have usually formed through retrogressive sliding (Canals et al. 2004). The complex internal structure and the step-like headwall morphology displayed by the Mauritania Slide Complex together with the fact that most of the lower headwall scars occur at considerable water depths, i.e., up to ~ 2,000 m deep, suggest that its process of development during a major event was characterised by retrogressive sliding. In this case, the initial sediment failure was started from the lowermost headwalls and was then followed by a series of discrete failures which progressed upslope. In the seismic data (e.g., Figs. 8, 9) we observe, especially in the slope areas, the presence of widespread thin acoustically transparent layers intercalated within thick well-layered sediment units. We interpret these thin layers which commonly underlie failed sediment as weak layers which facilitated sediment failure. The process of retrogressive slide development must have exploited the widespread presence of these weak layers as glide planes. In the Parasound data, these glide planes are observed as prolonged strong to weak sub-bottom reflectors which commonly underlie proximal debris flows, and may be traced upslope directly into slide scars or onlaps (Figs. 6, 7). As no slides are observed upslope beyond the linearly aligned cold water carbonate mounds (Fig. 3), it is most likely that the mounds played an influential role in halting further upslope slide retrogression particularly in the southern parts of the slide. It is interesting to note that the sediment failures are limited upslope at ~ 600 m water depths, which is close to the upper boundary of gas hydrate stability in deep water sediment (e.g., Bohrmann et al. 1998; Milkov and Sassen 2000). However, our data do not provide any clear indications, like enhanced buried reflectors or gas hydrate BSR (bottom simulating reflector), to directly link the sediment failures to gas hydrate destabilisation.

The C14-age determination of sediment cores from the uppermost debris flow layers recovered from different locations in the slide returned C14-age dating of 10.5–10.9 cal. ka B.P. representing the age of the last major slide event (Henrich et al. 2006). Slide development during a major event may have been significantly modified by later minor instability events which included remobilization of pre-existing debris flows as well as translational sliding (this is discussed in detail in the last section). However, the time lapse between the phases of multiple instabilities within the last major slide event may have escaped the resolution of the C14-age dating method. The complete age description of the slide complex has, however, not yet been established.

Possible trigger mechanisms for slide development

Following the creation of a slide 'pre-conditioned' environment along the Mauritanian margin, i.e., the rapid build up of thick sediment piles intercalated with widespread weak layers, the stage was then set for a trigger mechanism to initiate the mass sediment failure events which would lead to slide development. We now examine and evaluate the potential trigger mechanisms which are likely to have initiated the development of the Mauritania Slide Complex based on indications from our data as well as those commonly documented for other passive marginal settings. These are mainly: excess pore-pressure (generated mostly through methane gas, decaying gas hydrates and sea level fluctuations, etc.), earthquakes and diapiric movements.

Excess pore pressure

Build-up of excess pore pressure in upper sediment layers is known to be capable of triggering mass sediment failures (Laberg and Vorren 1995; Vorren et al. 1998). In the seismic data, we note the presence of widespread and pervasive acoustically transparent vertical linear zones, which commonly occur with wavy reflectors, in the main slide depositional areas (e.g., Figs. 12, 13). We interpret these features as evidence of widespread distribution of excess pore-pressure resulting from over-pressurised gas or fluids within the slide complex. The rapid pile-up of huge quantities of sediment along the Mauritanian margin most likely entrapped organic matter, i.e., from upwelling-induced sedimentation as well as fluvial sources, which probably decomposed into methane gas to give rise to the excess pore-pressure build-up. Excess pore pressures could also be generated within near-bottom seafloor sediment by sea level fluctuations as a result of periodic changes in hydrostatic pressure within the sediment (e.g., Lee et al. 1996). As noted by Henrich et al. (2006), the timing of the last major debris flow depositional event, i.e., 10.5–10.9 cal. ka B.P., is suggestive that the youngest major failure event may have been triggered by the rising sea level during the transition between the last glacial and the present interglacial.

From these lines of evidence, it is presumable that build-up of excess pore pressure in poorly consolidated upper sediment layers along the slope area of the margin constitute the most significant trigger mechanism for the Mauritania Slide Complex.

Earthquakes

Jacobi (1976) suggested that earthquakes associated with the Cape Verde Rise and adjacent fracture zone extensions may have triggered the slide events. Seismic hazard modelling results of the deep more basin, offshore Norway (e.g., Lindholm et al. 2005), have demonstrated that surface sediment layers located as far as ~ 100 km from the earthquake source experience longer durations of seismic movement than the source area as a result of seismic energy trapped by the sediment. In a similar vein, as the area of the Mauritania Slide Complex is located within the thickly sedimented Senegal Mauritania Basin, where the depocenter is ~ 10 km deep (Wissmann 1982), we expect the area to be very vulnerable to sediment destabilisation from any earthquake activities from Cape Verde Islands and nearby fracture zones. However, in the absence of any comprehensive paleo-seismic analysis in the region, the actual role played by the earthquakes in the development of the slide could only be speculative.

Diapiric growth as a possible trigger mechanism and its influence on recent slide development

We note that the Mauritania Slide Complex is located within the area of salt diapirs, which lies between latitudes 16°N–19°N (Wissman 1982), along the Mauritanian margin. Our seismic data interpretation shows that most of the slide area has been subjected to subsurface sediment mobilization and diapiric growths (e.g., Figs. 9, 10, 11). Salt movements in the margin, believed to have began in Miocene/Pliocene time following sediment overloading from the Senegal River paleo-estuary (Wissman 1982), appear to have continued up to this time though there might have been several long periods of inactivity. As the depocenter of the paleo-estuary shifted progressively southwards towards its present location near 16°05′N, other factors like high sediment accumulation from upwelling-induced sources and wind-blown sediment must have sustained the salt halokinesis. Apart from fracturing and deforming overlying sediment, the upward movement would also have locally created oversteepening of affected slope and rise areas. This observation is consistent with studies elsewhere, e.g., in the Gulf of Mexico (Tripsanas et al. 2004) and off North Carolina (Cashman and Popenoe 1985) where episodic movements of underlying salt bodies are believed to have triggered slope failures.

Though we do not have data control over the growth history of the diapirs, our data interpretation allows us to envisage the influence of diapiric growths on seafloor stability and recent slide development by a three-stage evolutionary model outlined as follows (Fig. 15):

(i) The last major slide event resulted in the formation of widespread debris flow deposits probably through retrogressive slope failure of previously well-layered slope sediment (Fig. 15, stage 1). The age of this major event is represented by the 10.5–10.9 ka obtained from core dating.

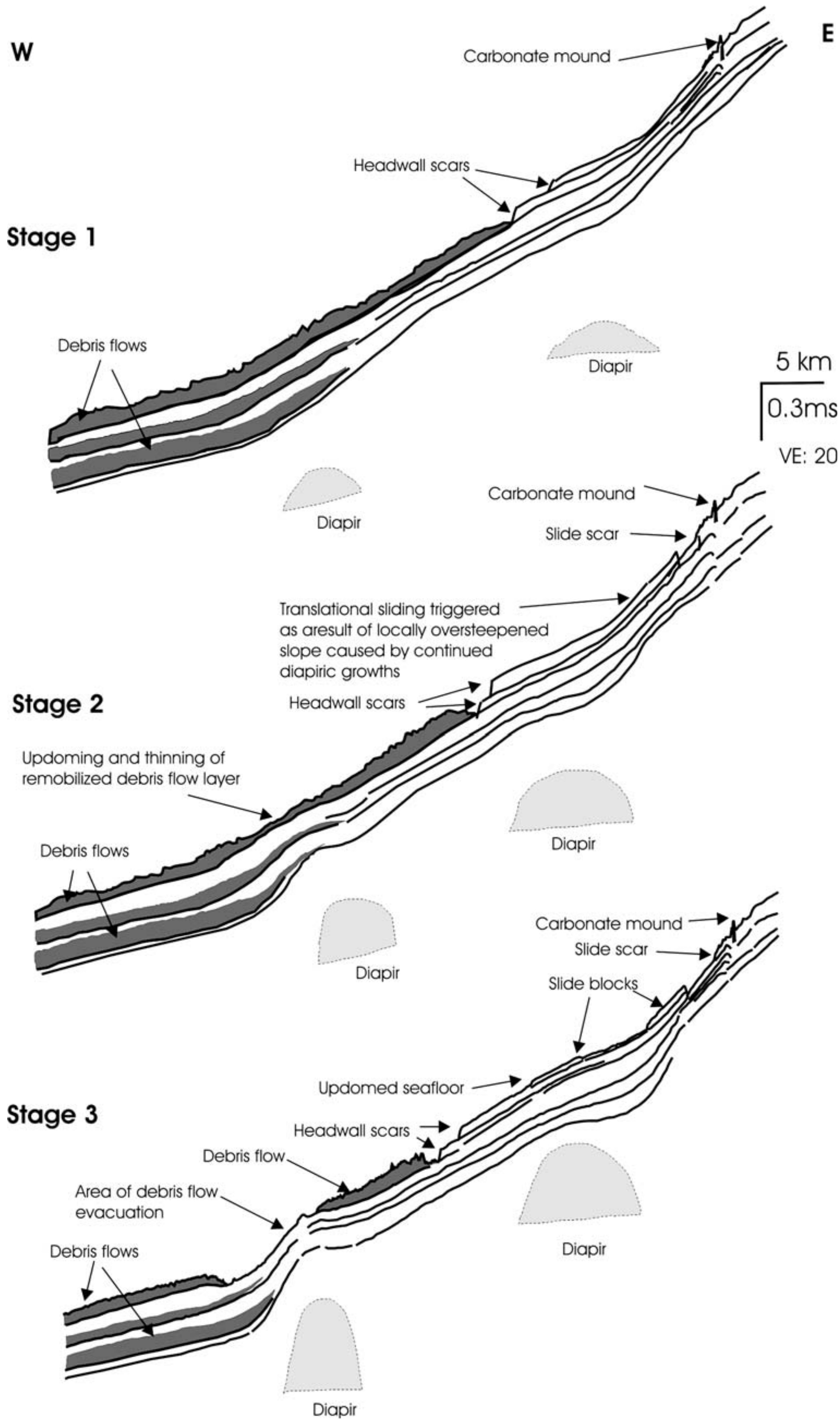
(ii) Following this event continued diapiric growths locally uplifted the upper and lower slope areas, including: (a) the area immediately upslope the upper headwall scar, which previously had undisturbed sediment, and (b) the area downslope the lower scar. In the upper slope area, initial diapiric growths locally increased the seafloor gradient, thereby inducing translational sliding along planar failure surfaces. In this case, the very thin acoustically transparent layers within the well-stratified upslope sediment packages may have facilitated the sliding process by serving as lithological planes of weakness. In the lower slope area, the seafloor debris flow layer responded to diapiric growths by gradually thinning and withdrawing towards the downslope flank of the now uplifting seafloor (Fig. 15, stage 2).

(iii) In the upper slope area, progressive upward diapiric growths led to a slight disintegration of the slide blocks accompanied by further downslope movement which may have eventually slowed down or stopped on encountering the detached debris flow deposit. In the lower slope area, the growths led to a complete detachment of the overlying less cohesive and increasingly weakened debris flow layer at the downslope flank of the updomed crest leaving an isolated debris flow remnant in the upslope flank (Fig. 15, stage 3).

Our model suggests that diapiric growths have the tendency to later destabilize overlying sediment previously unaffected by retrogressive failures of even major slide events. In the case of pre-existing seafloor debris flow deposits, the growths would thin or considerably weaken the layers and eventually dismember or disintegrate them thereby inducing renewed mobility to the flows.

Translational sliding and debris flow remobilization may still be an active process within the Mauritania Slide Complex as evidenced by recent updoming and seafloor instabilities induced by the apparently, still

Fig. 15 Schematic illustration of the influence of diapiric growths on seafloor stability and recent development of the Mauritania Slide Complex. The model is based on our interpretation of Profile GeoB03-054 (Fig. 9). Stage 1: deposition of debris flows during last major slide event. Stage 2: continued diapiric growths cause uplifts of seafloor accompanied by locally increased slope gradients leading to translational sliding and remobilization of pre-existing debris flows. Stage 3: further diapiric growths lead to more uplifts of overlying sediment and then disintegration of seafloor debris flow deposit. See text for detailed explanation



active diapiric growths. In many cases, seafloor topographic lows created at the flanks of the domed areas have constituted pathways for remobilized debris flows (e.g., Fig. 11). Additionally, the rugged seafloor topography created by the isolated and detached remnants of the pre-existing slide materials may locally give rise to increased bottom current velocities, thereby leading to erosional removal of portions of the deposits for further redistribution into the deep sea.

Considering all the scenarios for slide initiation discussed above, it is unlikely that any single trigger mechanism could be solely responsible for initiating all the slide events. In addition, the marked complexity in morphology exhibited by the Mauritania Slide Complex suggests that its stages of development must have been influenced by the interplay between more than one of the triggering mechanisms discussed above. However, because of their more regional character, triggers like excess pore pressures and, probably, earthquakes may have been more influential in initiating major slide events which were later modified by diapiric growths and sub-surface sediment remobilization.

Conclusions

- Recentlly acquired Parasound sediment echosounder and high resolution multi-channel seismic reflection data have afforded a more detailed characterisation of the Mauritania Slide Complex than previously reported. Apart from further constraining the seafloor morphology of the slide complex, the new data have allowed a detailed visualization and investigation of the internal structure of the slide including headwall features, basal sliding surfaces as well as the geometry and character of slide deposition.
- The slide has affected an area in the order of 34,000 km^2 occurring between ~ 600 m and > 3,500 m water depths, hence ranking as one of the major slides on the NE Atlantic margin. Headwall scars commonly occur as a series of steps in seafloor morphology ranging between 25 and 100 m high and occurring between 600 and 2,000 m water depths.
- The ovate-shaped slide displays a long run-out distance > 300 km as a result of higher sediment flow mobility induced in its northern parts by bounding canyon systems and the Cape Verde Rise. In addition, widespread diapiric growths may have enhanced quicker disintegration of overlying weaker contouritic deposits thus contributing to increased sediment flow mobility.
- Slide development was pre-conditioned by uninterrupted deposition of probably upwelling-induced organic-rich sediment in an open slope environment which would have favoured rapid accumulation of poorly consolidated bedded sediment interspersed with thin lithologically weak layers.
- The presence of several vertically stacked debris flow deposits separated by well-layered sediment intervals revealed within the internal structure of the slide is suggestive that the stages of slide development have been characterised by multiple failure events. In addition, the series of step-like headwall scars which extend from great water depths ~ 2,000 m upslope to ~ 600 m, suggests a retrogressive mode of failure which may have been facilitated by widespread weak layers during a major slide event.
- Slide development during a major slide event may have been significantly modified by later minor instability events which involved remobilization of pre-existing debris flows as well translational sliding mainly as a result of diapiric growths.
- The data interpretation suggests excess pore pressures, resulting from decayed organic matter and/sea level rise, could be the most important trigger mechanism for slide formation. However, seismic shaking could have played a complementary or, at one time or the other, a leading role in triggering the sediment failures. Diapiric growths have also been important in destabilizing overlying sediment including unfailed areas. The combined activities of these factors are the most likely cause of the complex morphology of the Mauritania Slide Complex.

Acknowledgments We gratefully acknowledge the invaluable assistance and cooperation enjoyed from fellow cruise participants as well as the Captain and crew members of RV Meteor Cruise M58/1 during data acquisition. We are also very grateful to Dr. E. Flüh and an anonymous reviewer for their critical reviews of the manuscript. This is publication RCOM0392 of the DFG-Research Center ‘Ocean Margins’ (University of Bremen).

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