Earth and Planetary Science Letters 420 (2015) 102–115

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Implications of reduced turbidity current and landslide activity for the Initial Eocene Thermal Maximum – evidence from two distal, deep-water sites

Michael A. Clare [*], Peter J. Talling, James E. Hunt

National Oceanography Centre, Southampton, European Way, Southampton, SO14 3ZH, UK

ARTICLE INFO

Article history:
Received 8 May 2014
Received in revised form 8 March 2015
Accepted 9 March 2015
Available online 3 April 2015
Editor: J. Lynch-Stieglitz

Keywords:
IETM
PETM
submarine landslide
gas hydrate
geohazard
global warming

ABSTRACT

Previous studies propose that submarine landslides and turbidity currents may become more likely due to future rapid global warming. Determining whether global warming increases likelihood assists in assessment of landslide-triggered tsunami hazards and risk to seafloor structures. Other studies propose that landslides helped to trigger past rapid climate change due to sudden release of gas hydrates. Two deep-water turbidite records show prolonged hiatuses in turbidity current activity during the Initial Eocene Thermal Maximum (IETM) at ∼55 Ma. The IETM represents a possible proxy for future anthropogenically-induced climate change. It is likely that our records mainly represent large and fast moving disintegrative submarine landslides. Statistical analysis of long term (>2.3 Myr) records shows that turbidity current frequency significantly decreased after the IETM. Our results indicate that rapid climate change does not necessarily cause increased turbidity current activity, and do not provide evidence for landslides as a primary trigger for the IETM.

1. Introduction

A period of unusually rapid global warming occurred at ∼55 Ma (McInerney and Wing, 2011), termed the Initial Eocene Thermal Maximum (IETM). This hyperthermal represents the warmest period on Earth during the Cenozoic (Schmitz et al., 2001), featuring, at its peak, a dramatic 6–8 °C warming of global deep waters over a period of approximately 10 kyr (Kennett and Stott, 1991). The IETM is marked globally by a negative carbon isotopic ratio (δ^{13}C) excursion, which has been linked to methane emissions due to dissociation of gas hydrate in marine sediment. Other causal mechanisms have been invoked (Dunkley-Jones et al., 2010), but emissions of methane from marine hydrates are one of the most widely held explanations for IETM (Dickens et al., 1995; Katz et al., 1999, 2001). The IETM has been used as a proxy for present-day anthropogenically-induced global warming (Agnini at al., 2007; Dunkley-Jones et al., 2010).

Understanding changes in the frequency of landslides and turbidity currents in response to the IETM may help predict future changes in landslide and turbidity current frequency as climate warms. It has been proposed that rapid global warming will lead to significant increases in landslide and turbidity current frequency, due to gas hydrate dissociation in response to elevated ocean temperatures (Maslin et al., 1998; Nisbet and Piper, 1998; Owen et al., 2007; Lee, 2009; Maslin et al., 2010). Dissociation of gas hydrate can weaken slopes and increase the probability of slope failure (Grozic, 2010).

In addition to climate change causing variations in landslide or turbidity current frequency, it has been proposed that submarine landslides play a role in driving rapid climate change (Kennett et al., 2003; Maslin et al., 2004; Bock et al., 2012). These studies suggest that dissociation of gas hydrate within, or below, the failed slide material, may lead to significant emissions of methane (Katz et al., 1999; Hornbach et al., 2007; Maslin et al., 2010). It was proposed that release of methane (a strong greenhouse gas) from gas hydrate within marine sediment, due to landslides or other processes, was the major control on atmospheric methane abundance (Kennett et al., 2003). The validity of this "clathrate gun hypothesis" is contentious. Methane emissions from wetlands may exceed those from gas hydrates hosted in marine sediments, as suggested by isotopic analysis of methane within ice core records (Sowers, 2006). Here we consider whether our two study locations provide evidence that landslides may have helped to drive climate change through methane emissions. This has not previously been investigated using continuous turbidite records across well dated climatic excursions.

---

[*] Corresponding author. Tel.: +44 (0) 1491 820 869.
E-mail address: mac1y11@soton.ac.uk (M.A. Clare).

http://dx.doi.org/10.1016/j.epsl.2015.03.022

1.1. Turbidites as a record of disintegrative landslides

It is logistically difficult to accurately date a sufficient number of landslides (>100) around a basin margin for robust statistical analysis of recurrence intervals during the IETM. However, we have records of turbidity current frequency across the IETM, which contain distal landslide deposits. The large number (N = 285 to 421) of turbidites in our records enables statistical analysis of recurrence intervals. Turbidity currents can be triggered by a range of processes other than submarine landslides, however, such as storm waves and hyperpycnal river flood discharge (Normark and Piper, 1991; Piper and Normark, 2009; Talling et al., 2013). It is therefore important to assess the level of certainty that these turbidites are landslide triggered. Turbidity currents with suspended sediment volumes far in excess of the largest river floods are likely to be triggered by submarine landslides (Talling et al., 2007, 2014; Talling, 2014), although other triggers may cause flows that pick up sediment en-route. Individual turbidite beds cannot be mapped over large areas to determine volumes for either of our study areas. Thus, it cannot be shown unequivocally that our turbidites are landslide triggered. It is probable that some landslides occurred, but failed to disintegrate to form long run-out turbidity currents that reached our study areas. Therefore not all landslides are likely to be recorded in the datasets.

However, both datasets are inferred to come from distal basin plain depositional sequences, featuring minimal erosion (Weaver and Thomson, 1993; Whitmarsh et al., 1998; Schmitz et al., 2001). It is thought that landslides trigger many of the turbidites seen in other basin plain sequences, where volumes can be constrained (Elmore et al., 1979; Pilkey, 1988; Talling et al., 2007, 2012; Hunt et al., 2013; Clare et al., 2014) or cables have been damaged by flows (Piper and Savoye, 1993; Piper et al., 1999). It is thus reasonable to infer that a predominant fraction of turbidites within our basin plain sequences were triggered by landslides.

1.2. Geohazards and global sediment flux

Due to their potential volume and speed, submarine landslides can generate destructive tsunamis that cause fatalities, or damage expensive seafloor structures (Tappin et al., 2001; Bondevik et al., 2005). The morphology and extent of a landslide will affect its hazard potential. Deep-seated, fast moving landslides may be more prone to tsunami-genesis and release of gas hydrate, whereas more widespread, thinner failures triggered by seismic shaking may have a reduced influence. Regardless of initial mechanics, if a disintegrative landslide triggers a turbidity current, it may pose a hazard to pipelines and seafloor cable networks (Piper et al., 1999; Bruschi et al., 2006; Carter et al., 2012) that carry over 95% of transoceanic data traffic including the internet and financial services (Carter et al., 2009). Turbidity currents that result from disintegration of submarine landslides, as well as from other triggers, may reach speeds of up to 19 m/s (Piper et al., 1999). Understanding the frequency of submarine landslides and turbidity currents, regardless of trigger, is therefore important for geohazard assessments.

An individual landslide may comprise up to thousands of cubic kilometres of sediment, two orders of magnitude greater than the largest terrestrial landslides (Hühnerbach and Masson, 2004; Haflidason et al., 2005; Korup et al., 2007; Masson et al., 2010). Turbidity currents have also been shown to transport hundreds of cubic kilometres of sediment for several hundreds of kilometres (Talling et al., 2012). Submarine landslides and turbidity currents are therefore major contributors to global sediment flux.

1.3. Previous work

Of the previous studies that have attempted to quantify turbidity current recurrence frequency (e.g. Droxler and Schlager, 1985; Weaver et al., 1992; Beattie and Dade, 1996; Goldfinger et al., 2003; Romans et al., 2009; Atwater and Griggs, 2012), only a handful consider large numbers of events (N > 100) over long (>1 Myr) timescales (e.g. Weaver et al., 1986; Clare et al., 2014; Hunt et al., 2014). Submarine landslide frequency studies typically analyse fewer than ten events (e.g. Geist and Parsons, 2010). Exceptions exist with up to 68 dated events (e.g. Owen et al., 2007; Urlaub et al., 2013); however, these global databases only extend back in time to a maximum of 180 ka.

Despite this, many studies have drawn conclusions about the influence of variables such as sea level and global temperature variations on landslide recurrence rate (e.g. Owen et al., 2007; Brothers et al., 2013). Conversely, some studies have shown that non-random processes, such as sea level change, may not exert a dominant control on landslide (Geist and Parsons, 2010; Urlaub et al., 2013, 2014) and turbidite recurrence (Beattie and Dade, 1996; Hunt et al., 2013; Clare et al., 2014). To make more meaningful, quantitative inferences on triggering and conditioning factors, there is a need for statistically robust (N > 100) datasets of landslide ages to be acquired in a variety of settings.

2. Aims

Our first aim is to test whether rapid global ocean warming at the IETM (∼ 55 Ma) coincides with an increase in turbidity current activity. This is to determine whether global warming may have promoted slope instability, or vice-versa through dissociation of gas hydrates. We analyse deep-water turbidite records (Fig. 1) from the Zumaia coastal outcrop in NE Spain (2.3 Myr) and from ODP borehole records on the Iberian Margin (5.5 Myr). Here we assume that these turbidity currents were mainly triggered by submarine landslides. The datasets contain sufficient bed quantities for statistical analysis (i.e. N > 100).

Secondly, we aim to determine if recurrence intervals of turbidity currents were significantly different prior to, and after, the IETM interval over a window of ∼1 Myr. This is to assess if the IETM exerted a longer-term influence on turbidity current activity. Here we make no assumption on the nature of turbidity current trigger.

Thirdly, we aim to determine whether our results are consistent with previously published deep-water records across the IETM. We discuss the implications of our work for predicting future submarine landslide and turbidity current activity, and whether landslides may contribute to rapid climate change through gas hydrate dissociation and methane emissions.

3. Study areas

The datasets selected for this study satisfy four main criteria. Firstly, they represent a continuous sedimentary record including the IETM. Second, they feature sufficient (N > 100) turbidites for statistical analysis. Third, hemipelagic mud can be distinguished clearly from turbidite mud. This allows the cumulative thickness of hemipelagic mud to be measured, and used as a proxy for time between dated horizons in the stratigraphy. This method (Clare et al., 2014) allows turbidite recurrence times to be estimated. Fourth, the sections have good age dating.

The first site is a coastal exposure at Itzurun Beach, Zumaia in NE Spain (Fig. 1B). This is one of the most expanded and continuous sections through the IETM worldwide (Canudo and Molina, 1992; Canudo et al., 1995; Schmitz et al., 2001). A robust age and