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EA Gas Hydrates and Genetic Link Between Miocene Seafloor Methane Seeps and Underlying Fluid Conduit Plumbing, East Coast Basin, New Zealand*

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Abstract

Methane-derived authigenic carbonates (MDACs) have recorded the seepage of hydrocarbons and the presence of gas hydrates in bathyal sediments of New Zealand's Hikurangi subduction margin since the onset of the modern convergent plate boundary ~25 Ma (Campbell et al., 2008; Barnes et al., 2010; Greinert et al., 2010). Modern offshore distal turbidites and uplifted Miocene bathyal mudstones of eastern North Island archive the expression of methane fluid expulsion, forming unusual carbonates as either seafloor seep limestones or sub-seafloor conduit concretions (Lédesert et al., 2003; Campbell et al., 2008, 2010; Nyman et al., 2010; Nyman and Nelson, 2011; Nelson et al., 2019). The conduit concretions are, in places, exhumed on the modern seabed, and in Miocene deep-water mudstones they may be preserved in-situ (Nyman, 2009; Campbell et al., 2010). Conduit concretions, some with tubular holes extending through their centres, are interpreted to mark subsurface fluid pathways, while seep limestones typically contain fossils of a chemosynthesis-based biota associated with seafloor seepage (Campbell et al., 2008). It is uncommon for both types to be exposed at a single location, particularly in the geologic record; consequently, any potential genetic link between them is usually inferred (Nelson et al., 2019). Three North Island Miocene seep localities (Rocky Knob, Karikarihauata Stream, Tauwharepare), exposed in the uplifted coast ranges of the East Coast Basin forearc (Field et al., 1997), preserve evidence of both subseafloor and seafloor seep MDACs (Campbell et al., 2008). Of these, the Rocky Knob locality, ~100 km inboard of the modern Australian/Pacific Plate subduction boundary, or Hikurangi Margin, as marked by the Hikurangi Trough (Field et al. 1997), is the largest single paleo-seep complex in New Zealand (Figure 1). It hosts a large volume of lithologically varied MDACs and a diverse and well-preserved fossil seep biota (Campbell et al., 2008; Saether et al., 2010a,b, 2012, 2016; Amano et al. 2014, 2015).

Lithofacies analysis, petrography and stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes (Figure 2) allow exploration for evidence of direct ties between paleo-conduit concretions and limestone build-ups formed from ancient methane seepage (e.g., Campbell et al., 2002; Schwartz et al., 2003; Clari et al., 2004; Campbell et al., 2008; Cau et al., 2015; Nelson et al., 2019). In the Miocene New Zealand example from Rocky Knob (Nelson et al., 2019), the authigenic carbonate components present include texturally varied microcrystalline calcite, fibrous aragonite, and granular, blocky and bladed calcite crystals, the latter infilling once-open central conduits within the concretions and in vugs and veins in the limestone. Their $\delta^{13}C$ values typically range from –52 to –20‰ VPDB indicating that anaerobic oxidation of methane (AOM), possibly mainly of thermogenic origin, was a primary process during carbonate precipitation in North Island paleo-seeps. Additionally, some components show a range of relatively less depleted $\delta^{13}C$ values, suggesting a diminished methane supply and increasing influence from marine bicarbonate. $\delta^{18}O$ values range widely from –6 to +4‰ VPDB, consistent with pore fluid evolution associated with gas hydrate formation and dissociation events and/or temperature shifts with burial.

Petrographic and isotopic similarities in cement components and concretions at Rocky Knob suggests a genetic tie between paleo-fluid plumbing and seafloor manifestations of methane seepage, with derivation from the same fluids albeit in different parts (i.e. sub-seafloor vs seafloor) of the seep complex.

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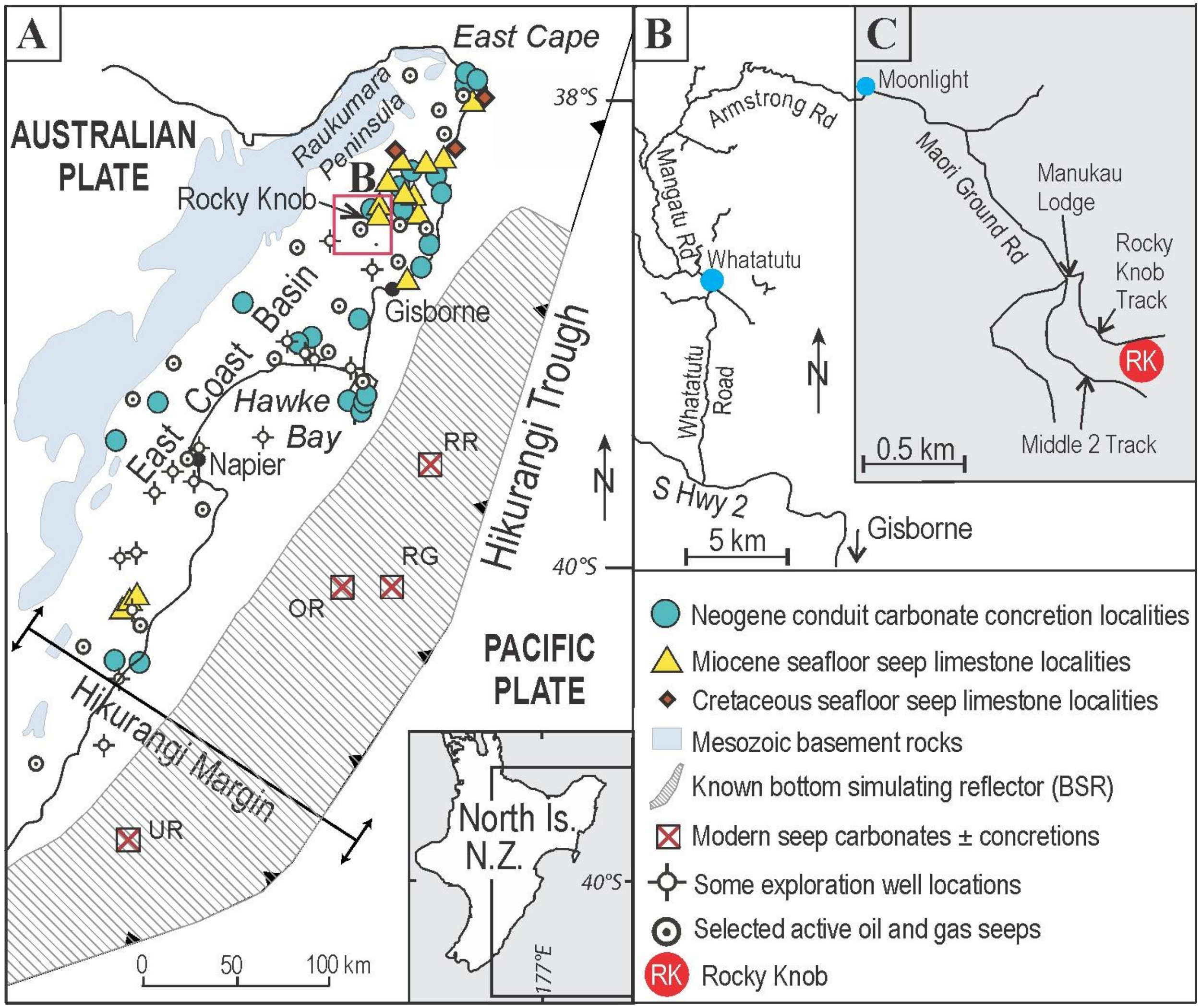

Figure 1. Hikurangi Margin seeps, past, and present. **A**, Map showing schematically the main onshore localities of known Miocene conduit concretions and seep limestones in the East Coast Basin of North Island, New Zealand (adapted from Nyman et al., 2010; Figure 2A). Also shown are the locations of some Cretaceous age seep limestones (Kiel et al., 2013), a small selection of the many known active gas/oil seeps and wells (Francis et al., 2004), the general distribution of offshore bottom simulating reflectors (BSRs) indicative of subsurface gas hydrates (Greinert et al., 2010), and four of the named offshore modern seep carbonate sites (RR, Ritchie Ridge; RG, Rock Garden; OR, Omakere Ridge; UR, Uruti Ridge; Lewis and Marshall, 1996). The labelled Hikurangi Margin zone incorporates the Hikurangi Trough and the inboard subduction complex and forearc basin of the forearc domain of Barnes et al. (2010). **B**, **C**, Enlarged location maps with roads/tracks to access Rocky Knob at about grid reference NZTM Sheet BF43 Te Karaka 2031212E, 5748762N (or NZMS Sheet Y16 Tauwharaparae 2941200E, 6310200N). Note that Map C is a further enlargement of the area after the end of Armstrong Road at Moonlight (Station). (Figure from Nelson et al., 2019.)

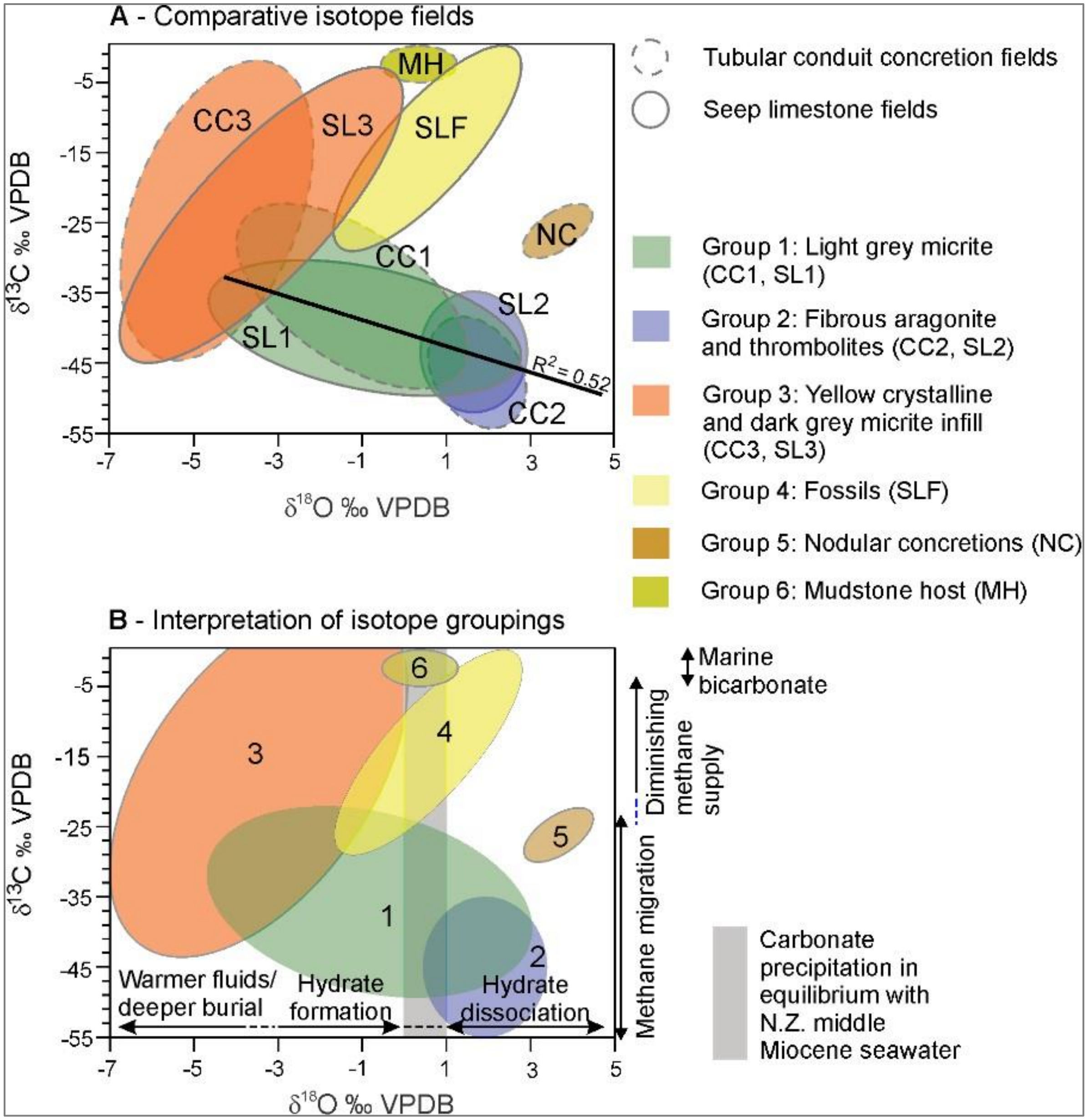

Figure 2. Carbon and oxygen stable isotopic values (A) and interpreted explanations of processes (B) for Miocene Rocky knob seep complex, East Coast Basin, North Island, New Zealand. Sub-seafloor conduit concretions (CC types) and seafloor seep limestones (SL) show some similarities in carbonate types (overlapping similar colours) and isotopic signatures. (Additional information for figure in Nelson et al., 2019.)