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Research paper

The spatial, temporal and volumetric analysis of a large mud volcano province within the Eastern Mediterranean

Christopher Kirkham [a, *], Joe Cartwright [a], Christian Hermanrud [b], Christopher Jebsen [c]

[a] Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, UK
[b] Statoil ASA, N-7005 Trondheim, Norway
[c] Statoil, N4032 Stavanger, Norway

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ABSTRACT

This paper documents and describes through the use of 3D seismic data a prolific mud volcano province within the Eastern Mediterranean. As many as 386 mud volcanoes were mapped within the post-salt succession of the western slope of the Nile Cone, offshore Egypt, using high resolution 3D seismic data. The mud volcanoes within this field display significant geometrical variability in diameter (c. 550 m to c. 5660 m), height (c. 25 m to c. 510 m) and volume (c. 0.1 km^3 to c. 3.3 km^3) and lie at depths ranging from c. > 6000 m subsea to c. 3100 m at the seafloor. A close spatial relationship between mud volcanoes and base-salt depressions and regions of anomalous thinning within the immediate pre-salt succession, combined with documented core samples taken from mud volcanoes within this region present a powerful argument for a pre-salt source of mud. 3D seismic interpretation and volumetric analysis of these mud volcanoes and their source region permit the definition and quantification of their depletion zones. A conceptual model for a dynamic liquefaction and sediment withdrawal process is proposed whereby mud is fed into a central conduit as the depletion zone propagates radially and episodically outwards resulting in a the formation of a concentric depletion zones. Prolonged mud volcanism within this region over the last ~5.3 Ma implies the potential for long lived pre-salt overpressure and continued mud volcanism following the catastrophic hydrodynamic impact of the Messinian Salinity Crisis. It is suggested that the scale of mud volcanism means that this region should be considered as among the largest mud volcano provinces in the world.

1. Introduction

Large mud volcano provinces are increasingly recognised as genetically distinct, well defined regions with a prolific flux of mud to the surface over discrete periods of geological time and where hundreds of mud volcanoes have been mapped (Kholodov, 2002; Milkov, 2000). Good examples of such regions include the central Caspian Sea and adjacent areas of Azerbaijan, the Makran, and Trinidad and the Barbados ridge (Kopf, 2002). The central Caspian/onshore Azerbaijan province is a good example, with over 250 significant mud volcano edifices identified to date (Bagirov et al., 1996; Jakubov et al., 1971; Soloviev and Ginsburg, 1994). Equally impressive is the suite of over 450 mud volcanoes that have been interpreted along the Barbados Ridge (Kopf, 2002; Brown and Westbrook, 1988). These large mud volcano provinces have a common geological context: they are located within generally convergent tectonic settings characterised by high sedimentation rates suggesting that a combination of these factors promotes the development of highly overpressured source regions to provide the necessary driving energy for the extrusional process (Kopf, 2002; Loncke et al., 2004; Milkov, 2000).

In this paper we report a large mud volcano province of previously unrecognised extent from the western margin of the giant Nile Deep Sea Fan (NDSF) (Fig. 1). Surface mud volcanism has been recognised in this area before in numerous studies in the past decade largely from marine geophysical data acquired on research cruises. These recent mud volcanoes form part of a regionally extensive phase of mud volcanism within the Eastern Mediterranean Sea, particularly on the Mediterranean Ridge and the NDSF (Kopf, 2002; Kopf et al., 2001; Kopf and Behrmann, 2000; Mascle et al., 2006, 2014; Dupré et al., 2010; Loncke et al., 2004; Dupré et al., 2014; Pierre et al., 2014) (Fig. 1). More than 150 mud

* Corresponding author.
E-mail address: chriskirkham6@outlook.com (C. Kirkham).

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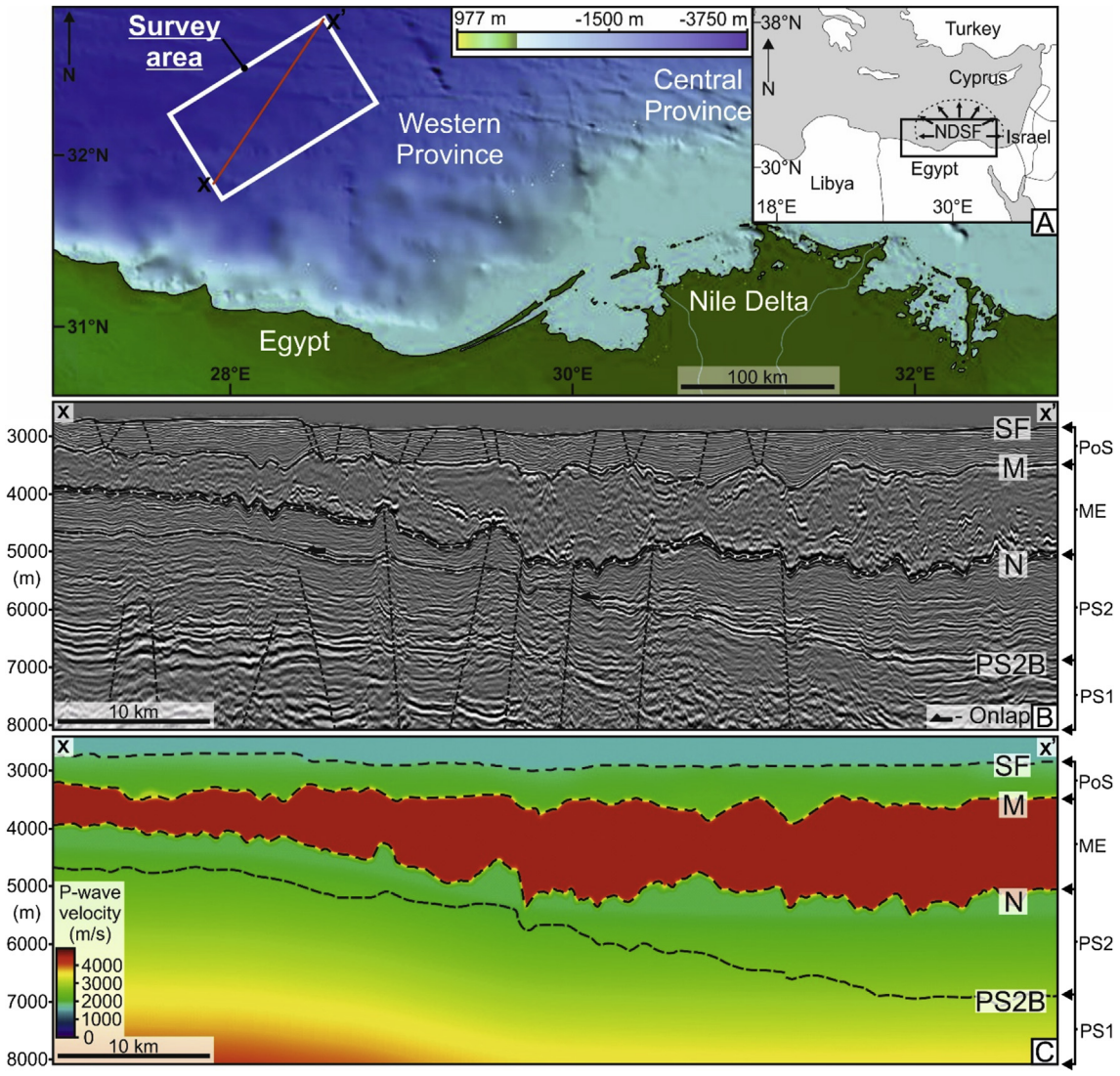

Fig. 1. A: Location map of the study area in the western province, Eastern Mediterranean, showing the setting of the three-dimensional (3D) seismic survey used in this study (white box) and the line of section for Fig. 1B and Fig. 1C (red line x-x'). The dashed black line within the regional Eastern Mediterranean map displays the approximate margins of the Nile Deep Sea Fan (NDSF). B: Pre-stack depth migrated seismic profile through the study area showing the main stratigraphic units. C: Pre-stack depth migrated velocity profile displaying p-wave velocity throughout the successions within this study area. SF – Seafloor; M – Horizon M; N – Horizon N; PS2B – Pre-salt 2 base; PoS – Post-salt; ME – Messinian Evaporites; PS1 – Pre-salt 1; PS2 - Pre-salt 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

volcanoes and also pockmarks have been documented specifically in the region of the NDSF within the Egyptian passive margin (Loncke et al., 2004), but these observations were restricted to mud volcanoes at the present day seafloor, observable via near-bottom investigation techniques and swath acoustic data (Loncke et al., 2004). Other buried mud volcanoes have been previously identified particularly within the western province, however the extent of their interpretation has until now been restricted to few seismic profiles that have primarily focused on the Menes Caldera rather than the wider western NDSF region (Dupré et al., 2014; Mascle et al., 2014). The Mediterranean Ridge >300 km to the northwest represents a neighbouring region of prevalent mud volcanism that contrasts to the Egyptian passive margin, in that the mud volcanoes have formed within the tectono-sedimentary accretionary prism of the Africa-Eurasia subduction zone and are often spatially associated with thrust faults (Mascle et al., 2014; Robertson, 1996). The mud volcanoes offshore Egypt within this study represent a separate specific case governed by different mechanisms that will be explored within this paper.

Our study is based primarily on the interpretation of a large 3D seismic survey over this area, and has allowed the recognition and mapping of several hundred buried mud volcanoes to substantially augment the inventory of those previously identified (Fig. 2). The 3D seismic data thus permits a rare opportunity to analyse the distribution of extrusive bodies within a large mud volcano province. In addition to the analysis of the spatial and temporal distribution, the peculiar characteristics of the mud volcanism in this area combined with exceptional seismic imaging meant that a volumetric analysis could also be conducted on the plumbing system for individual mud volcanoes. The plumbing system in this context refers to the physical and process linkages between the source region for the remobilised fluids and solids, the conduit and the surface edifice. In particular, the seismic data allows the clear identification of the source region for the extruded mud through the recognition of geometrical characteristics that point to a specific location for the depletion zone for each mud volcano.