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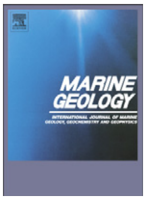

Frequency and timing of landslide-triggered turbidity currents within the Agadir Basin, offshore NW Africa: Are there associations with climate change, sea level change and slope sedimentation rates?

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A B S T R A C T

Older sequence stratigraphic models suggested that submarine landslide and turbidite activities are greatest during sea-level lowstands. However, growing evidence indicates that many turbidite systems are also active during sea-level transgressions and highstands. The Moroccan Turbidite System comprises three depocentres, of which Agadir Basin is closest to the Moroccan slope and Canary archipelago. The very large volumes of sediment transported by individual sediment flows in this system suggest that they are triggered by landslides. Extensive core coverage and dating control for the Agadir Basin deposits have provided an excellent opportunity to derive accurate records of turbidite (and associated landslide) frequency for the last 600 ka. Previous studies in the more distal Madeira Abyssal Plain depocentre have indicated that large volume (>50 km^3) turbidites occurred at oxygen isotope stage (OIS) boundaries. This study of Agadir Basin confirms that two major turbidites (beds A5 and A12) occurred during glacial–interglacial transitions associated with OIS4 and OIS6. However, this association is based on just two examples, and two other large-volume turbidites (beds A7 and A11), did not occur at a stage boundary. The main conclusion of this study is that 90% of turbidites and landslides occurred during rising and high sea level, which represents 40% of the total time during the last 600 ka. Only 10% of the turbidites and landslides occurred during glacials (40% of the time), with a paucity of turbidites and landslides at peak glacial lowstands. A comparison to sediment accumulation rates in the source area of the turbidite suggests that landslides did not occur preferentially during periods of more rapid sedimentation rate, although sedimentation rates in this area only varied from 4 to 6 g cm^{-2} ka^{-1}.

1. Introduction

Submarine landslides and associated tsunamis are significant geohazards to local and far-field populations and infrastructure (Lee et al., 2003; Masson et al., 2006; Watts, 2003). Understanding recurrence intervals of such events, through dating the landslide deposits, is important for geohazard assessments. However, dating of proximal landslide deposits is often hindered by erosion of hemipelagic sediments and associated amalgamation of multiple landslide deposits (Watts and Masson, 1995).

Disintegrative submarine landslides can generate long run-out sediment gravity flows, such as turbidity currents. The distal deposits of these turbidity currents can contribute to more accurate assessments of recurrence intervals than studies of the proximal landslide deposit (Weaver, 2003; Gracia et al., 2010; Masson et al., 2011). Landslide-generated sediment gravity flows are capable of spreading over submarine fans and abyssal plains (Piper and Normark, 1982; Weaver et al., 1992; Wynn et al., 2002; Skene and Piper, 2003, 2006; Talling et al., 2007; Hunt et al., 2011), which are often low-energy and non-erosive environments (Weaver and Thomson, 1993; Weaver, 1994). Consequently, hemipelagic/pelagic sediment is usually deposited and preserved between flow events, allowing relatively accurate dating of the turbidites (Weaver and Kuijpers, 1983; Weaver et al., 1992).

Older sequence stratigraphic models, often based on study of outcrop or subsurface systems, suggest that submarine landslides and development of turbidite fans occur predominantly during lowstands and rapid regressions of sea-level (Mitchum et al., 1977a,b; Vail et al., 1977; Vail and Todd, 1981; Shanmugam and Moiola, 1982; Mitchum, 1985; Vail, 1987; Kolla and Macurda, 1988; Posamentier and Vail, 1988; Posamentier et al., 1988; Kolla, 1993; Kolla and Perlmutter, 1993). Furthermore, investigations of Late Quaternary submarine landslides in parts of the Atlantic Ocean have reported that landslide activity is more prevalent during glacial sea-level lowstands (Piper et al., 2003; Hutton and Syvitski, 2004; Lee, 2009). These models further suggest that turbidite activity is reduced during highstand conditions.

However, growing evidence suggests that there is also significant submarine turbidity current activity during sea-level transgressions and highstands, associated with interglacial periods. Although not all of these turbidites are triggered by landslides, examples of highstand-

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active turbidite systems include the Bengal, Indus, Amazon, Mississippi, Nile, and La Jolla fans (Flood et al., 1991; Kolla and Perlmutter, 1993; Weber et al., 1997; Prins and Postma, 2000; Carvajal and Steel, 2006; Covault et al., 2007; Ducassou et al., 2009; Covault and Graham, 2010). The timing of maximum turbidity current activity appears to be variable in different locations worldwide (Covault and Graham, 2010). Although, this variability may stem from sources other than landslides, such as river floods or storms, from differing glacial processes, or from tectonism (Prior et al., 1989; Paull et al., 1996). Examination of submarine landslide and turbidity current activity in a given area enables better geohazard assessments of recurrence intervals and preconditioning factors. These studies will also improve sequence stratigraphic models used in hydrocarbon exploration.

The present study focuses on the modern deepwater mixed siliciclastic–volcaniclastic Agadir Basin of the Moroccan Turbidite System (MTS), on the Northwest African passive continental margin (Fig. 1) (Wynn et al., 2000a, 2002). The volumes involved in the turbidites mapped across this system ($\gg 1$ km^3) imply that they have been sourced by landslides (Talling et al., 2007), and not by other processes such as river floods or storms.

Previous studies on turbidites in the Moroccan Turbidite System have focused on the Madeira Abyssal Plain (Weaver et al., 1992; Wynn et al., 2002). However, the 'background' hemipelagic sedimentation rate in the Madeira Abyssal Plain is slow (~0.5 cm/1000 years), which hinders accurate dating of turbidites (Weaver and Kuijpers, 1983). In addition, this distal depocentre only records the largest flows that run out for almost 1500 km (Weaver et al., 1992; Wynn et al., 2002; Talling et al., 2007). Farther east, Agadir Basin is the depocentre most proximal to Agadir Canyon (Fig. 1), which is the main source for siliciclastic flows in the Moroccan Turbidite System (Wynn et al., 2002; Talling et al., 2007; Frenz et al., 2009; Sumner et al., 2012). The more proximal location of Agadir Basin means that it contains a record of smaller-volume flows unable to reach the Madeira Abyssal Plain. This provides a more complete record of Late Quaternary landslide activity from the Moroccan slope, although it will not include small flows restricted to the continental slope or upper Agadir Canyon. Furthermore, the hemipelagic sedimentation rate in Agadir Basin is higher than on the Madeira Abyssal Plain, at 1.2–1.8 cm/1000 years, which provides greater temporal resolution when dating individual turbidites.

The first aim of this study is confirm the stratigraphy of Agadir Basin during the last 160 ka and extend it to 600 ka. In many alternative deep marine locations the hemipelagite and turbidite mud cannot be distinguished from one another, which precludes accurate dating. The sediments recovered from Agadir Basin enable clear distinction between the sediment types, and through oxygen-isotope profiles, biostratigraphy and chemostratigraphy can be dated accurately. The second aim is to analyse the timing and frequency of siliciclastic turbidites from the Moroccan slope. This will provide an understanding of controls on their recurrence rate and potential magnitude. This in turn, will also demonstrate if there is an association between sea level (or rates of change in that level) and the frequency of turbidites and their associated submarine landslides.

2. Geological setting and previous work

Agadir Basin is located off the Atlantic Moroccan continental margin (Fig. 1) (Wynn et al., 2002). Wynn et al. (2002) demonstrated that the turbidite stratigraphy of Agadir Basin, Seine Abyssal Plain and Madeira Abyssal Plain can be correlated. Subsequent work has proposed a layer-cake stratigraphy of siliciclastic and volcaniclastic beds for the last 160 ka in Agadir Basin (Frenz et al., 2009).

Hemipelagite compositional variation between glacials and interglacials is present and has been used to more robustly date the correlate

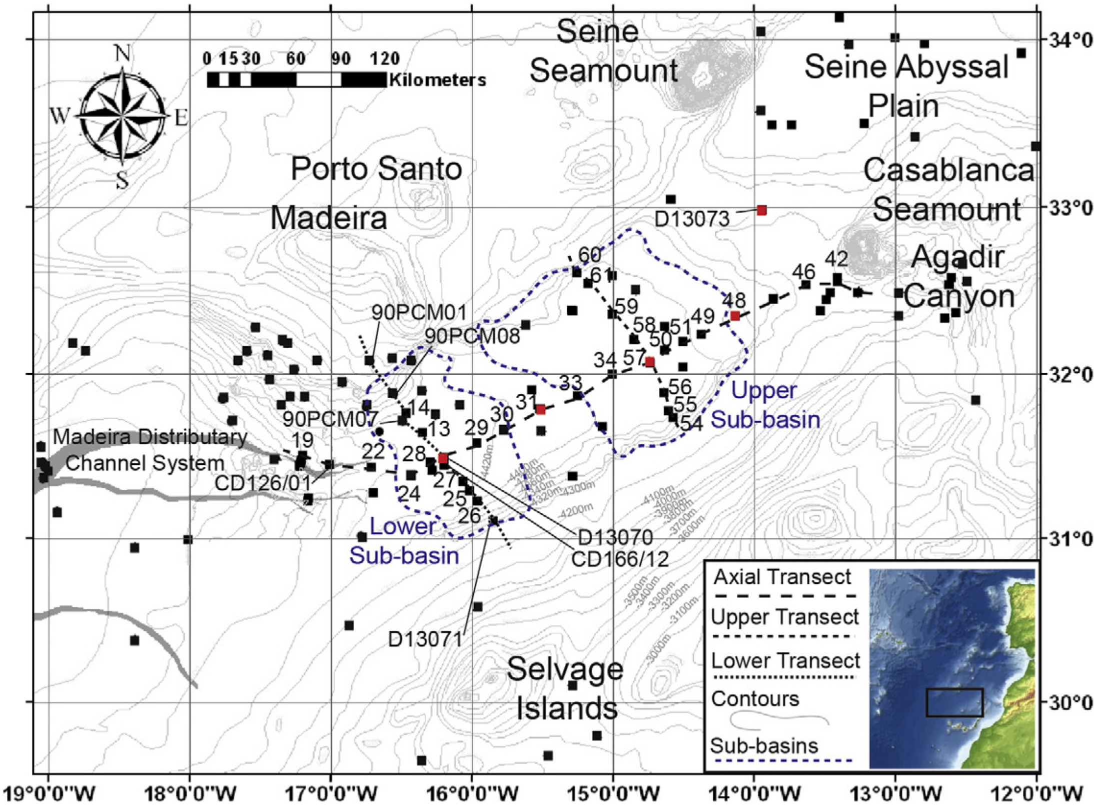

Fig. 1. Contour map of Agadir Basin located seaward of Agadir Canyon on the Northwest African passive margin. The map shows the core coverage available and the location of correlation panel transects. Contours generated from GEBCO bathymetry at 100 m intervals to 4000 m and then at 20 m intervals at >4000 m. Black squares denote piston cores in the study area, where the numbered cores represent cores shown in this study, and red squares denotes cores shown in this study for development of the stratigraphy. Axial transect shown in Fig. 6, upper transection in Fig. 7 and lower transection in Fig. 8.