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Sedimentary response to Milankovitch-type climatic oscillations and formation of sediment undulations: evidence from a shallow-shelf setting at Gela Basin on the Sicilian continental margin

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ABSTRACT

A multi-proxy chronological framework along with sequence-stratigraphic interpretations unveils composite Milankovitch cyclicity in the sedimentary records of the Last Glacial–Interglacial cycle at NE Gela Basin on the Sicilian continental margin. Chronostratigraphic data (including foraminifera-based eco-biostratigraphy and $\delta^{18}O$ records, tephrochronological markers and ^{14}C AMS radiometric datings) was derived from the shallow-shelf drill sites GeoB14403 (54.6 m recovery) and GeoB14414 (27.5 m), collected with both gravity and drilled MeBo cores in 193 m and 146 m water depth, respectively. The recovered intervals record Marine Isotope Stages and Substages (MIS) from MIS 5 to MIS 1, thus comprising major stratigraphic parts of the progradational deposits that form the last 100-ka depositional sequence. Calibration of shelf sedimentary units with borehole stratigraphies indicates the impact of higher-frequency (20-ka) sea level cycles punctuating this 100-ka cycle. This becomes most evident in the alternation of thick interstadial highstand (HST) wedges and thinner glacial forced-regression (FSST) units mirroring seaward shifts in coastal progradation. Albeit their relatively short-lived depositional phase, these subordinate HST units form the bulk of the 100-ka depositional sequence. Two mechanisms are proposed that likely account for enhanced sediment accumulation ratios (SAR) of up to 200 cm/ka during these intervals: (1) intensified activity of deep and intermediate Levantine Intermediate Water (LIW) associated to the drowning of Mediterranean shelves, and (2) amplified sediment flux along the flooded shelf in response to hyperpycnal plumes that generate through extreme precipitation events during overall arid conditions. Equally, the latter mechanism is thought to be at the origin of undulated features resolved in the acoustic records of MIS 5 Interstadials, which bear a striking resemblance to modern equivalents forming on late-Holocene prodeltas of other Mediterranean shallow-shelf settings.

1. Introduction

It is widely accepted that the high-frequency patterns of climate change and sea level fluctuations are controlled by modulations in solar radiation, which in turn are ultimately linked to orbital cyclicity (Milankovitch, 1930). First detected in marine records through variations in the ocean's isotopic composition (Emiliani, 1955; Shackleton and Opdyke, 1973; Hays et al., 1976), these patterns were subsequently used to reconstruct the astronomically paced SPECMAP curve (e.g., Imbrie et al., 1984; Martinson et al., 1987; Raymo, 1997; Petit et al., 1999; Lourens, 2004). Recognition of orbital cyclicity within shelf depositional units, however, has long been impeded by the difficult task of correlating $\delta^{18}O$-derived deep-sea stratigraphy with the sea level shaped depositional architecture on continental shelves (Ridente et al., 2008). Only the successive popularization of very high resolution subbottom imagery during the past two decades enabled researchers to unravel the control of composite Milankovitch cyclicity upon the internal organisation of depositional (seismic) units. While 40 ka cyclicity predominantly controlled stratigraphic shelf architecture during the Pliocene and Lower Pleistocene (e.g., Carter et al., 1998; Massari et al., 1999; Kitamura et al., 2000), post-800 ka sequence generation

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is led by 100-ka/20-ka eustatic sea level fluctuations (e.g., Clark et al., 2006; further references provided below). As development and preservation of such high-frequency sequences is favoured by high sedimentation and comparable subsidence rates (Mitchum and Van Wagoner, 1991), they are typically recognised at shallow-shelf (mainly prodeltaic) settings on Quaternary continental margins both within and outside the Mediterranean (e.g., Piper and Aksu, 1992; Sydow and Roberts, 1994; Marsset et al., 1996; Rodero et al., 1999; Trincardi and Correggiari, 2000; Hiscott, 2001; Berné et al., 2002; Ridente and Trincardi, 2002; Osterberg, 2006; Ridente et al., 2008, 2009; Liu et al., 2010). Internal architecture of their stratigraphic record is predominantly ascribed to 100-ka glacio-eustatic cycles comprising progradational clinoforms that record deposition during distinct systems tracts (TST: transgressive systems tract; HST: highstand systems tract; FSST: falling-stage systems tract; LST: lowstand systems tract). Lack of clear seismic evidence of inter-unit stratigraphic boundaries, however, often led authors to interpret these successions as a single regressive (FSST) sequence (e.g., Ercilla et al., 1994; Chiocci, 2000; Hübscher and Spieβ, 2005; Liquete et al., 2008). Less frequently, a dominance of 20-ka paced sequences has been reported, manifesting in the presence of a subordinate sequence boundary during Marine Isotope Stage (MIS) 4 (e.g., Osterberg, 2006) and multiple progradational events during MIS 5 (e.g., Hiscott, 2001; Liu et al., 2010) as well as MIS 3 (e.g., Marsset et al., 1996). Only few continental shelf settings (such as the Adriatic Sea and the Gulf of Cádiz) display both orders of Milankovitch cyclicity, the Glacial–Interglacial 100-ka periodicity and the higher-frequency 20-ka periodicity (respectively, Somoza et al., 1997; Ridente et al., 2008).

In this paper we present evidence of full composite Milankovitch cyclicity recorded in thick sedimentary successions from a shallow-shelf muddy setting at Gela Basin on the southern Sicilian continental margin (Fig. 1). Two drill sites, the 54.6-m-long GeoB14403 and the 27.5-m-long GeoB14414 from respective water depths of ~193 m and ~146 m, are strategically located to recover key segments of the progradational units related to the Last Glacial–Interglacial cycle and cover MIS 1 – MIS 5 sedimentary units. Accompanied by high-resolution acoustic subbottom imagery, they provide the chronostratigraphic framework for a physical correlation to shelf deposits in order to decipher the internal stratigraphic signature of composite 20-ka/100-ka cyclicity. Coevally, the erosive unconformity related to the Last Glacial Maximum (LGM) exposes undulation features within MIS 5 units that can be compared to those found in late-Holocene HST prodeltas on other Mediterranean margins (e.g., Cattaneo et al., 2004; Urgeles et al., 2007; Rebesco et al., 2009).

In essence, we exploit a rich dataset comprising drilled sedimentary records and high-resolution acoustic profiles in order to (1) develop a multi-proxy based chronostratigraphic framework

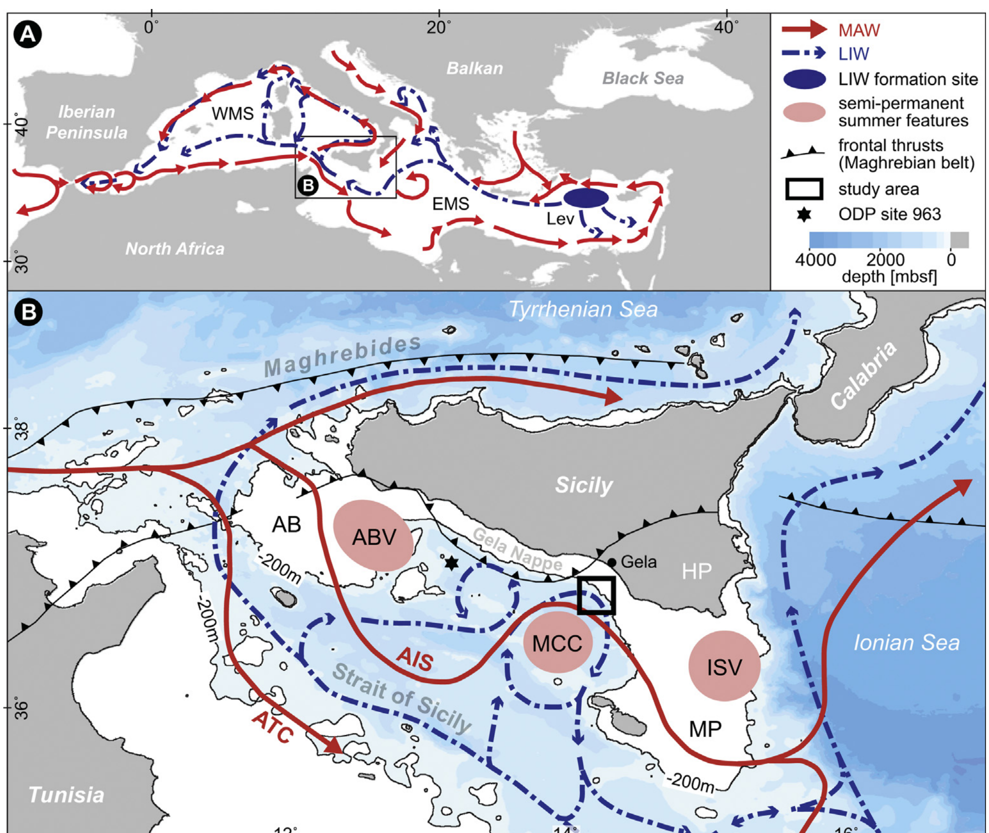

Fig. 1. A) Main pathways of surface (Modified Atlantic Water, MAW) and intermediate (Levantine Intermediate Water, LIW) waters in the Mediterranean Sea showing formation area of the LIW (after Millot, 1999; Hernández-Molina et al., 2006). WMS = Western Mediterranean Sea; EMS = Eastern Mediterranean Sea; Lev = Levantine Sea. B) Scheme of two-layer exchange circulation in the Strait of Sicily (SoS), modified from Lermusiaux and Robinson (2001), Béranger et al. (2004) and Ciappa (2009). Fresh surface waters from the Atlantic Ocean meander along the Tunisian and Sicilian shelf (red arrows, between 0 and 200 m), accompanied by a concurrent subsurface outflow of relatively more saline Mediterranean waters (blue arrows, between 200 and 600 m). Main water masses: MAW = Modified Atlantic Water, LIW = Levantine Intermediate Water; surface water branches: AIS = Atlantic Ionian Stream, ATC = Atlantic Tunisian Current; mesoscale summer features: ABV = Adventure Bank Vortex (cyclonic); MCC = Maltese Channel Crest (anticyclonic); ISV = Ionian Shelfbreak Vortex (cyclonic); AB = Adventure Bank; HP = Hyblean Plateau; MP = Malta Plateau. Main tectonic elements are redrawn according to Jenny et al. (2006). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)