Sedimentary Geology 323 (2015) 148–166

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Sea-level control on turbidite activity in the Rhone canyon and the upper fan during the Last Glacial Maximum and Early deglacial

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ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form 15 April 2015
Accepted 16 April 2015
Available online 26 April 2015

Editor: B. Jones

Keywords:
Rhone Turbidite System
Turbidites
Hyperpycnite
Sea level
Last Glacial Maximum
Western Mediterranean

ABSTRACT

The timing, routing, and processes of sediment transfer from the continents to the oceans at millennial time-scale are still largely unknown. The potential of turbidite systems (dominantly deposited during sea-level lowstands) to record global or regional environmental fluctuations is usually under-exploited because of the difficulty to obtain robust chronostratigraphic constraints in turbiditic deposits, and therefore to tie changes in sedimentary processes to environmental fluctuations. We were able to obtain a millennial-scale chronostratigraphy based on oxygen isotopes of the scarce foraminifera preserved in turbiditic deposits of the Rhone Turbidite System within the Western Mediterranean. Our results show that 1) objective criteria can be defined for the selection of foraminifera preserved within the pelagic intervals between the turbiditic sequences, in order to obtain a reliable isotope stratigraphy; 2) turbidites triggered by hyperpycnal currents are described for the first time within the Rhone Turbidite System. They are related to the periods of direct fluvial connection with the canyon head (during the sea-level lowstand and early rise), and to a period of high sediment flux in relation to the massive recession of the Rhone glaciers in the Alps; 3) the lithofacies change passing from hyperpycnal to "Bouma-type" is dated at ca 19 cal. ka BP, which might correspond to an acceleration of sea-level rise (19-ka Meltwater Pulse).

1. Introduction

It is commonly accepted that most of the detrital sediments are transferred to the deep-sea during sea-level lowstands, accumulating along the continental slope and rise as gravity deposits, especially in the form of turbidites (Posamentier and Vail, 1988). However, the precise timing, as well as the processes that control these transfers, are still largely unknown or constitute matter for debate (Castelltort and Van Den Driessche, 2003; Allen, 2008; Covault and Graham, 2010). The influence of climate and environmental changes on the nature of turbidites has been recognized (Bouma, 2001), but in return, these deposits are considered unusable for paleoceanographic and paleoclimatic reconstructions because they are, by definition, made of reworked material. Some studies, however, have shown that the hemipelagic sediments interbedded within turbiditic series can provide valuable and very expanded archives of past climate changes (Nakajima and Itaki, 2007; Toucanne et al., 2008; Lebreiro et al., 2009; Bourget et al., 2010; Henrich et al., 2010; Pierau et al., 2010; Jorry et al., 2011; Pouderoux et al., 2012; Bonneau et al., 2014). The quality of the results relies on the capacity to distinguish hemipelagic from turbiditic beds, and on the presence of a pelagic component (commonly biogenic carbonates) to obtain chronostratigraphic constraints based on radiocarbon dating, oxygen isotopes, or microfaunal assemblages.

In this paper, we establish a precise chrono-stratigraphic framework of the Rhone Turbidite System, western Mediterranean Sea, during the Last Glacial Maximum (LGM) and Early Deglacial. This enables us 1) to quantify fluctuations in the sediment accumulation rates, 2) to characterize the sedimentary processes that have controlled the fluctuations of turbiditic overbank processes, and 3) to link the functioning of the Rhone Turbidite System to sea-level fluctuations and to climate changes in the Mediterranean area.

2. Study area: general framework and previous work

2.1. The Gulf of Lions continental margin

The Gulf of Lions is a young (23 Myr, Aquitanian) passive margin constituting the north-western part of the Mediterranean Sea (Le Pichon et al., 1971). It comprises a relatively large (50–70 km) continental shelf, with the shelf break being situated at water depths ranging from 120 to 170 m. The continental slope is incised by several canyons, up to 1000 m deep (Berne et al., 1998) (Fig. 1). The source of sediments is dominated by the Rhone River and outlined by the large delta that composes nearly 1/3 of the coast of the Gulf of Lions

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http://dx.doi.org/10.1016/j.sedgeo.2015.04.009
0037-0738/

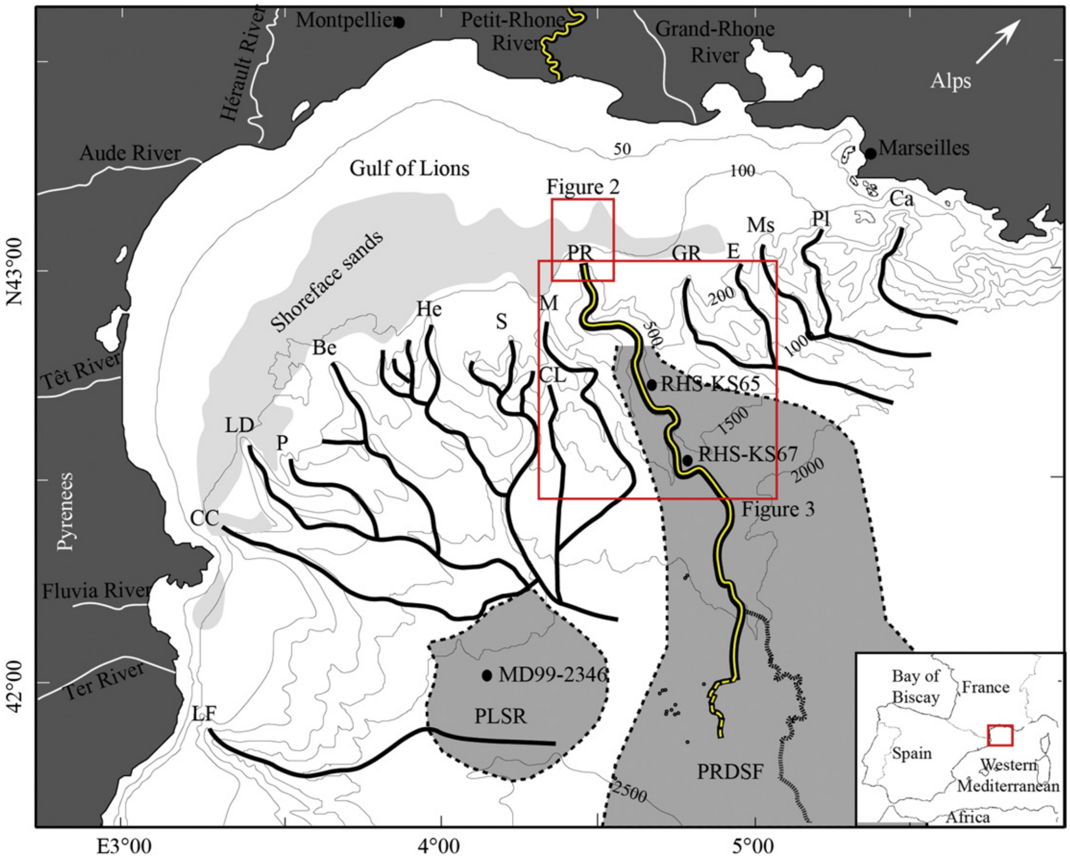

Fig. 1. Map of the Gulf of Lions (Dennielou et al., 2009) with position of the study area and the cores used in this study (Figs. 2, 3). CC: Cap de Creus Canyon; LD: Lacaze-Duthiers Canyon; LF: La Fonera Canyon; P: Pruvot Canyon; Bo: Bourcart Canyon; He: Hérault Canyon; Se: Sète Canyon; Ma: Marti Canyon; PR: Petit-Rhone Canyon; GR: Grand-Rhone Canyon; Ms: Marseille Canyon; Pl: Planier Canyon; Ca: Cassidaigne Canyon; PLSR: Pyreneo-Languedocian Sedimentary Ridge; RTS: Rhone Turbidite System. Light grey on the shelf indicates location of shoreface sands after Aloïsi (1986) and modified by Berné et al. (2007). Medium grey with dashed rim indicates the location of the Rhone Turbidite System and of the Pyreneo-Languedocian Sedimentary Ridge. Yellow line indicates the Rhone River, the Petit-Rhone Canyon and the turbiditic channel. Black circles indicate sediment cores.

(L'homer et al., 1981; Vella et al., 2005). In addition, the general anti-clockwise circulation in the Gulf of Lions has contributed to the westwards development of an elongated mud belt on the mid-shelf (Berné et al., 2007; Fanget et al., 2013). Along the shelf edge, modern hydrodynamic processes are dominated by wind-driven circulation (Ulses et al., 2008) and dense water cascades (Canals et al., 2006) that rework relict sand bodies at the shelf edge and contribute to the export of sediment through the canyon and onto the base of slope (Bassetti et al., 2006; Canals et al., 2006; Gaudin et al., 2006a; Palanques et al., 2006; Dennielou et al., 2009).

At the base of slope, two large sedimentary bodies, the Rhone Turbidite System and the Pyreneo-Languedocian Sedimentary Ridge have dominantly developed during the Plio-Quaternary high-frequency glacio-eustatic fluctuations (dos Reis et al., 2005; Droz et al., 2006). They belong to the Lowstand Systems Tracts of fourth-order glacio-eustatic cycles in the early “Exxon” model of sequence stratigraphy (Posamentier and Vail, 1988).

2.2. Morphology and structure of the Rhone Turbidite System

The Rhone Turbidite System is the largest sediment body in the western Mediterranean. It is a thick (3600 m) accumulation of sediments from the base of the slope down to the Balearic Abyssal Plain at water depths up to 2850 m. The early development of the Rhone Turbidite System, during the Pliocene (Droz et al., 1991; dos Reis et al., 2005), identified as the Rhone Basal Complex (Droz et al., 2006) followed the re-flooding of the Mediterranean after the Messinian Salinity Crisis (Clauzon, 1973; Hsü et al., 1973; Lofi et al., 2003; Bache et al., 2012). In the distal domain, the radial channel network connects the Rhone Turbidite System to the Petit-Rhone Canyon (Jegou, 2008). This morphology characterizes dominantly muddy sediment sources, as is the case for the Amazon fan (Flood et al., 1991; Pirmez and Flood, 1995), the Bengal Fan (Curray et al., 2002), and the Indus fan (Kolla and Coumes, 1987).

Our study is focused on the canyon and upper fan initially described by Droz (1983). This will be illustrated through recent bathymetric data (Figs. 2, 3) acquired during the RHOSOS (RHOne SOurce to Sink) cruise (2008).

The Petit-Rhone Canyon is, at mid-slope, about 12.6 km wide and 500 m deep. In its upper part (between 500 and 1350 water depths) the canyon has a U-shape with a stepped structure and well-developed internal terraces (Droz, 1983; Dennielou et al., 2009). Similar well-developed terraces have been already described in canyons feeding turbidite systems like the Cap Breton canyon (Cirac et al., 2001), the Cap Timiris Canyon (Antobreh and Krastel, 2006), and the Zaire/Congo canyon (Babonneau et al., 2002). Sedimentary records on the terraces are interpreted as dominantly aggradational and therefore indicate a sedimentary environment favourable for the record of past turbiditic activity (Babonneau et al., 2004; Gaudin et al., 2006b). As in other canyons of the Gulf of Lions (Baztan et al., 2005), a narrow meandering axial incision is observed in the canyon, but it only starts beyond the 300 m depth contour line (compared to 120 to 200 m for other canyon heads).

The upper fan, between 1 350 m and 2 000 m water depths, displays a perched valley, 12 to 4 km wide and 500 to 200 m deep, that progressively decreases in depth and width in the seaward direction (Droz, 1983; Torres et al., 1997; Fanget, 2009). The valley is cut by an