Earth and Planetary Science Letters 473 (2017) 190–204

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Immediate propagation of deglacial environmental change to deep-marine turbidite systems along the Chile convergent margin

Anne Bernhardt[a,b,*], Wolfgang Schwanghart[b], Dierk Hebbeln[c], Jan-Berend W. Stuut[c,d], Manfred R. Strecker[b]

[a] *Institute of Geological Sciences, Freie Universität Berlin, Germany*
[b] *Institute of Earth and Environmental Science, Potsdam University, Germany*
[c] *MARUM – Center for Marine Environmental Sciences, University of Bremen, Germany*
[d] *NIOZ – Royal Netherlands Institute for Sea Research, Department of Ocean Systems, and Utrecht University, Texel, The Netherlands*

ARTICLE INFO

Article history:
Received 28 July 2016
Received in revised form 11 May 2017
Accepted 14 May 2017
Available online xxxx
Editor: H. Stoll

Keywords:
signal propagation
turbidity currents
Chile
sediment-routing system
connectivity
Last Glacial Maximum

ABSTRACT

Understanding how Earth-surface processes respond to past climatic perturbations is crucial for making informed predictions about future impacts of climate change on sediment fluxes. Sedimentary records provide the archives for inferring these processes, but their interpretation is compromised by our incomplete understanding of how sediment-routing systems respond to millennial-scale climate cycles.

We analyzed seven sediment cores recovered from marine turbidite depositional sites along the Chile continental margin. The sites span a pronounced arid-to-humid gradient with variable relief and related sediment connectivity of terrestrial and marine environments. These sites allowed us to study event-related depositional processes in different climatic and geomorphic settings from the Last Glacial Maximum to the present day. The three sites reveal a steep decline of turbidite deposition during deglaciation. High rates of sea-level rise postdate the decline in turbidite deposition. Comparison with paleoclimate proxies documents that the spatio-temporal sedimentary pattern rather mirrors the deglacial humidity decrease and concomitant warming with no resolvable lag times.

Our results let us infer that declining deglacial humidity decreased fluvial sediment supply. This signal propagated rapidly through the highly connected systems into the marine sink in north-central Chile. In contrast, in south-central Chile, connectivity between the Andean erosional zone and the fluvial transfer zone probably decreased abruptly by sediment trapping in piedmont lakes related to deglaciation, resulting in a sudden decrease of sediment supply to the ocean. Additionally, reduced moisture supply may have contributed to the rapid decline of turbidite deposition. These different causes result in similar depositional patterns in the marine sinks. We conclude that turbiditic strata may constitute reliable recorders of climate change across a wide range of climatic zones and geomorphic conditions. However, the underlying causes for similar signal manifestations in the sinks may differ, ranging from maintained high system connectivity to abrupt connectivity loss.

1. Introduction

In light of global change, understanding how the Earth's surface responds to climate forcing is increasingly important to make informed predictions about future environmental perturbations and their impact on sediment production and transport (Pelletier et al., 2015). As soon as predictions concern changes in the sediment-routing system related to millennial environmental changes, however, extrapolations beyond decadal to centennial measurements from historic records may lack a conceptual basis (Brunsden and Thornes, 1979). Sedimentary records extend historical data sets and potentially reflect past environmental changes, but their interpretation is compromised by our incomplete understanding of how sediment supply (Qs) signals are generated in the initial erosional zone (Armitage et al., 2013; Godard et al., 2013; Braun et al., 2015; Garcin et al., 2017). Moreover, the details of how sediment sources and sinks are dynamically linked by a sediment-routing system that reliably transfers (Covault et al., 2010; Bonneau et al., 2014), buffers (Clift and Giosan, 2014), destroys (Jerolmack and Paola, 2010), modifies, or amplifies environmental signals (Simpson and Castelltort, 2012), are crucial when interpreting sediment archives in the light of past up-

---

[*] Corresponding author.
E-mail address: anne.bernhardt@fu-berlin.de (A. Bernhardt).

http://dx.doi.org/10.1016/j.epsl.2017.05.017

land changes (e.g., Romans et al., 2016; Hoffmann, 2015). This is particularly true for terrigenous sediment accumulations in the ultimate sink, the deep-marine realm, and their value for environmental reconstruction (e.g., Romans and Graham, 2013; Castelltort et al., 2015).

In an ideal setting, environmental signals propagate through the sedimentary system from the erosional zone via a transfer zone to a depositional zone (Schumm, 1981). The transitions between these zones are not strict as they potentially all contribute to sediment production, transfer, and storage (e.g., Bracken et al., 2015). The concept of sediment connectivity describes the sediment transfer from all potential sources to all sinks through different geomorphic compartments and can be used to describe the continuity of sediment transfer in a sediment-routing system (e.g., Bracken et al., 2015). Connectivity is a three-dimensional property (longitudinal, lateral and vertical). Longitudinal connectivity includes upstream-downstream relationships and denotes the ability of a river to transfer or accumulate sediment; lateral connectivity denotes the supply of sediment to the river channel (hillslope-channel, channel-floodplain); and vertical connectivity links surface-subsurface interactions of water, sediment, and nutrients (Brierley et al., 2006). Furthermore, connectivity is subject to changes over time. Systems with a high degree of longitudinal connectivity can rapidly transmit environmental signals (Hoffmann, 2015). Lateral connectivity can act in two ways: coupling between rivers and floodplains can increase the sediment-residence time in the fluvial domain, whereas enhanced hillslope-river coupling can increase sediment transfer to the fluvial system (Heckmann and Schwanghart, 2013). Climate change such as aridification may decrease Qs to the depositional zone (e.g., Syvitski et al., 2003) not only by lowering erosion rates, but also by decreasing inter- and intracompartmental connectivity (e.g., Jain and Tandon, 2010; Bracken et al., 2015). Intermediate sediment storage as a result of low connectivity may occur in alluvial fans, river floodplains, on the shelf and within submarine canyons (e.g., Hinderer, 2012; Allin et al., 2016).

The response time of a sedimentary system to any perturbation is determined by the response times of the associated erosion and transfer zones. The complexities of sediment transfer introduce time lags that may overlap with timescales of forcing signals and obliterate any signal to be recorded in the sink (Jerolmack and Paola, 2010; Coulthard and Van de Wiel, 2013). A classification of systems into ‘reactive’ and ‘buffered’, i.e. the period of the forcing is longer than the response time and vice versa (*sensu* Allen, 2008), may not fully embrace the complexities and potential pitfalls in interpretations of sedimentary records. Long response times of the erosional or transfer zones may result into a delayed or no recording of the forcing in the archive; however, a decrease in connectivity may lead to the same results.

Stratigraphic records in deep-marine sinks are complicated by changes of the shelf-transfer zone due to sea-level variations. However, turbidity currents form one of the volumetrically most important sediment-transport processes on Earth; e.g., a single turbidity current can transport >10 times the annual sediment flux from global fluvial systems (Talling et al., 2007). Turbidity-current frequencies have a wide range of implications as they affect the efficiency of organic carbon burial, and hence the global carbon cycle and related climate change (Galy et al., 2007), and pose severe hazards for important seafloor infrastructure (Carter et al., 2014). Furthermore, submarine fans represent the final sink of terrigenous sediments and are key locations for the quantification of land-to-sea sediment transfer at a global scale. A global comparison of deposition rates on submarine fans has shown that submarine flow activity is highly variable in time and not always directly linked to sea-level changes (Covault and Graham, 2010). During high sea level, inundated continental shelves can accommodate sediment, whereas under low sea-level conditions sediment can bypass the shelf. Thus, sea-level variations can modulate the connectivity between the transfer zone and deep-marine sink (e.g., Toucanne et al., 2012). Currents parallel to the shelf, however, can transport sediment into canyons that incise the shelf break and reduce the residence time of sediment on the shelf during sea-level highstands (e.g., Covault et al., 2007; Bernhardt et al., 2016). Few field studies investigated whether high-frequency climatic changes are reflected in the marine turbidite record (e.g., Toucanne et al., 2008, 2009, 2012; Ducassou et al., 2009; Romans et al., 2009; Covault et al., 2010; Bonneau et al., 2014; Clare et al., 2015). These studies suggest that low-order mountain rivers rapidly transfer sedimentary signals of millennial-scale climate cycles to the deep-marine record, especially if rivers connect to submarine canyons along narrow shelves (Romans et al., 2009; Covault et al., 2010; Bonneau et al., 2014). In contrast, large alluvial river systems draining onto wide shelves tend to buffer external signals (Métivier and Gaudemer, 1999) so that records of deep-marine sinks significantly lag upland erosion (Clift and Giosan, 2014). Whether fluvial routing systems buffer or rapidly react (*sensu* Allen, 2008) to environmental perturbations may also change through time. For example, Western European routing systems had a higher degree of connectivity during deglaciation than today due to lower base level (Toucanne et al., 2012).

Tracing the impact of climatic perturbations on deep-marine archives in regions with well documented climatic changes will improve our understanding of how environmental signals can be deconvolved in these ultimate sinks. In this study, we test how a deglacial humidity decrease propagates into clastic deposits along the Chile continental margin (Fig. 1). In particular, we investigate how the migration of the moisture-laden Southern Hemisphere Westerly Winds (SHWW) (e.g., Denton et al., 1999; Lamy et al., 1999) is reflected in the turbidite record of three sites at 30°S, 32.5°S and 38–40°S with contrasting present-day climates, topographic gradients, and thus different degrees of connectivity between sediment sources and sinks (Fig. 1). Therefore, we analyze deep-sea sediment cores containing turbidite successions from the Last Glacial Maximum (LGM) to the present and compare these to multiple climate proxies to determine lag times in the sediment-system response. With this approach, we tackle the following research questions:

1. How does an onshore decrease in humidity affect clastic sediment export to the deep ocean?
2. At what tempo is the climatic Qs signal generated and transferred into the marine realm?
3. How do changing boundary conditions, such as onshore climate and system connectivity, affect signal propagation?

2. Regional setting

2.1. Tectonic setting, geomorphology and study sites

The Chile convergent margin features pronounced climatic and geomorphic gradients and well-documented paleoenvironmental changes, and thus provides an excellent test site for the investigation of climate-signal propagation to the ocean over the last glacial–interglacial cycle. We chose three sites offshore the presently arid (30°S, Site A), semiarid (32.5°S, Site SA), and humid (38–40°S, Site H) sectors of the Chile margin that represent a north-south decrease in average onshore topographic gradient and increase in shelf width (Figs. 1, 2). As turbidite records can be subject to authigenic processes (e.g., Wang et al., 2011), or render incomplete records due to bypass and erosion, we compiled the records of several cores at sites A and H to minimize the ef-