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Non-linear response of the Golo River system, Corsica, France, to Late Quaternary climatic and sea level variations

Andrea Forzoni [a,*], J.E.A. Storms [a], Tony Reimann [b], Julien Moreau [c,d], Gwenael Jouet [c]

[a] Department of Geoscience and Engineering, Section Applied Geology, Delft University of Technology, The Netherlands
[b] Netherlands Centre for Luminescence Dating, Soil Geography and Landscape Group, Wageningen University, The Netherlands
[c] IFREMER, Brest, France
[d] CEREGE, Aix en Provence, France

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ABSTRACT

Disentangling the impact of climatic and sea level variations on fluvio-deltaic stratigraphy is still an outstanding question in sedimentary geology and geomorphology. We used the Golo River system, Corsica, France, as a natural laboratory to investigate the impact of Late Quaternary climate and sea level oscillations on sediment flux from a catchment and on fluvio-deltaic stratigraphy. We applied a numerical model, PaCMod, which calculates catchment sediment production and transport and compared modeling output to the sedimentary record of the Golo alluvial-coastal plain, whose chronology was reinterpreted using new optical stimulated luminescence (OSL) ages on feldspars. Our modeling, OSL ages, and geomorphological results indicate that the two main phases of braidplain development in the Golo alluvial-coastal plain occurred during the cold–dry phases of MIS5 and during the late MIS4-early MIS3, as a consequence of high catchment erosion rates and low water discharge. Incision and sediment reworking occurred during sea level low stand periods (MIS4 and late MIS3-MIS2). High sediment flux pulses from the catchment outlet were generated during the Lateglacial and early Holocene, as a result of the release of sediments previously stored within the catchment and enhanced snowmelt. Our results suggest a non-linear response of the Golo River system to climatic and eustatic changes, caused by sediment storage within the catchment and geomorphological thresholds. This indicates that a direct comparison between palaeo-climate and stratigraphy is not possible without considering catchment sediment storage and sediment transport delays out of the catchment.

1. Introduction

Fluvial systems are key elements of the geological cycle because of their fundamental role in reshaping the Earth's surface and in transporting water and sediments from continents to the global ocean. Through such reshaping and transporting processes external forcing, such as climate, tectonics, and eustatism, is recorded in landscapes and in basin stratigraphy. During the last decades, hydrologists, geomorphologists and stratigraphers have developed modeling techniques to simulate erosional and fluvial processes at different spatial and temporal scales (Tucker and Slingerland, 1997; Coulthard et al., 2002; Storms and Swift, 2003; Muto and Steel, 2004; Kettner and Syvitski, 2008; Martin et al., 2010; Rohais et al., 2012). Comparing experimental results to observed stratigraphy and geomorphological data they have been able to test their hypothesis and quantify the impact of external forcing on fluvial systems.

In a comprehensive review of Quaternary and modern systems and experimental work Blum et al. (2013) showed how fluvial systems dynamics and stratigraphic architecture are the result of the complex interaction between sediment supply and variations in accommodation space, function of sea level changes, tectonics and fluvial-bathymetric gradients. In particular, they showed that early sequence stratigraphic model for fluvial valleys, considering complete sediment bypass as a result of sea level fall, do not stand up to theoretical, experimental, and field evidence. Instead, periods of incision correspond with sediment export minima, whereas periods of lateral migration and channel belt construction occur with increased sediment flux.

* Corresponding author. Tel.: +31 15 27 86948.
E-mail address: a.forzoni@tudelft.nl (A. Forzoni).

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For example, the Rhine–Meuse fluvial system in the southern Netherlands is an excellent and well-studied system to investigate the impact of climatic and eustatic changes on river systems (Huizink, 1999; Bogaart and van Balen, 2000; Veldkamp and Tebbens, 2001; Bogaart et al., 2003; Busschers et al., 2007; Vandenberghe, 2008; Van Balen et al., 2010). During cold–dry glacial phases, periglacial processes and low vegetation cover led to high erosion rates and, consequently, high sediment supply and accumulation of coarse sediments in braidplains and alluvial fans. Aggradation and lateral channel migration during sea level fall were favored by the lengthening of the river longitudinal profile, which extended through the English Channel towards the Atlantic. At the glacial–interglacial transition, during sea level rise, the Rhine and the Meuse River incised the previously deposited sediments as a result of increased fluvial water discharge, and subsequently evolved to meandering systems filling in their valleys with floodplain deposits during interglacial periods.

Analogue models of fan-deltas in flume tanks have illustrated how different parts of the fluvial systems react differentially and inertially to external forcing (Muto and Swenson, 2005; Kim et al., 2006; Petter and Muto, 2008). For example, Van Heijst and Postma (2001) showed that, in the early stages of sea level fall, aggradation occurred in the upper part of the fluvial system, meanwhile an erosional knickpoint developed from the shelf edge and migrated upstream on the continental shelf. Similarly, numerical models have indicated a non-linear response of fluvial systems to climate forcing. This response is controlled by various thresholds, such as bedrock channel incision or landslide initiation (Tucker and Slingerland, 1997), by buffers, such as large floodplains (Metivier and Gaudemer, 1999), and by delays and autogenic behavior (Coulthard and Van de Wiel, 2007; Allen, 2008; Jerolmack and Paola, 2010). These studies showed that the record of external forcing in landscapes and stratigraphy is generally better preserved in small source-to-sink systems with little sediment storage in their catchments.

Because of its small size, the well constrained coastal and offshore sedimentary archives, and the limited storage area within the catchment, the Golo River system (Corsica, NW Mediterranean) is an excellent laboratory to investigate the transmission of climatic and eustatic sea level fluctuations across a fluvial system. Recent studies on the catchment and alluvial-coastal plain (Sømme et al., 2011; Skyles, 2013; Moreau et al., in prep.), and on the shelf and submarine fans (Deptuck et al., 2008; Gervais et al., 2006a, 2006b; Sømme et al., 2011; Calvès et al., 2012) have given new insights into the architecture and evolution of the Golo River system, illustrating how major modifications in stratigraphy, sediment storage and dispersal occurred as a response to climatic and eustatic sea level changes. The cut-and-fill pattern of the Golo fluvial terraces and the stacking pattern of sedimentary unit on the shelf were interpreted by Sømme et al. (2011) as the result of balance/imbalance between sediment supply and fluvial transport capacity. Still, the link between the timing, the spatial distribution and magnitude of geomorphological changes, and external forcing remains unclear and untested.

The objective of this paper is to reconstruct the sediment flux and fluvial dynamics history of the Golo River system, resulting from changes in external forcing, and to investigate how this history affected the geomorphic and stratigraphic evolution of the Golo catchment and alluvial-coastal plain. We used a numerical model, PaCMod (Forzoni et al., 2013) to simulate catchment evolution, fluvial dynamics, and sediment flux from the Golo catchment. Then we compared modeling results to geomorphological data and new optically stimulated luminescence (OSL) ages from the Golo coastal plain, to unravel how climate-induced fluvial dynamics interacted with sea level variations during the Last Glacial–Interglacial cycle. Finally, we compared our findings on the Golo fluvial system to other field and modeling studies, adding to the ongoing discussion on long-term climatic and eustatic forcing on landscape evolution and sediment flux from catchments.

2. Background

2.1. Geological and geomorphological setting

The Golo River is the major fluvial system of the island of Corsica, France (Fig. 1). The eastern part of the catchment is underlain by Mesozoic oceanic crust and meta-sedimentary rocks, deformed during the late Cretaceous and Cenozoic (Alpine Corsica), while the western part is underlain by Paleozoic granodioritic rocks (Hercynian Corsica). The present day rugged relief of the catchment is a result of the recent phase of regional uplift (Plio-Quaternary), which rejuvenated the Miocene low-relief landscape (Fellin, 2005). In the upland steep-sloped valleys, slope gravitational processes are the main contributor to denudation, and the sediments eroded from hillslopes are deposited in narrow, confined floodplains. Terraced remnants of ancient floodplains occur predominantly in the low relief area close to the Hercynian–Alpine contact, and in the Marana Plain, the alluvial-coastal plain bordering the Tyrrhenian Sea (Sømme et al., 2011) (Fig. 1).

In the Marana Plain, the Golo River accumulated thick conglomeratic wedges during the Pleistocene (Conchon, 1972, 1978) and repeatedly incised into these deposits as a result of long term uplift (Fellin, 2005) and climatic variations of sea level and of sediment supply (Sømme et al., 2011). In the alluvial plain, these coarse braidplain deposits are organized in a cut-and-fill pattern, with the younger units located at progressively lower topographic levels (Fig. 2). The modern floodplain of the Golo River is characterized by gravelly-sandy braided fluvial deposits in the west and by finer grained (sandy–silty) meandering fluvial deposits towards the east. Moreau et al. (in prep.) showed that the modern floodplain has developed inside an incised valley, which becomes wider and deeper seawards (Fig. 2). At the coast, beach ridges extend both in a north- and southward direction from the river mouth. The areas landward of the beach ridges are characterized by swamps and, in northern part of the Marana Plain, the Biguglia lagoon separates the Corsican mainland from a spit system.

A chronology of the alluvial-fluvial deposits, based on OSL, has been proposed by Sømme et al. (2011) and Skyles (2013). These studies indicated that the modern floodplain, Fy3, developed during the Lateglacial–Holocene, filling in an incised valley formed during MIS2, and that the older terraced deposits, Fy2 and Fy1, were accumulated at some time during the last 100 ka. In particular, quartz OSL ages in the Marana Plain (Skyles, 2013) yielded MIS4-early MIS3 ages for Fy2 and a minimal MIS4 age for Fy1. In the methods section we describe new OSL ages from the Marana Plain, and discuss the different OSL age models for the terrace chronology. In the discussion we compare this chronology to geomorphological data and modeling results and discuss the (mis)match between the data.

The offshore part of the Golo source-to-sink system consists of two sedimentary domains: the continental shelf and the slope-basin floor (Calvès et al., 2012) (Fig. 1). Seismic analysis on the external part of the shelf (Deptuck et al., 2008; Sømme et al., 2011) showed different sedimentary wedges stacked during the Last Glacial–Interglacial cycle, characterized by seaward inclined reflectors (clinoforms). Submarine canyons have developed on the external part of the shelf and on the continental slope, and are connected to the basin-floor fans. These deep-marine sedimentary bodies, accumulating in the tectonically subsiding Corsica Trough, are the final sink for the Golo River source-to-sink system, for other smaller river systems on the northeastern margin of Corsica, and for rivers on the Italian northwestern margin.