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The submerged paleolandscape of the Maltese Islands: Morphology, evolution and relation to Quaternary environmental change

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A B S T R A C T

After the end of the Last Glacial Maximum, 450 km^2 of former terrestrial and coastal landscape of the Maltese Islands was drowned by the ensuing sea level rise. In this study we use high resolution seafloor data (multibeam echosounder data, seismic reflection profiles, and Remotely Operated Vehicle imagery) and bottom samples to reconstruct ~300 km^2 of this submerged Maltese paleolandscape. The observed paleolandscape is exceptionally well preserved and comprises former coastal landforms – (i) fault-related escarpments, (ii) paleoshore platforms and associated shorelines, (iii) paleoshoreline deposits, and (iv) mass movement deposits – and former terrestrial landforms – (v) river valleys, (vi) alluvial plains, (vii) karstified limestone plateaus, and (viii) sinkholes. These elements indicate that the paleolandscape has been primarily shaped by tectonic activity combined with fluvial, coastal, slope instability and karstic processes; these are the same processes the shaped the current terrestrial and coastal landscape. By correlating the identified landforms with the timing of known changes in sea level during the last glacial cycle, we infer that the alluvial plains and the shallowest limestone plateaus had up to 100 kyr to develop, whereas the paleoshoreline deposits are likely to have formed between 28 kyr and 14 kyr. The most prominent paleoshore platforms, shorelines and river valleys were generated between 60 kyr and 20 kyr. Fluvial erosion is likely to have been prevalent during periods of low sea level (Last Glacial Maximum and stadial conditions during MIS 3), whereas karst processes should have been more effective during warm and humid interstadial periods. Our results have implications for improving the characterization of past environments and climates, as well as providing a much needed background for prehistoric and geoarcheological research in the central Mediterranean region.

1. Introduction

Reconstructions of past sea level changes indicate that for the last 1 Myr, global sea level has predominantly persisted at elevations lower than at present by as much as 130 m (Imbrie et al., 1989; Siddall et al., 2003). This implies that, in the present interglacial, extensive areas of former terrestrial and coastal landscapes are submerged. Recently there has been a growing interest in the study of these submerged paleolandscapes (e.g. Bailey and Flemming, 2008; Pollard, 2011), which has been driven by the significant improvements in seafloor mapping technology made in the last decade. The investigation of submerged paleolandscapes is relevant to numerous stakeholders for a variety of reasons, among which are:

(i) Submerged paleolandscapes constitute archives of long-term paleoenvironmental change, in particular of fluctuations in climate and sea level (e.g. Anzidei et al., 2011).
(ii) Understanding how coastal regions have evolved in response to sea level change in the past can allow us to predict how they will respond to sea level rise associated with future climate change (e.g. Solomon et al., 2007).
(iii) The study of submerged coastlines is instrumental in geoarcheological and paleoethnological investigations because they preserve evidence of early humans and their activities (e.g. Galili et al., 1993; Skaarup and Grøn, 2004).
(iv) Mapping of submerged paleolandscapes indirectly supports international policies, such as the European Union Marine Strategy Framework Directive, which requires member states to carry

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out initial assessments of the environmental status of their shallow coastal waters (e.g. Micallef et al., 2012).

(v) Construction of seafloor infrastructure of strategic national importance requires thorough investigation of the geology of the shallow seafloor and the geohazards associated with it (e.g. Alcatel Submarine Networks, 2003).

The Maltese Islands are located in the central Mediterranean Sea (Fig. 1A). After the end of the Last Glacial Maximum, at least 450 km^2 of the Maltese coastal area, which is equivalent to the size of 150% of the present archipelago's landmass, has been submerged (Lambeck et al., 2011), (Fig. 1B). Very little is known of this submerged paleolandscape due to paucity of hydrographic and marine geo-environmental data. Detailed exploration and investigation of this submerged paleolandscape is fundamental to understanding past regional changes in climate and sea level, and the associated development of coastal landscapes. The Maltese Islands and the surrounding marine environment provide an excellent setting for studying submerged paleolandscapes. The prevalently semi-arid climate (Chetcuti et al., 1992), predominantly carbonate lithologies (Pedley et al., 1976), relative neotectonic stability (Pedley, 2011) and limited terrigenous sediment supply, combined with the generally weak

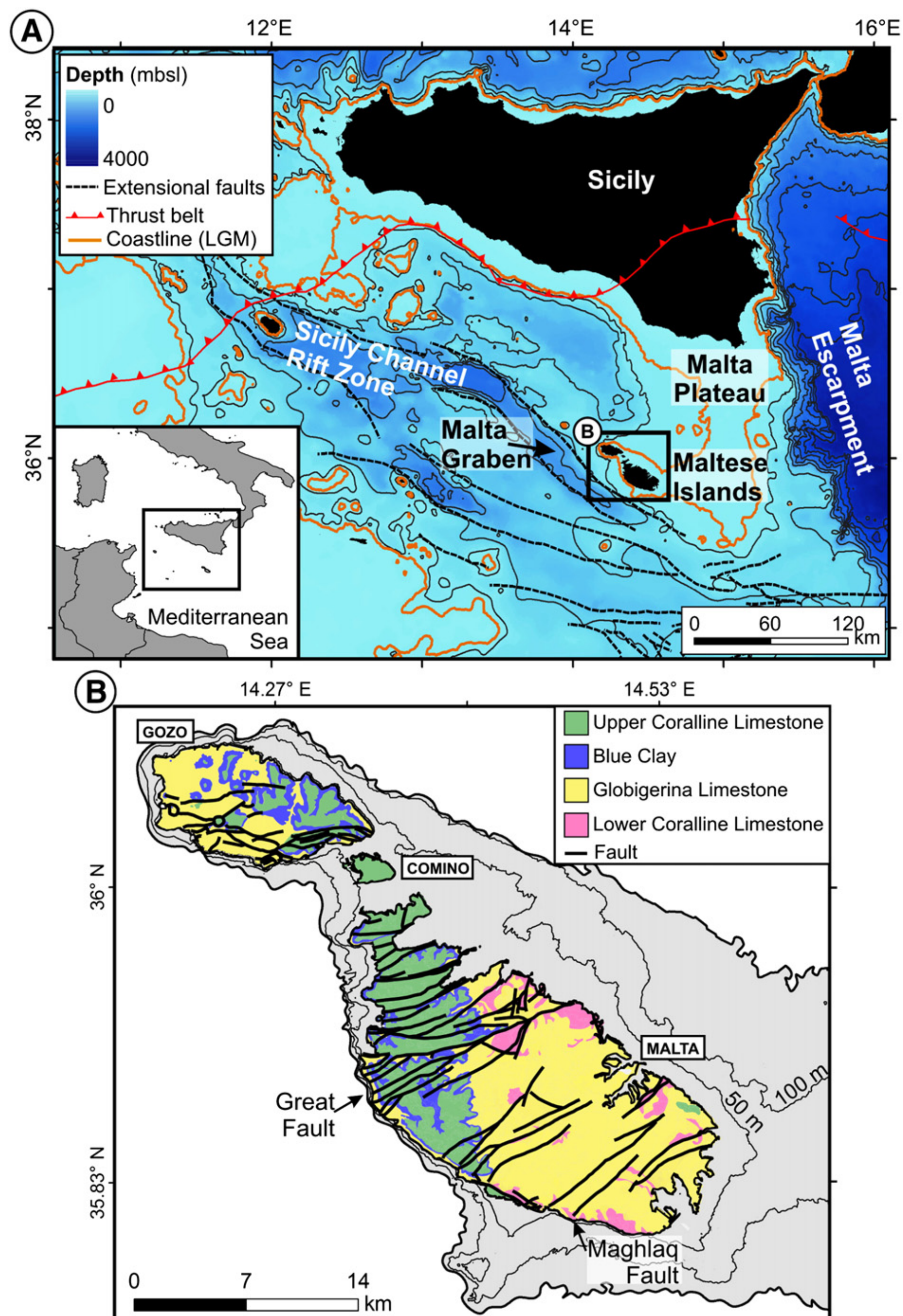

Fig. 1. (A) Bathymetric map of the Pelagian Platform, central Mediterranean Sea, showing the location of the Maltese Islands and the principal morpho-structural features (isobaths at 500 m intervals (Smith and Sandwell, 1997; Catalano et al., 2008). The coastline during the Last Glacial Maximum (LGM) is denoted by a solid orange line. (B) Map of the main terrestrial geological formations and fault systems of the Maltese Islands (Government of Malta, 1993) and an isobath map of the Maltese coastal waters. The area shaded in gray shows the extent of the Maltese Islands during the Last Glacial Maximum (Lambeck et al., 2011). The area in white corresponds to seafloor where no bathymetric data are available.