Marine and Petroleum Geology 72 (2016) 98–109

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Composition of Pliocene to Quaternary mixed terrigenous and calcareous sandy beds in contourite drift deposits at ODP Site 1119 off New Zealand: Insights into sandy drift development and drift petroleum reservoir characterization

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A R T I C L E I N F O

Article history:
Received 18 August 2015
Received in revised form
5 January 2016
Accepted 7 January 2016
Available online 11 January 2016

Keywords:
Contourite
Sand
Sediment drift
Pliocene
Pleistocene
New Zealand
Provenance
Foraminifers

A B S T R A C T

ODP (Ocean Drilling Program) Site 1119 was drilled in drift successions deposited by northward flowing currents on the Canterbury slope, South Island, New Zealand. Pliocene (~3.9 Ma) to Pleistocene drift accumulation was concomitant with tectonic uplift and sediment supply from the Alpine Fault plate boundary to the west, glacial development and eustatic sealevel change that created cyclicity in sandy input. Sand detrital and biogenic modes of very fine and fine sand fractions from 24 unconsolidated core samples (44 thin sections) were determined. Fine sand fractions contain an average of 52% bioclastic debris, with bioclasts making up 23% of the very fine sand fraction. Foraminifers are the dominant bioclasts, with pelagic more common than benthic varieties. The average proportions of monocrystalline quartz, plagioclase and potassium feldspar are similar in both size fractions (average QmKP of ~25:12:63). In contrast, the very fine sand fractions have, on average, higher lithic (QFL%L of 16 vs. 3%), mica (Totalgrain%M of 10 vs. 6%), and dense mineral (Totalgrain%D of 8 vs. 5%) content as compared with the fine sand fractions. Younger clinoform drape (Unit I) and older mounded drift (Unit II) seismic facies showed no distinct detrital compositional differences in their sand fractions, though bioclast content ranges higher in the fine sand fraction of Unit II. Albite feldspar, metamorphic rock fragment, and chlorite components in the sand are consistent with a schist provenance. Other components such as biotite, plagioclase, and K-feldspar require a contribution from metasedimentary and volcanic rocks. Thus there is some along-slope mixing during sediment transport by south-to-north flowing currents. Cemented microporous sandstone at the base of the section provides some insight into contourite burial diagenesis. This work provides a better understanding of the compositional variability of sand components of drift successions which are potential hydrocarbon reservoirs elsewhere.

1. Introduction

Contourite drift deposits resulting from ocean bottom currents occur along continental slopes and rises are found in all major ocean basins (e.g., Brackenridge, et al., 2011; Hernández- Molina et al., 2011; Rebesco et al., 2014). Along or sub-parallel to slope currents shape the seafloor through oceanographic processes that, in conjunction with sea-floor bathymetry, sediment supply, and turbidity, control drift deposition (e.g., Faugères et al., 1993; Viana et al., 1998; Hernández-Molina et al., 2011; Rebesco and Camerlenghi, 2008; Rebesco et al., 2014). Bottom-current velocities capable of forming contourites can transport up to coarse sand (Shanmugam, 2008). However, most continental-margin contourite drifts comprise dominantly muddy facies with varying proportions of terrigenous and calcareous components (Stow and Holbrook, 1984; He et al., 2008; Stow et al., 2008; Rebesco et al., 2014). The higher terrigenous sand content of some drifts is often a function of sediment supply via glacial processes or results from cannibalization of sediment previously deposited within slope canyons (He et al., 2008; Stow et al., 2008; Rebesco et al., 2014). In contrast, sand-sized biogenic debris (foraminifers) can be supplied directly by settling from the water column (Stow et al., 2008).

The few comprehensive descriptions of sandy drifts have

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http://dx.doi.org/10.1016/j.marpetgeo.2016.01.006
0264-8172/

focused more on their lithofacies and less on their petrology and provenance, as most are composed mainly of foraminifers (e.g., Shanmugam et al., 1993; Viana et al., 1998; Rebesco et al., 2014). Some notable exceptions include terrigenous-dominated drift deposits resulting from Mediterranean outflow in the Gulf of Cadiz (Nelson et al., 1993) recently drilled during Expedition 339 (Stow et al., 2013; Rebesco et al., 2014), the glacially fed sandy contourites (70–80% sand) at the base of the West Shetland slope (Masson et al., 2010), and the Canterbury drifts recovered at Ocean Drilling Program (ODP) Site 1119 on Leg 181 off New Zealand (Fig. 1; Carter et al., 1999). We focus herein on sandy contourite intervals at Site 1119, reporting on their compositional variability and provenance. Our data constrain terrigenous sand transport distance and source area, characterize the proportion and types of sand-sized biogenic components, and define a temporal trend in foraminifer/bioclast content associated with drift evolution, all of which are factors relevant to evaluating the prospectivity of such deposits as hydrocarbon reservoirs. Drift deposits have been touted as potential hydrocarbon reservoirs, especially where clean, well-sorted sandy contourite facies are overlain and sealed by hemipelagic muddy facies in stratigraphic traps (e.g., Viana et al., 2007; Shanmugam, 2008; Viana, 2008; Stow et al., 2011; Rebesco et al., 2014). Whereas sediment sorting and grain size have been discussed in the literature cited above, sediment composition and its possible link to reservoir character have only been cursorily evaluated and is the focus of this study based on samples from Ocean Drilling Program (ODP) Site 1119.

2. Background on Canterbury basin and ODP Site 1119

The Canterbury Basin extends offshore from the Canterbury Plains, on South Island, New Zealand (Fig. 1). This is a passive margin setting where Cretaceous rifting was followed by thermal subsidence, culminating in Oligocene peak flooding, after which terrigenous shelf progradation was caused by increased sediment delivery and accumulation associated with the development of the nearby Alpine Fault transform plate boundary and associated Southern Alps mountain range (Fulthorpe and Carter, 1991; Browne and Naish, 2003). The outer shelf and slope of the basin run parallel with the northward trend of the modern Southland and Subantarctic Fronts, which have produced significant contourite drift deposits through time. The Canterbury drifts and the modern equivalents of the currents thought to have produced them have been studied and characterized, as summarized by Carter (2007) and Land et al. (2010) and references cited therein. The oldest drift deposits are of earliest Miocene age and are now uplifted and partly exposed onland thanks to Neogene tectonism (Carter, 1988, 2007). Detailed outcrop and seismic stratigraphic studies have defined the geometry and extent of several drifts across the Canterbury foothills, extending under the shelf and slope including the most recent phase (3.9–0 Ma) drilled at ODP Site 1119 (Fig. 2; Carter et al., 1999, 2004a; Fulthorpe and Carter, 1991; Lu and Fulthorpe, 2004).

Site 1119 was drilled in 395 m water depth and ~96 km east of the present shoreline, and penetrated ~495 m of middle to upper slope section with 90% core recovery (Fig. 3; Carter et al., 1999, 2004b; Carter, 2005). Shipboard scientists described the largely muddy lithologies with mostly unconsolidated sandy interbeds and laminae (~10% net sand) along with their sedimentary structures, mainly cm-scale lamination/bedding with sand beds 2–300 cm thick exhibiting gradational to abrupt tops and bottoms. Only two thin beds in the section were interpreted as turbidites, the remainder as bottom-current deposits. They determined the age of the sediments using bio- and magneto-stratigraphic datums and related the section to previously defined seismic stratigraphic units, dividing the succession into three main units (Figs. 2 and 3; Carter et al., 1999). They interpreted the lowermost mudstone Unit III to be drape deposits on an underlying sediment drift (BIG GREY in Fig. 2) that was not penetrated at this site, but crops out onshore. Overlying sand-bearing muddy deposits of Unit II were subdivided into three subunits corresponding to three seismically defined drifts that represent intermediate-water depth slope deposits. The topmost Unit I was deemed to be a drift drape over upper slope

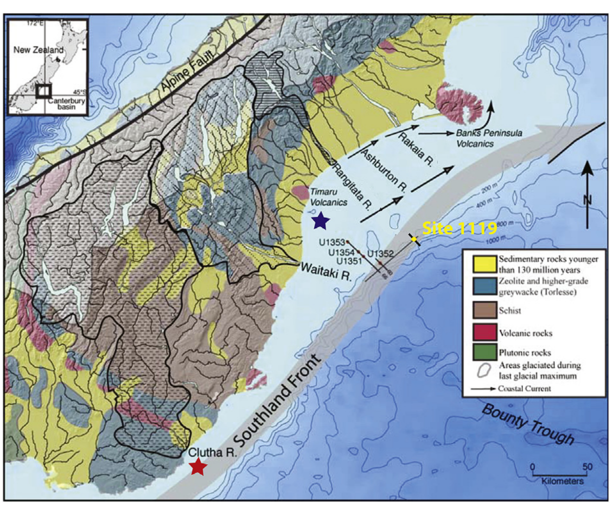

Fig. 1. Site location map. Geologic and bathymetric map of South Island, New Zealand with fluvial drainages and main drainage basins, a simplified geology after Forsythe and Aitken (1995) and glacial extent during last glacial maximum from Coates (2002) after Suggate (1990). Ocean Drilling Program Site 1119 is highlighted in yellow, with more recent Integrated Ocean Drilling Program (Expedition 317) sites U1351–U1354 also shown. Southwest to northeast flowing shelf currents are indicated, as well as the large scale Southland Front. Short line passing through Site 1119 is location of seismic line pictured in Fig. 2. Red star highlights location of Clutha River sediment input to the shelf sedimentary system. Blue star highlights area where Waitaki and Rangitata rivers transmit sediment to the shelf. Similar star symbols are used to denote the composition of sediment from these rivers on Fig. 7. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

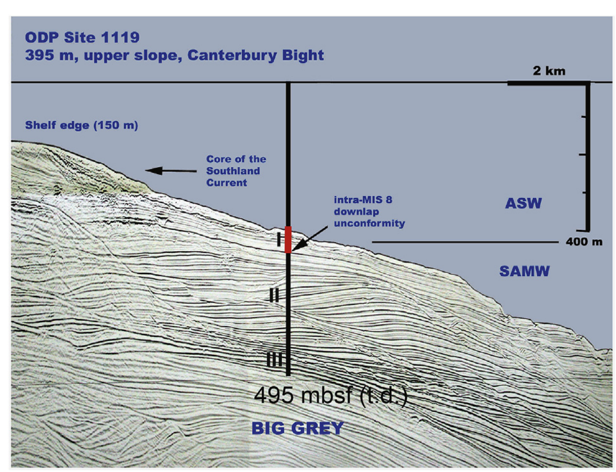

Fig. 2. Northwest-southeast oriented seismic section showing the location of and units drilled at Site 1119, as well as local hydrodynamic conditions. The present boundary between water masses is also shown: ASW (Australasian surface water) and SAMW (Subantarctic mode water). BIG GREY refers to drift D11 of Lu and Fulthorpe (2004), which was not penetrated at Site 1119. The seismic line is located in Fig. 1. Figure modified from Carter et al. (2004a).