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The formation of giant clastic extrusions at the end of the Messinian Salinity Crisis

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ABSTRACT

This paper documents the discovery of five multi-km scale lensoid bodies that directly overlie the upper surface of the thick (>1 km) Messinian Evaporite sequence. They were identified through the analysis of 3D seismic data from the western Nile Cone. The convergence of the upper and lower bounding reflections of these lensoid bodies, their external and internal reflection configuration, the positive 'depositional' relief at their upper surface, and the stratal relationship with underlying and overlying deposits supports the interpretation that these are giant clastic extrusions. The interpretations combined with the stratal position of these clastic extrusions demonstrate a prior unsuspected link between periods of major environment change and basin hydrodynamics on a plate scale.

All five lensoid bodies were extruded onto a single, seismically resolvable marker horizon correlatable with the end of the Messinian Salinity Crisis (Horizon M). It is argued that the source of these clastic extrusions is pre-Messinian in origin, which implies massive sediment remobilisation at depth in the pre-evaporitic succession and intrusion through the thick evaporite layer. We propose that the scale and timing of this dramatic event was primed and triggered by near-lithostatic overpressure in the pre-evaporitic sediments generated through (1) their rapid burial and loading during the Messinian Salinity Crisis and (2) catastrophic re-flooding during its immediate aftermath.

The largest of these clastic extrusions has a volume of over c. 116 km^3, making it amongst the largest extruded sedimentary bodies described on Earth. The findings extend the understanding of the upper scale of other analogous clastic extrusions such as mud volcanoes and sediment-hosted hydrothermal systems. Following the 2006 eruption of the Lusi sediment-hosted hydrothermal system in Indonesia, an understanding of the upper scale limit of clastic extrusions has even greater societal relevance, in order to increase awareness of the risk posed by the potential size and longevity of future giant clastic extrusions.

1. Introduction

The remobilisation and eruption of clastics at the seabed or surface during the formation of clastic extrusions including mud volcanoes and sediment-hosted hydrothermal systems is significant for several reasons: (1) they provide a route for methane flux to the atmosphere, (2) their flux can vary as a prior indication or response to earthquakes, (3) they are indicative of major basinal hydrodynamic perturbations, (4) they represent a geological hazard that can have a significant impact on human society if extruded in a populated area (Mazzini and Etiope, 2017; Milkov, 2000). This is demonstrated by the societal impact that the 2006 eruption of the Lusi sediment-hosting hydrothermal system had on the population of the Porong sub district, within the Sidoarjo district in east Java (Rudolph et al., 2011; Davies et al., 2008; Mazzini et al., 2007). Clastic extrusions are widely developed in highly mobile tectonic belts and in some intra-plate settings (see Kopf, 2002). They are particularly prevalent in settings that experience rapid sedimentation, thrust loading, active horizontal tectonic compression or in igneous and hydrothermal systems (Milkov, 2000; Mazzini and Etiope, 2017).

An interesting open question exists as to the upper scale limit of clastic extrusions. Documented estimates for the largest mud volcanoes are variable and range from 12 km^3 to 22.3 km^3 to potentially >100 km^3 (Davies and Stewart, 2005; Kopf et al., 2001; Mazzini and Etiope, 2017). A better understanding of the upper scale limit of clastic extrusions is important to fully explain these natural phenomena.

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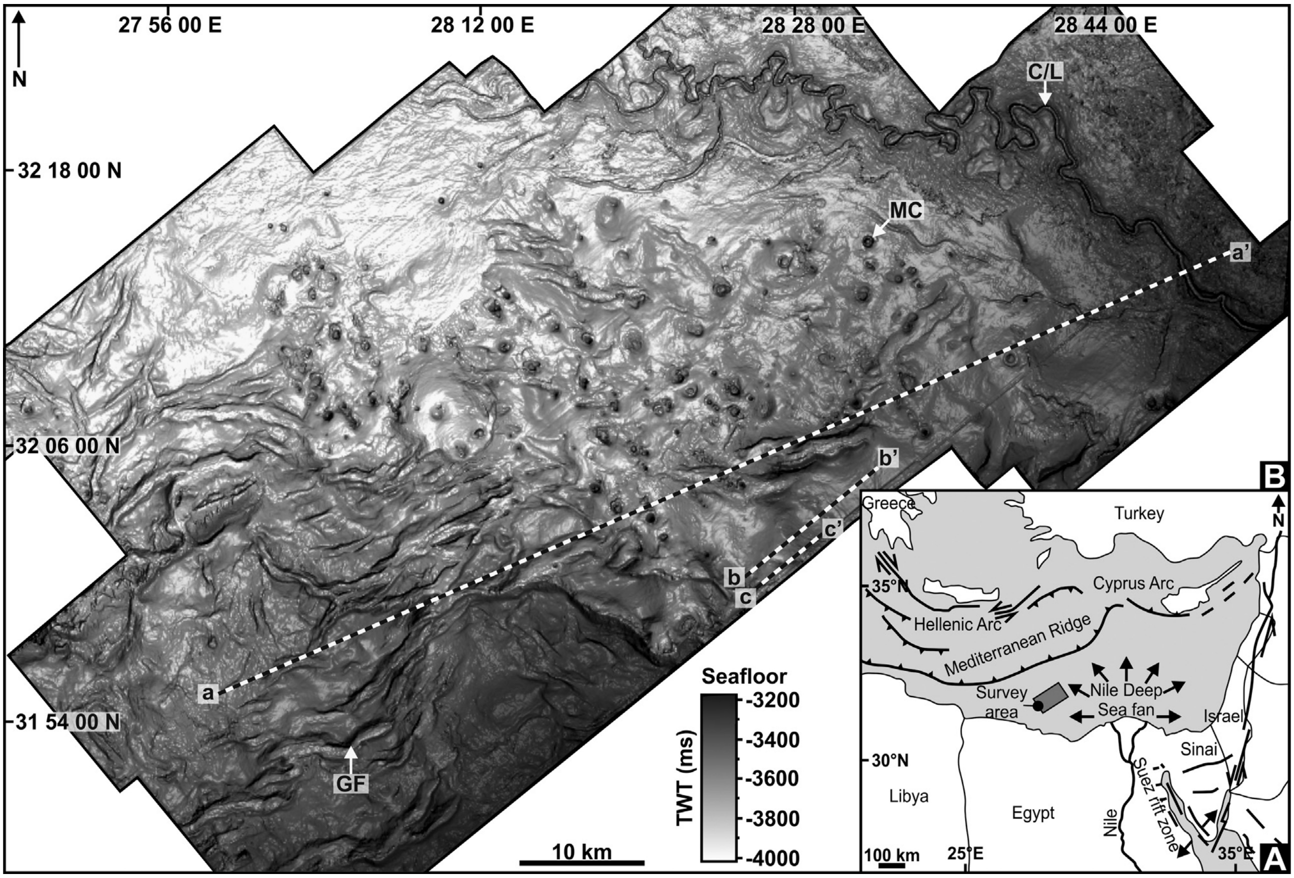

Fig. 1. (A) Map of the Eastern Mediterranean showing the location of the study region within the western Nile Cone. The location of the 3D seismic survey is highlighted, offshore Egypt. (B) Seafloor map within this seismic study area. Prominent geomorphological features include a large number of circular mud cones (MC) primarily distributed within the central region of the study area, numerous growth faults (GF) to the southwest and a channel/levee system (C/L) to the northeast. The lines of seismic section in Fig. 2 (a–a′) and Fig. 4 (b–b′ and c–c′) are displayed.

Periods of major environmental or regional tectonic perturbations can have a significant impact on the hydrodynamic regime at depth within a basin. Focused fluid venting events associated with the Messinian Salinity Crisis (MSC) have been increasingly documented in recent years (see Bertoni and Cartwright, 2015 for review), particularly linked to the early stages of the crisis.

For example, in the Levant Basin (Eastern Mediterranean) pockmark craters at the base of the Messinian have been linked to methane venting as a response to the drawdown of the water column and unloading of pre-Messinian overpressured gas accumulations at the onset of the MSC (Bertoni et al., 2013). The fall in sea level has also been linked with the destabilisation of gas hydrates in the Western Mediterranean Basin (Lorca Basin, SE Spain). The breakdown of gas hydrates resulted in the release of large amounts of methane and caused sedimentary instability of Tortonian marls (Pierre et al., 2002). In addition, late Messinian fluid expulsion (mainly methane) through mud volcano conduits that transect the Messinian succession have been correlated to the drawdown in sea level at 5.55 Ma in the Central Mediterranean, along the basin margin (Iadanza et al., 2013).

There is, however, an absence of evidence for large-scale fluid venting events associated with the terminal stages of the MSC. This is surprising given that it has been postulated that rapid evaporite deposition and late MSC sea level fluctuations may have had a significant impact on basinal hydrodynamics (Bertoni and Cartwright, 2015).

In this paper we present evidence for a major, short-lived, volumetrically dramatic phase of sediment remobilisation and extrusion that occurred at the termination of the MSC. The evidence is based on 3D seismic interpretation of a group of large lensoid sedimentary bodies, the upper surfaces of which downlap onto Horizon M (regionally defined as the marker for the end of the MSC). The seismic survey is located in the western portion of the Nile Cone where earlier studies have identified significant Pliocene and younger mud volcanism (Loncke et al., 2004; Mascle et al., 2014; Kirkham et al., 2017b; Dupré et al., 2010; Giresse et al., 2010; Prinzhofer and Deville, 2013) (Fig. 1). The main aims of this paper are to describe and account for the origin of these unusual lensoid bodies and place them in a wider genetic context with reference to well constrained events occurring in the Mediterranean Basin at this time of extreme environmental change at the end of the MSC.

We propose that the most likely explanation for the lensoid bodies is that they are giant clastic extrusions. The findings presented within this paper further develop the understanding of the upper scale of clastic extrusions. This has significant implications for our understanding of: (1) the potential risk and societal impact that future large scale clastic extrusions could pose to populated regions; (2) predicting the potential longevity of modern clastic extrusions such as the Lusi sediment-hosted hydrothermal system; (3) a previously undocumented major basinal hydrodynamic event that is correlatable within the terminal stages of the MSC; (4) prior unsuspected links between periods of major environment change and basin hydrodynamics on a plate scale.

2. Geological context

The study area is located at the south-western distal limit of the Nile Cone, which is the deepwater continuation of the Nile