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► **To cite this version:**

Gérôme Calvès, Mads Huuse, Peter Clift, Stéphane Brusset. Giant fossil mass wasting off the coast of West India: The Nataraja submarine slide. *Earth and Planetary Science Letters*, 2015, 10.1016/j.epsl.2015.10.022 . hal-01242470

**HAL Id: hal-01242470**

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Submitted on 12 Dec 2015

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## **Giant fossil mass wasting off the coast of West India: The Nataraja submarine slide**

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### Abstract

We used two-dimensional prestack depth migrated seismic reflection profiles and seafloor bathymetry to describe the continental margin structure and a massive mass transport deposit off the west coast of India. This giant slide runs from the Gujarat–Saurashtra margin to the Laxmi Basin. It is over 330 km long, a maximum of 190 km wide and its runout basal gradient is  $1.2^\circ$ . We name this giant mass wasting deposit the Nataraja Submarine Slide. This slide covers  $49 \pm 16 \times 10^3 \text{ km}^2$  and represents a volume of  $19 \times 10^3 \pm 4 \times 10^3 \text{ km}^3$ , making it the second by volume of any passive margin landslide/mass transport deposit. Seismic facies analysis allows the internal structure of the mass transport deposit to be described as far as the toe. This slide has been able to circumvent massive seamounts, thus highlighting the capacity of the flow and its potential energy during emplacement in a funnel between the slope of the Western Indian passive margin and the Laxmi Ridge. Stratigraphically, the emplacement of the Nataraja Slide predates the main pulse of sedimentation during the late Miocene–Recent associated with the Indus Fan but follows rapid sedimentation across Sand SE Asia during the Early–Middle Miocene. The margin architecture at the head of this slide is associated with a gravity-controlled fold and thrust belt that may have caused slope steepening and triggering of the slide.

**Keywords:** mass wasting slide seismic reflection West Indian margin Arabian Sea

## 1. Introduction

Landslides occur on and offshore, and range in volume from  $m^3$  to  $10^3 km^3$ .

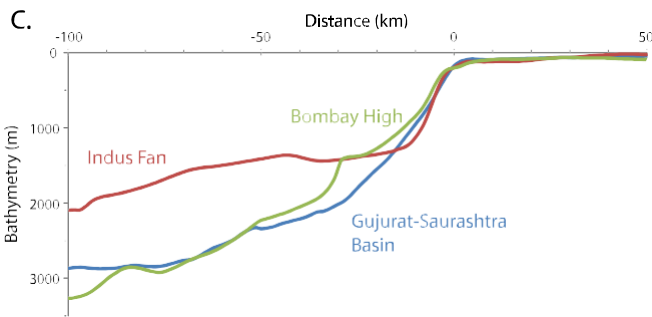
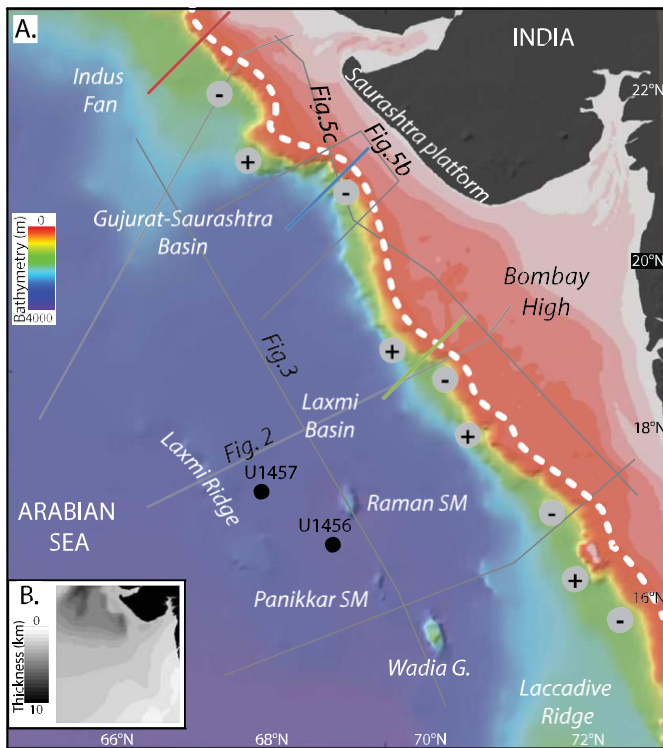
Triggering mechanisms are often unknown and almost certainly differ between settings (Hampton et al., 1996). Mass wasting/mass transport deposits represent some of the most challenging and important sedimentary and mechanical features for geoscientists and structural engineers to understand (e.g., Masson et al., 2006). Offshore, along both passive or active margins (Moscardelli and Wood, 2015), mass wasting plays an important role in shaping most continental slopes that lead to deep abyssal plains and help to form the architecture of deep water sedimentary systems when associated with turbidity currents (Embley, 1976; Woodcock, 1979; Bellaiche et al., 1986). Mass movements can, in certain circumstances, affect man-made installations, such as deep sea cables or subsea offshore structures (Gennesseaux et al., 1980; Piper et al., 1988). Movement of the overlying water column during emplacement may generate

tsunamis, as documented for the well known Holocene Storegga Slide in the North Atlantic offshore Norway (Janssen et al., 1987; Bugge et al., 1988; Yamada et al., 2012). Despite the numerous sea floor features described and the proposed mechanisms for triggering slides (e.g., overpressure, fluid/sediment mobilization, earthquake) the limited number of giant slides in the rock record that have been studied in detail do not allow a definitive analogy to be made between these modern and ancient examples.

The morphology of the present day margin of western India (Naini and Kolla, 1982; Chakraborty et al., 2006) is characterized by a series of arcuate concave up and concave down features at the shelf to slope transition (Fig. 1). At this scale we can define the margin as being associated with a series of prograding sedimentary wedges and/or retrograding erosive slopes (Steffens et al., 2003). The main sedimentary body within this part of the western Indian Ocean is the Indus Fan (Fig. 1B) that contains up to 11 km of sediments (Exxon, 1985; Clift et al., 2001). The surficial shapes found along the margin can be summarized by three dip bathymetric profiles (Fig. 1C). The northern profile corresponds to the Indus Fan and shows a convex upward profile reflecting the excess of Plio–Pleistocene sediments accumulated by this thick sedimentary body (Fig. 1B). Although the influence of deltaic sedimentary systems differs between the three areas, we note that the profile along the Gujarat–Saurashtra sector shows a concave upward geometry compared to its neighbors, suggestive of mass wasting (Coleman and Prior, 1998; Adams and Schlager, 2000). Slope failure of Plio–Pleistocene deposits spatially associated with hydrates, rapid sedimentation rates or seismicity has been documented along the slope of the Western Indian margin (Rao et al., 2002).

The Laxmi and Gujarat–Saurashtra Basins have been extensively described and analyzed in relation to the rifting history of Gondwana, with particular attention having been paid to the continent-ocean transition (e.g. Bhattacharya et al., 1994a; Todal and Edholm, 1998; Chaubey et al., 2002; Krishna et al., 2006; Calvès et al., 2008, 2011; Misra et al., 2015). Nonetheless, detailed description of the drift sequences of the Gujarat–Saurashtra and Laxmi Basins has not been performed previously because of the limited available seismic reflectivity

on coverage and modest number of wells/boreholes drilled in the area. Our study builds on previous studies and uses two-dimensional Pre-Stack Depth Migrated (Pre-SDM) seismic reflection data to describe the large-scale geometry of the margin. We identify some key facies that form a major sediment volume and represent the product of a major late Miocene event in the history of this margin. We define the spatial extent, the internal structure and tectonic origin of this previously undescribed sedimentary body. This seismically observed structure has recently been calibrated during International Ocean Discovery Program (IODP) Expedition 355 (Pandey et al., 2015). Preliminary results from Sites U1456 and U1457 (Fig. 1A), support our initial interpretation that were completed before drilling.



**Fig.1.** A. Regional setting of the Western Indian margin and adjacent Arabian Sea Basin. These seismic data used for this study are marked by grey lines. Along margin, convex up and convex down morphology of shelf to slope are expressed by positive and negative grey symbols, respectively. B. Thickness map of sediments within the study area (Exxon, 1985), note the extent of the Indus fan deep center north of the study area. C. Bathymetric profiles across shelf and slope from three locations along the margin, these profiles are either convex up (Indus Fan, i.e. high sediment rate and important deep sea fan) or concave up (Bombay High or Gujarat-Saurashtra Basin). The two IODP drill sites U1456 and U1457 are located in the southwestern part of the study area (Pandey et al., 2015).

## 2. Materials and methods

The approximately 3500 km of seismic reflection data used in this study (Fig. 1A) are part of the much larger regi-

on all India SPAN™ survey acquired and processed by LONGX Technology in 2006–2007. The acquisition was designed for crustal scale imaging by using a long receiver cable with a 10.1 km maximum offset and a large source size of 7480 cu in. Crustal scale imaging is achieved by an 18 s two-way time record (equivalent to around 40 km depth). The prestack depth migrated data were remigrated (Kirchhoff PreSDM) using velocities derived from iterative tomographic velocity modeling. A vintage single channel seismic reflection profile RC1707 from the Lamont–Doherty Earth Observatory has also been used (Fig. 1; accessed by the GeoMapApp 3.3.9–link: <http://www.geomapp.org/>).

We analyzed these seismic reflection lines at two different scales, from the mega (basin) scale to the architectural elements scale. At the scale of the architectural elements, seismic facies analysis (Mitchum et al., 1977) was used to document and describe the kinematic indicators of the mass transport complexes (MTC) as defined by Bullett al. (2009). Identification of the headwall, extensional domain, translational domain and contractional toe domains (Priore et al., 1984) is based on the external and internal geometry of the mass wasting package, as imaged by these seismic reflection data. The classification of attached/detached MTC follows the scheme of Moscardelli and Wood (2008). The regional GEBCO (British Oceanographic Data Centre, 2003) bathymetric data are used to describe the margin and locate the various structures where the slide is present.

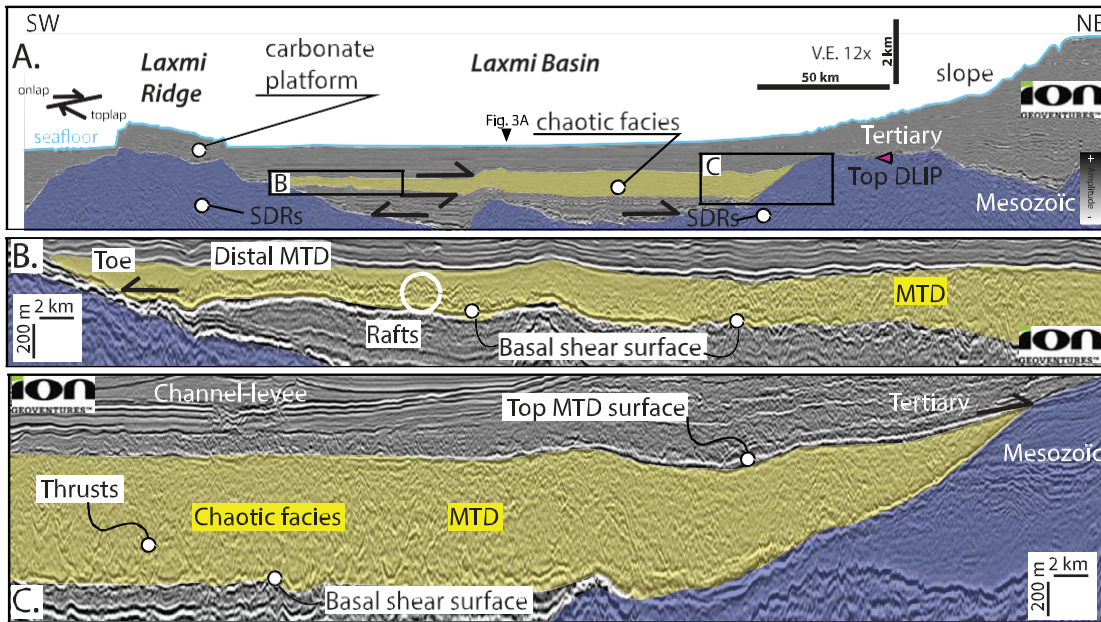
In spring 2015, two IODP sites were drilled in the southwestern part of our study area (Fig. 1A). We refer to this preliminary age control and sedimentary facies from on-board analysis to calibrate our geophysical observations (Pande et al., 2015).

### 3. Results

#### 3.1. Margin scale structure – Nataraja slide location

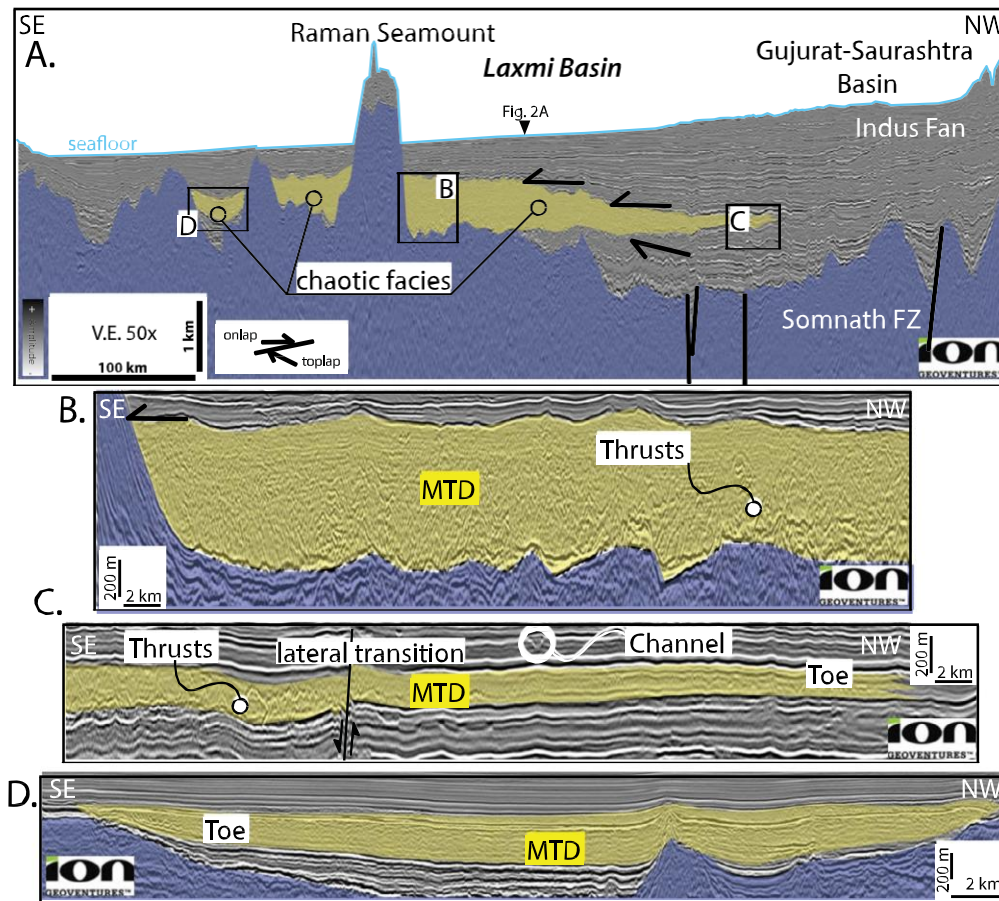
The present day structure of the western Indian margin is mainly dominated by a series of infilled drift basins spanning from the landward Gujarat–Saurashtra margin to the Laxmi Basin and bounded to the west by the Laxmi Ridge, where seaward dipping reflectors (SDR) mark the transition between aborted oceanic basin crust to the true oceanic accretion generated along the Carlsberg Ridge (e.g. Naini and Talwani, 1982; Calvès et al., 2011; Misra et al., 2015). This setting is the result of a repeated ridge jump marked by SDR sequences on both sides of the Laxmi Ridge.

The main geodynamic event to have shaped the onshore part of the margin is the Deccan Large Igneous Province (e.g. Wellman and McElhinny, 1970; Mahoney, 1988). This event is marked seaward by a prominent seismic reflection package overlain by carbonate platforms (Calvès et al., 2008, 2011) and in turn buried by Cenozoic siliciclastic deposits largely sourced from the Indian continent and Himalaya via the Indus River (e.g., Clift et al., 2001) (Fig. 2A). The flat lying flood basalts are in transition with seaward dipping reflection packages in the Laxmi Basin (Calvès, 2009; Misra et al., 2015; Fig. 2A).



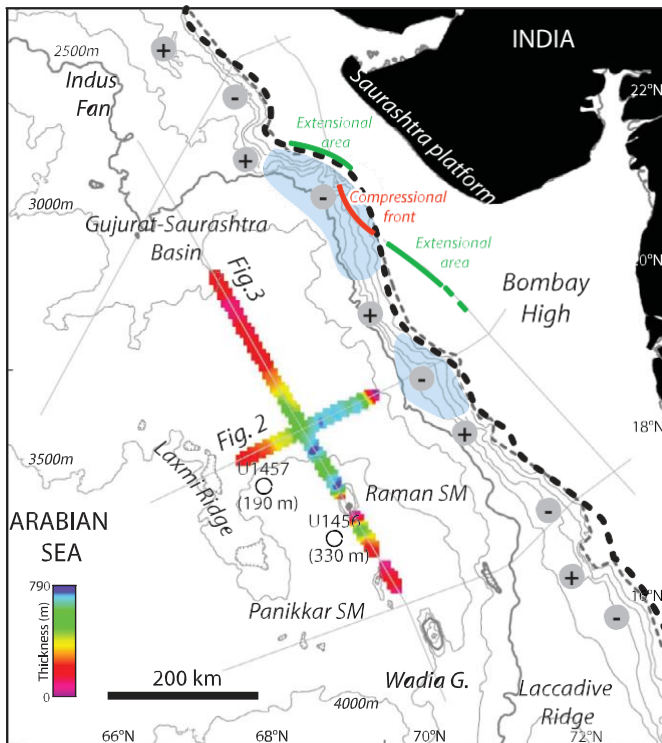
**Fig.2.** Regional prestack depth migrated seismic reflection profiles across the Bombay High, Laxmi Basin to Laxmi Ridge. A. This seismic reflection profile of the margin shows the width of an extensive chaotic seismic facies within the Cenozoic section. The Meso–Cenozoic transition below the slope of the margin is marked (purple filled arrow) by the top of the Deccan Large igneous Province (top DLIP) seismic high amplitude reflective event. Seaward Dipping Reflector (SDR) sequences are observed on both sides of the Laxmi Basin. B. The chaotic seismic facies is marked by massive thrust and onlap and downward on the Mesozoic sequence. C. Toward the Laxmi Ridge the chaotic seismic facies thins laterally. D. Toward the Panikkar Sea mount the facies is less chaotic and the slide thins and onlaps against the structural basement highs, see Fig. 1 A for profile location.





**Fig.3.** Regional prestack depth migrated seismic reflection profiles NW–SE across the Laxmi Basin and Raman Seamount and, Gujarat–Saurashtra to Laxmi basins B., the chaotic seismic facies is thick toward the SW, note the portion of the Indus Fan and its giant channel levees. The chaotic seismic facies runs further south, beyond the Raman Seamount. Note change of scale between displays, see Fig. 1 A for profile location.





**Fig.4.** Isopach map of the Natarajaslide. These seafloor contours are spaced every 500 meters. The geomorphological elements of these seafloor surface are similar to Fig. 1. Thickness of the mass wasting deposits of the two IODP sites U1456 and U1457 are marked in brackets (Pandey et al., 2015). Two concave down morphologies of the margin are marked in the slope by blue shaded areas. These are marking potential mass missing to their lateral section along the downslope of the West Indian margin. The shelf margin geometry is related to large scale gravity spreading of the slope with concave down areas underlain by contractional deformation (see Fig. 5). (For interpretation of the reference to color in this figure, the reader is referred to the web version of this article.)

The Cenozoic Indus Fan sequence is composed at its base by continuous parallel seismic reflections that overlap onto structural highs (Figs. 2B, 2C, and 3A). Above this sequence a package defined by chaotic facies of regional extent covers most of the Laxmi Basin. This package thin towards and eventually overlaps the Laxmi Ridge to the SE (Fig. 2A). It is thick towards the NE, where it is >750 m thick (Fig. 4). The internal organization of this sequence is composed of chaotic to discontinuous seismic facies packages, bright steeply dipping reflections, rotated discontinuous stratal reflections and low amplitude structureless facies (insets Figs. 2A and 2B). Each of these facies can be interpreted as mass transport deposits and help to define the potential location of the ultimate head scarp and toe (e.g., Bull et al., 2009) (Figs. 2, 3, 4 and 5). The 2D grid does not allow complete mapping of the mass transport deposit, but the overall extent and large scale thickness variation, and thus volume, is constrained with reasonable certainty. These seismic reflection profiles in the deep basin allow only the identification of the toe region of the slide (Figs. 2B, 3C, and 3D). We are able to define the edge of the seaward part of the slide where thin deposits and less chaotic facies (

Figs. 2B, 3C, and 3D) are expressed to the NW, SW and SE (Fig. 4). The NE to S polarity of the slide and especially it has been drilled at both IODP Sites U1456 and U1457 (Pandey et al., 2015). Regional slopes to the basement, as well as the modern bathymetry are also consistent with emplacement towards the south. The chaotic facies on lap the foot of the Raman Seamount (Figs. 3A and 3B). The Raman and Pannikar Seamounts, located in Laxmi Basin (Figs. 1A and 3B; Bhattacharya et al., 1994b), constituted barriers to the flow of the slide deposit, which flowed around these features towards the south (Fig. 3B). The core mass transport deposit (Fig. 4) thickness varies from ~330 m at Site U1456 to ~190 m

at Site U145 (Pandey et al., 2015). These thickness variations in the SW part of the Nataraja slide are in agreement with the isopach map computed from the top and base of these seismically defined chaotic facies in this region (Fig. 4).

The architecture of the proximal part of the margin offshore the Saurashtra platform (Figs. 3, 5B and 5C) is composed of a deep water fold and thrust belt that involves the Cenozoic sedimentary package. The NW part of the study area shows a thin sedimentary cover, compared to the adjacent areas, with a transition into a major trough where two buried stacked compressional features are identified and which are seen to emanate from detachments that run into the slope of the margin. These tectonic structures are linked to extensional structures that see significant piles of sediment extending toward the SE (Fig. 5C). The main depocenter of the western margin of India is associated with the Bombay High (e.g., Biswas, 1982; Rao, 1991; Figs. 1B and 5A).

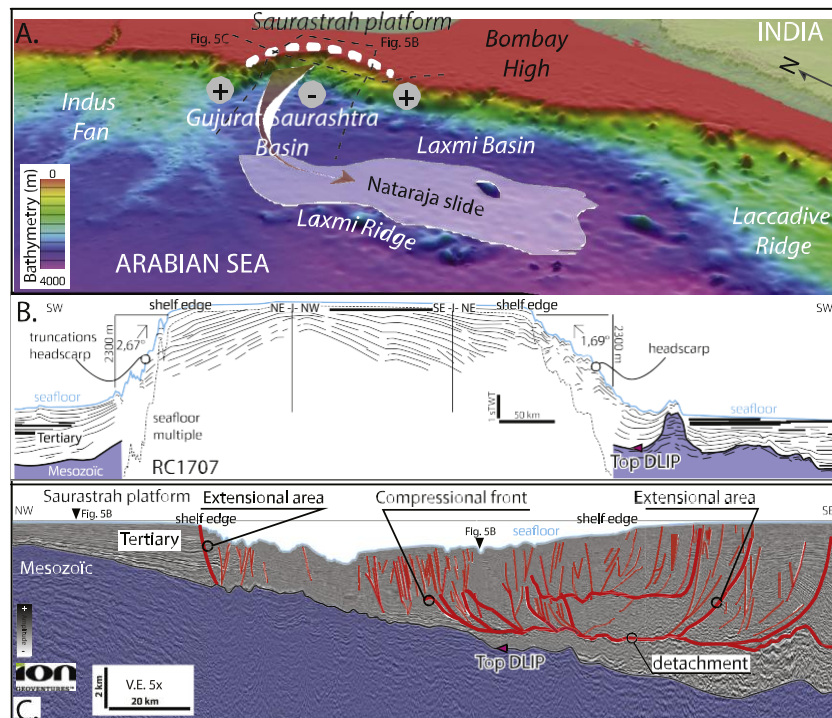
The headwall domain of this mass wasting complex is located in the slope of the Gujarat–Saurashtra Basin. Based on the morphology of the margin, two concave up areas are located upslope of the Nataraja Slide (blue shaded areas, Fig. 4). Based on the polarity of these seismic facies and drilling results from IODP Expedition 355, we favor the northern polygon (north of 20°N, Fig. 4) as a potential headwall source for the following reasons: Based on bathymetry/slope gradient and seismic profiles, the headwall is inferred to run along the slope and shelf break (Figs. 1 and 5A). The truncated reflections at the shelf edge/slope transition mark the head of the scar (Fig. 5B). Slope gradients in the headscarp region range from 1.6° to 2.7°, which are typical of the décollement level in upper slope and headscarp regions along passive margins (Harris and Whiteway, 2011). The distal basal lower half gradient of the mass transport deposit lies at a gradient of 1.2°. This value is consistent with the largest slides that tend to occur on the lowest surface slopes (McAdoo et al., 2000).

Before the recent drilling of Sites U1456 and U1457, there was no precise age information for the landslide facies itself. However, its age is bracketed downward by the presence of up to 1150 m of basin fill deposit between the slide and the top of the volcanic basement and overlying Paleogene carbonate platforms (Calvès et al., 2008), and upward by the channel levee complexes of the Indus Fan, which are dated as Early Miocene and younger further north (Clift et al., 2001). The stratigraphic position of the mass transport deposit is calibrated further north where it is top and base markers correlate with hemipelagic sediments from a borehole with poorly resolved ages from early to late Miocene (~15 Ma) (<http://www.dghindia.org;well:GSDW11A>) (Figs. 2A and 3A). At Site U1456 (Fig. 1A), the sediment lying immediately above and within the mass transport deposit is dated at <10.8 Ma, whereas sediment lying directly underneath the deposit is dated as 13.5–

17.7 Ma (Pandey et al., 2015). The age gap between the two represents erosion at the drillsite linked to MTC emplacement around 10.8 Ma and does not indicate slow sediment transport. The best age estimate for the Nataraja slide is thus between around 10.8 Ma (late Miocene).

### 3.2. Size and volumetric of the Nataraja MTD

The size of the headscarp in the Gujarat–Saurashtra Basin is ~100 km along the NW–SE axis and ~90 km along its NE–SW axis (Figs. 4 and 5A). Its present day minimum height is ~2300 m, this corresponds to the top of the truncated reflections on the shelf edge transition to the base of the slope where continuous reflection begins (Fig. 5B). The estimated volume of the headscarp can be computed as the quarter of an ellipsoid, so that its volume is estimated at  $\sim 11 \times 10^3 \text{ km}^3$ . The Nataraja Slide has a surface extent of  $\sim 49 \pm 16 \times 10^3 \text{ km}^2$  and a volume of some  $19 \times 10^3 \pm 4 \times 10^3 \text{ km}^3$ , which makes this one of the largest known mass transport complex deposits along any passive margin so far documented on Earth. At the scale of the margin, the slide represents  $8\% \pm 3\%$  of the Cenozoic sediment deposited in the Gujarat–Saurashtra and Laxmi Basins (Fig. 1B; Exxon, 1985, whole volume of  $\sim 600 \times 10^3 \text{ km}^3$ ). The minimum volume of the scarp observed on the bathymetry and the estimates of the Nataraja Slide deposit are of the same order. The real size  $> 100 \text{ km}^2$  and volume  $> 1 \text{ km}^3$  of the Nataraja Slide allow us to classify it as an attached mass transport deposit in the terminology of Moscardelli and Wood (2008, 2015).



**Fig. 5.** A. Extension of the buried Nataraja slide and potential source area. The runout distance is about 550 km for a length of 338 km and a maximum width of 193 km, volumetric estimates is  $19 \times 10^3 \pm 4 \times 10^3 \text{ km}^3$ . B. Line drawing of seismic single channel RC1707 (Columbia–Lamont–Doherty Earth Observatory, GeoMapApp). C. Regional NW–SE prestack depth migrated seismic reflection profile across the shelf and slope of the West India continental margin offshore the Saurashtra platform. The structural style of the Tertiary section is associated with a stack of two compressional deepwater fold and thrust belt. Deccan Large igneous Province is marked with a purple arrow (top DLIP).

**Table1**

Volumetric and height to fall horizontal run out ratio of the 'giant' submarine landslides (i.e. volume > 10<sup>3</sup> km<sup>3</sup>) and associated references.

Slidename	Runout length	Height H	H/l ratio	Vol	Reference
Nauruan	230	5000	0.022	5000	Normark et al. 1
Israel Slump Complex	150	2000	0.013	1000	Frey Martinez et
Sahara Slide	780	3300	0.004	1100	Embley 1976
Ruine Slide	120	2300	0.019	1200	Gea et al. 2007
Hinlonen Slide	300	1400	0.005	1350	Vanneste et al.
Cane Fear Slide	420	4250	0.010	1400	Pononnet et al.
Eastern Amazon Fan MTCs	275	3300	0.012	1500	Piner et al. 199
Western Amazon Fan MTCs	245	3000	0.012	2000	Piner et al. 199
Storegga Slide	770	3720	0.005	3000	Canal et al. 20
Avaharas Formation	500	500	0.001	10000	Callot et al. 200
South Makassar Strait MTC	120	1700	0.014	2438	Armandita et al.
Makran accretionary comp	150	600	0.004	42000	Burget et al. 2008
Agulhas Slump	750	800	0.001	20331	Dingle 1977
Giant Chaotic Body	255	3000	0.012	50000	Torelli et al. 199
Nataraja	550	3150(+15	0.006	18745(+4	This study

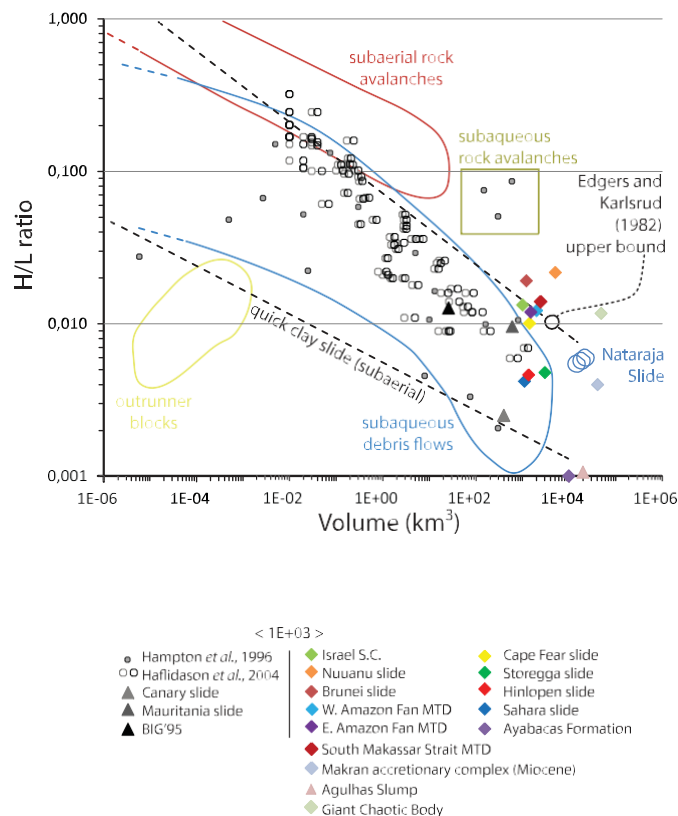
#### 4. Discussion

##### 4.1. Significance of the Nataraja Slide

We have compiled from various sources the height to the ratio of the originating slope height to horizontal run out of submarine slides as a function of the volume of each mass wasting deposit (e.g., Edgers and Karlsrud, 1982; DeBlasio et al., 2006). Globally, the Nataraja Slide is the second largest marine mass transport deposit along a passive margin by volume, only smaller than the Agulhas lump (Dingle, 1977) (Table 1, Fig. 6). Based on the size and shape of this body, the long run out of this mass transport deposit across a gentle slope, covering long distances and the development of a thick deposit further pushes the envelope proposed by DeBlasio et al. (2006), as well as the empirical curves of submarine landslides of Edgers and Karlsrud (1982) to their limits. This slide has a source located in a mixed sedimentary margin sequence and its sink is structurally bounded by major bathymetric features, which we argue have facilitated its run out distance by focusing it. The potential mixed lithologies sourced from the slope of the West Indian Margin could explain the various features observed within the core slide deposits (Pandey et al., 2015). The observedolistostromes in the Makran (onshore Pakistan, Burget et al., 2008) or the Giant Chaotic Body (offshore Gibraltar, Torelli et al., 1997) are the largest chaotic sedimentary bodies yet observed. These two sedimentary bodies share a specific geodynamic and structural setting, an accretionary prism, which is different from the passive margin structural framework of the West Indian Margin where we observe the Nataraja Slide (e.g. Naini and Talwani, 1982).

##### 4.2. Genetic factors of the Nataraja Slide

At the margin scale, the stratigraphic and structural setting of the proximal source area allows us to propose a spatial association of the headwall and the compressional front below the slope of the margin (Fig. 5C). This configuration, which is found along many passive margins, accretionary prisms and transform margins, is a source of many slides and of mass wasting genesis (e.g., Morley, 2009; Morley et al., 2011). At the scale of the slide the kinematic evidence for a single event associated with this slide is related to the geometry of the compressional/extensional features from its body to its toe. The absence of multiple stacked compressional features in this slide (Figs. 2B, 2C and 3B) argue for a single mass movement. A basal shear surface is only identified at the bottom of the mass transport complex (Fig. 2B). The potential period of emplacement of the Nataraja Slide is coincident with major changes in southern Asia (Clift, 2006). One factor is the climatic evolution and change in sedimentary production and sedimentation around the continental margins of South and SE Asia at that time. During the early Paleogene the margin recorded carbonate platform growth followed by a stress shift expressed by focal clastic sedimentary loading (Whiting et al., 1994) that has played an important role on building sequences of sedimentary gravitational sliding. This is observed on other margins around the Indian Ocean such as the Krishna–Godavari Basin (Rao, 2001) and Rovuma Basin (Mahanjan and Franke, 2014). The Middle to Early Miocene was a time of rapid sediment delivery to the continental margins of India, driven by faster erosion caused by a heavy summer monsoon. Development of a major clastic wedge may have resulted in gravitational instability that resulted in collapse ~10.8 Ma.



**Fig.6.** Height of fall to horizontal run out ratio of the slide as a function of the volume of the mass wasting deposits. The colored envelopes are from De Blasio et al. (2006, see with in for compiled data). Individual slides are from Haflidason et al. (2004) for the Storegga slide off Norway and from various slides in the global ocean (Hampton et al., 1996). Giant slides are depicted by triangles or colored diamonds for volumes  $>10^3 \text{ km}^3$  (see Table 1 for references). Curves from Edgers and Karlsrud (1982), the upper bound values for submarine landslides and subaerial quick clay slides are plotted for reference. (For interpretation of the reference to color in this figure legend, the reader is referred to the web version of this article.)

#### 4.3. Perspectives

Regionally, the Nataraja Slide, if associated with a single catastrophic event, could have left its mark on the coastal record of the Arabian Sea in the form of tsunamiogenic deposits, although the  $>10.8 \text{ Ma}$  age of the deposit may make preservation an issue when searching for equivalent sediments on shore. The structural analysis of dense gravity data on the slide should allow determination of the kinematics of this slide and the potential mechanisms of its emplacement (catastrophic or creeping). The long run out and the relationship with these amounts in the Laxmi Basin however could argue from catastrophic emplacement. Specific characterization of these sediments associated with the slide is needed to infer any role played by base level variation, hydrated dissociation, local tectonics or even basin fluid migration in relation with hydrocarbon generation. Coming after a time of rapid margin sedimentation may argue in favor of gravitational instability as the underlying cause.

In the Arabian Sea the present day risk of coastal tsunamis is analyzed assuming a source of mass movements from the Makran accretionary prism, or even the Andaman to Java arc in the case of far field sources (e.g. Heidarzadeh et al., 2008; Okal and Synolakis, 2008). This approach is associated with the limited occurrence of earthquakes along the western continental margin (Chandra, 1977), because these are common causes of tsunamis in the Indian Ocean region. Yet no risk assessment is discussed in these studies with a source of mass movements and water column displacements related to the West Indian Continental margin. Our description of the Nataraja Slide highlights this region as a potential source of mass movements in the Western Indian Ocean and should guide future research on this margin. Given the large sediment mass that has been built along the western continental margin during the Pliocene–Pleistocene phase of rapid sediment delivery the potential for further major mass wasting events may well exist. This new information about a large Late Miocene event is central to refining our assessment of tsunami hazard along the densely populated western coast of India. Convex upward areas along the margin are more likely to slip, this is skis underlined by the depth and slope of the décollement observed below the Saurashtra shelf that is deeper than it formed originally.

#### 5. Conclusions

This paper reports the discovery and first description and quantification of the giant Nataraja Slide offshore Mumbai, the second largest landslides of its kind discovered along any passive margin worldwide. The landslide covers around  $5 \times 10^4 \text{ km}^2$  and comprises some  $2 \times 10^4 \text{ km}^3$  sediment. It is late Miocene in age. The Nataraja Slide's role in



forming a topographical high for the eastern border of the Indus Fan can be questioned. In both active and passive margins we should consider that mass wasting has importance alongside carbonate accumulation and fluvial input in shaping these seafloor of sedimentary basins. The Nataraja Slide will require further studies to fully understand its structure and spatial organization, which may be achieved in part with future work on the cores recovered by IODP Expedition 355.

## 6. Author contributions

G.C. has framed the study of the Nataraja Slide, and all authors have contributed to the main ideas described in this manuscript and to its writing.

## Acknowledgements

The authors would like to thank ION Geoventures<sup>®</sup> for allowing the use of the Indian Span<sup>®</sup> seismic survey and publication of this work. We are also grateful to IHS<sup>®</sup> for use of Kingdom software and Midland Valley<sup>®</sup> for use of Move. We would like to thank

D.J.W. Piper for review of an earlier version of the manuscript and insightful comments. The editor Peter Shearer and reviewers Joe Cartwright and Michael Strasser and an anonymous reviewer are thanked for their constructive comments.

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