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Research paper

Temporal changes of fault seal and early charge of the Maui Gas-condensate field, Taranaki Basin, New Zealand

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ABSTRACT

Fault seal due to juxtaposition or the generation of low-permeability fault rock has the potential to change through time with displacement accumulation. Temporal variations in cross-fault flow of hydrocarbons have been assessed for the Cape Egmont Fault (CEF), Taranaki Basin New Zealand, using displacement backstripping, juxtaposition and Shale Gouge Ratio (SGR) analysis. The timing of hydrocarbon migration and charge of the giant Maui Gas-condensate Field across the CEF have been assessed using seismic reflection lines (2D & 3D), coherency cubes, VShale curves from the Maui-2 well and PetroMod modelling. Displacement–backstripping analysis suggests that between the Late Miocene and early Pleistocene (5.5 and 2.1 Ma) sandstone reservoir units of the Maui Field (Mangahewa, Kaimiro and Farewell Formations) and underlying source rocks (Rakopi Formation) were partly juxtaposed across the CEF with low SGRs (< 0.2) present in the fault zone. Following 2.1 Ma SGRs increased to 0.2–0.55 adjacent to the Eocene–Palaeocene reservoir succession which was not in juxtaposed contact with source rocks. PetroMod modelling using these SGR values and juxtaposition relationships supports cross-fault flow prior to 2.1 Ma with later charge across the fault being less likely. Gas chimneys and the gas–water contact in the Eocene reservoir proximal to the fault suggest that despite limited cross-fault flow, upward leakage of hydrocarbons from the reservoir occurred after 2.1 Ma, possibly associated with active fault movement or fracturing related to faulting, and may account for the loss of an early oil phase.

1. Introduction

Faults have long been known to influence the lateral and vertical migration of hydrocarbons (e.g., Smith, 1966; Davies, 1984; Childs et al., 1997; Losh et al., 1999; Garden et al., 2001; Manzocchi et al., 2010). Fault displacement can produce juxtaposition of reservoir and seal rocks, promoting or retarding cross-fault flow (Allan, 1989) (Fig. 1a & b). Fault slip may also entrain clay-rich wall rock or cause cataclasis and associated grain-size reduction, resulting in a reduction in fault-rock permeability (Weber et al., 1978; Downey, 1984; Knipe, 1992; Antonellini and Aydin, 1994; Heath et al., 1994; Yielding et al., 1997, 2010; Foxford et al., 1998; Fossen and Bale, 2007). The impact of clay within fault zones on the lateral flow of hydrocarbons has been extensively studied and numerous methods proposed to quantify fault-seal potential (Bouvier et al., 1989; Lindsay et al., 1993; Fulljames et al., 1996; Yielding et al., 1997, 2010; Childs et al., 2007; Yielding, 2012). Shale gouge ratio (SGR), for example, estimates the proportion of clay in a sequence that has passed a point on a fault (Yielding et al., 1997) and has been shown to be a robust method for calibrating lateral fault seal in basins worldwide (Yielding, 2002).

Fault seal studies mainly consider the present-day juxtapositions and proxies for low-permeability fault rock (Fig. 1a), which is valuable for fault-seal assessment on production timescales. However, in circumstances where fault growth and hydrocarbon generation/migration are synchronous, understanding the displacement history and associated changes in stratigraphic juxtapositions may be important for characterising the influence of fault seal on reservoir charge and trap formation for geological timescales (Kurz et al., 2008; Giampaoli, 2013), (Fig. 1). Such spatial and temporal changes in fault seal are often inferred from differences in pressure and/or the composition of fluid inclusions (e.g., Parry, 1998; Do Nascimento et al., 2005). These differences across

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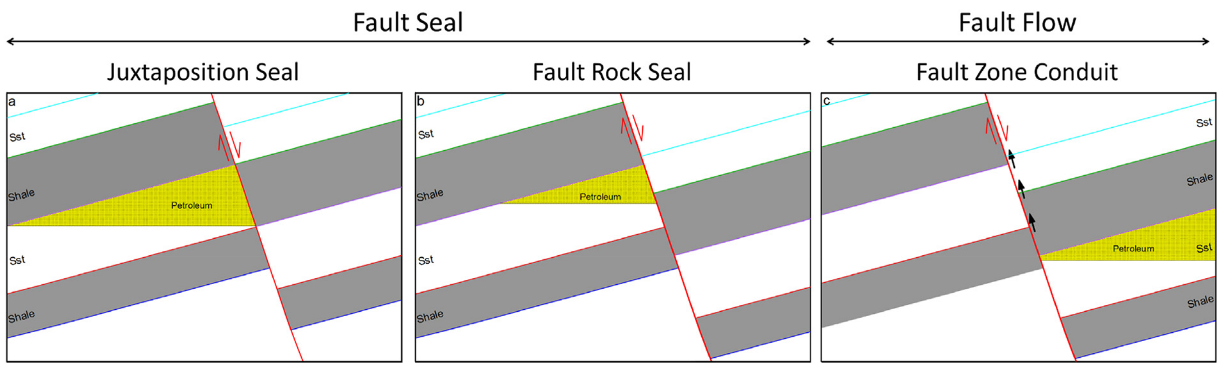

Fig. 1. Models for fault seal by juxtaposition of reservoir and seal horizons (a), and by low permeability fault rock created as a result of fault movement (b). c) Fault zone acting as a conduit to up-sequence migration of petroleum.

faults may, however, also partly arise due to up-fault flow of hydrocarbons (Fig. 1c), the importance of which has been widely recognised, yet is not as well understood as lateral fault seal (e.g., Bell, 1989; Hooper, 1991; Revil and Cathles, 2002; Pratsch, 2007; Manzocchi et al., 2010).

In this paper we utilise displacement backstripping to chart temporal changes in fault-seal potential and juxtaposition since ~5.5 Ma on the Cape Egmont Fault (CEF) in the Taranaki Basin, New Zealand (Fig. 2). The paper has two main aims; 1) to determine whether temporal changes in fault seal can occur on normal faults and, 2) to test the idea that the giant Maui Gas-condensate Field (hereafter referred to as the Maui Field) in the immediate footwall of the CEF could have been charged across the fault. Despite having been discovered in the late 1960's, the charge of the field is still debated, with numerous migration models and histories proposed (Thrasher, 1990; Haskell, 1991; Wood et al., 1998; Funnell et al., 2001, 2004; Matthews, 2008). The results of the fault-seal history analysis may have generic application to other petroleum basins, while the Maui Field is New Zealand's largest hydrocarbon discovery and a better understanding of its charge history may assist with future exploration in the region. Understanding the potential for fault seal and up-dip flow on faults that appear to bound the

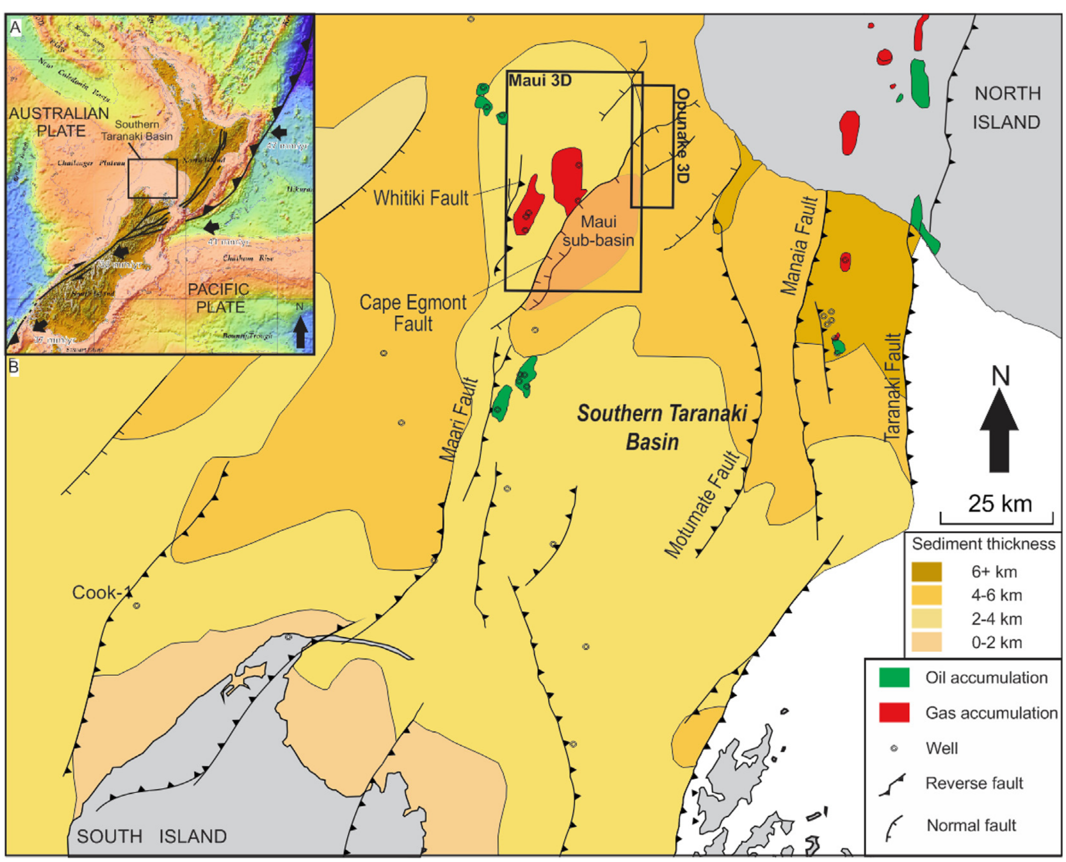

Fig. 2. Map of the Southern Taranaki Basin (see inset for location) showing some of the basin's main faults (triangles and ticks on faults indicate their dip directions, for reverse and normal faults, respectively), oil and gas accumulations, exploration wells and sediment thickness throughout the basin. Location of the two 3D seismic reflection surveys used in this study are outlined in black and labelled. Inset shows plate boundary setting and study area location. Relative plate motion vectors on inset are from Beavan and Haines (2001).