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Geostatistical analysis of seafloor depressions on the southeast margin of New Zealand's South Island — Investigating the impact of dynamic near seafloor processes on geomorphology

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ABSTRACT

Seafloor depressions are widespread on the present-day continental slope along the southeast coast of New Zealand's South Island. The depressions appear to be bathymetrically constrained to depths below 500 m, correlating to the top of the gas hydrate stability zone, and above 1100 m. Similar depressions observed on the Chatham Rise are interpreted to have formed as a result of gas hydrate dissociation, leading to the hypothesis that a similar origin can be applied for the depressions investigated in this study. Our investigation, however, has found limited geophysical or geochemical evidence to support this hypothesis.

The objective of this paper is to examine whether a causal relationship can be established between potential mechanisms of depression formation and the present-day seafloor geomorphology. Geostatistical analysis methods applied to multibeam bathymetry and interpretation of 3D seismic data have been used to empirically describe the geomorphology of the seafloor depressions and investigate potential correlations between geomorphology and other processes such as current flow along the shelf and slope in this region and underlying polygonal fault systems.

Although the results of our analysis do not preclude that the seafloor depressions formed as a result of gas hydrate dissociation, neither does our geophysical or geochemical evidence support the theory. Therefore, we propose an alternative mechanism that may have been responsible for the formation of these structures. Based on the evidence presented in this study, the most likely mechanism responsible for the formation of these seafloor depressions is groundwater flux related to the interaction of current systems and the complex geomorphology of submarine canyons on the southeast coast of the South Island.

1. Introduction

Seafloor depressions such as pockmarks are found in numerous locations worldwide, and are common in a range of continental margin settings (e.g. Judd and Hovland, 2007). Seafloor depressions are generally attributed to fluid discharge at the seafloor, although the exact mechanisms responsible for their formation and maintenance are often poorly understood. Thus the understanding of fluid migration and associated seafloor geomorphology features in sedimentary basins can be improved (Ussler et al., 2003). One of the primary motivations to understand seafloor depressions better is that they are frequently associated with significant hydrocarbon reservoirs at depth, making them a useful feature in basin exploration (Pinet et al., 2008). They may also play a significant role in the input of greenhouse gases, such as methane, to the ocean and atmosphere, and therefore can be linked directly to climate change processes (Gay et al., 2007; Andresen and Huuse, 2011).

Pockmarks are a commonly observed seafloor expression of focused fluid flow (e.g. Gay et al., 2007; Pilcher and Argent, 2007; Andresen and Huuse, 2011). The erosional nature of pockmarks is indicative of the erosive power of fluid venting that is commonly related to overpressurised reservoirs of biogenic or thermogenic gases, interstitial water or a combination of all three (e.g. Gay et al., 2007; Pilcher and Argent, 2007; Andresen and Huuse, 2011). Seafloor depressions are frequently related to subsurface features such as discontinuities and unconformities that create pathways for fluid migration. The distribution of pockmarks on the seafloor is controlled by the location of fluid migration pathways in the subsurface, therefore understanding the seafloor geomorphology may enhance understanding of fluid migration and the distribution of potential reservoirs at depth (Pilcher and Argent, 2007). Pockmarks may be found in either random or non-random distributions. The latter can have an organised spatial arrangement as a result of features in the subsurface such as buried channels, irregular underlying topography, mud diapirs,

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sediment slumps or faults (Pilcher and Argent, 2007; Brothers et al., 2012).

Numerous seafloor depressions have been identified in newly acquired data along the southeast margin of New Zealand's South Island at water depths of 550 to 1100 m (Fig. 1c). Recent commercial 3D seismic data and newly acquired high-resolution multibeam bathymetry have enabled the first detailed study of these seafloor depressions, the seafloor geomorphology and underlying structural controls (Fig. 1c). These depressions range in size from 20 to 700 m in diameter, have a seafloor relief of 10 to 20 m and are located in the vicinity of several steeply incised submarine canyons (Fig. 1). Similar features are found along the margin to the north on the Canterbury Shelf and extend eastward onto the Chatham Rise, where much larger structures of up to 12 km in diameter have been identified (see Fig. 1a) (Davy et al., 2010).

Davy et al. (2010) proposed that these features could be interpreted as pockmarks formed by processes associated with the dissociation of gas hydrates and the consequent release of methane into the overlying ocean. Processes such as continental ice sheet dynamics and sediment deposition, isostatic adjustment, mass wasting and erosion, changes to bottom water temperature and sea level fluctuations all have significant impacts on gas hydrate stability over glacial–interglacial cycles (Kennett et al., 2000; Mienert et al., 2000, 2005; Reagan and Moridis, 2008). Davy et al. (2010) suggested that gas hydrate dissociation occurred here as a result of an increase in bottom water temperature due to seaward migration of the Subtropical Front (STF) and sea level fall during the last interglacial–glacial transition (Davy et al., 2010). The objective of this paper is to investigate the cause of formation of the seafloor depressions described in this study in detail by assessing the following questions.

1. Is there evidence for a link between the formation of seafloor depressions and gas release due to the dissociation of gas hydrates or shallow gas reserves?
2. Can the location of the seafloor depressions be correlated to underlying structural controls such as polygonal fault systems?
3. Is groundwater flux a potential factor in the formation of the seafloor depressions?
4. Is there a statistically significant correlation between current direction and alignment of the depressions?

2. Regional setting

2.1. Basin development

The east coast of the South Island, south of the Chatham Rise (Fig. 1), is a classic passive continental margin (the Otago Margin and Canterbury Shelf) situated on the thinned block of mostly submerged continental crust referred to as Zealandia, which rifted away from Antarctica and Australia around 80 Ma (Mortimer, 2004; Mogg et al., 2008; IODP317 Expedition Scientists, 2010). The sedimentary evolution of the margin has been controlled by the transient interplay of the uplift and erosion of the Southern Alps, the competence and location of rivers draining the mountains, marine currents associated with the Subtropical Front (STF) and variability in relative sea level (Osterberg, 2006).

The Canterbury Basin covers an area of about 50,000 km^2 in water depths of up to 1600 m (Uruski, 2010). The basin is underlain by the Triassic–Jurassic aged Torlesse supergroup consisting primarily of Gondwana margin sedimentary units, exposed onshore on the South Island (Herzer and Wood, 1992; Uruski, 2010). During the Paleogene, the New Zealand land mass was peneplained. Subsequently, the upper Cretaceous sediments in the lower part of the basin were covered by >6000 m of uppermost Cretaceous and Tertiary sedimentary units deposited during a single, tectonically driven transgressive–regressive cycle (Carter et al., 1996; Lu et al., 2003; Uruski, 2010).

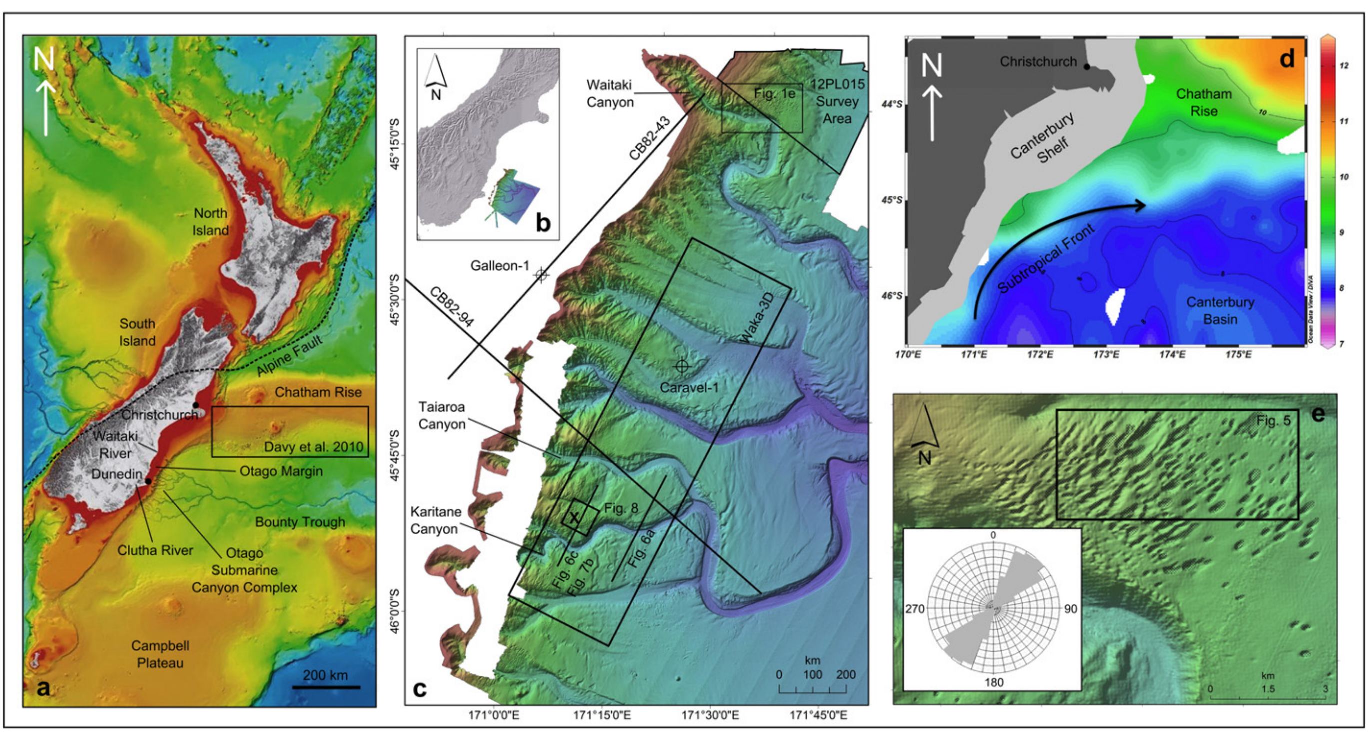

Fig. 1. (a) Bathymetric map of Zealandia, key locations and features referred to in this study are labelled. Data source: NIWA, 2012. (b) Location of the study area with reference to the South Island. Data sources: LINZ, 2009 and NIWA, 2012. (c) Multibeam bathymetry map of the modern slope on the southeastern margin of New Zealand's South Island, the location of seismic survey data and wells used in this study are marked. Box X delineates the area used for the analysis of polygonal faults in the subsurface (Fig. 7). Line 1200 crosses this box and is described in further detail in Fig. 6. Data sources: NIWA, 2012, GEOMAR, 2012 and 2003, and Anadarko and Origin Energy, 2012. (d) Plot of temperature gradient delineating the location of the Subtropical Front (STF) along the east coast of the South Island. Data source: World Ocean Atlas Data, 2013. (e) Enlarged section of multibeam bathymetry data immediately north of the Waitaki Canyon showing the seafloor depressions outlined by polygons. The inset rose plot shows the orientation of seafloor depressions across the margin, which generally occur north of the submarine canyons.