

The effects of anaerobic methane oxidation on benthic foraminiferal assemblages and stable isotopes on the Hikurangi Margin of eastern New Zealand

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ABSTRACT

A study of benthic foraminiferal assemblages from cold hydrocarbon seeps of the Hikurangi Margin, New Zealand, was undertaken during RV SONNE cruise SO191-3 to establish what effects, if any, methane-influenced pore waters had on the foraminiferal assemblages and the carbon isotopes of their tests. The results of this study indicate that Hikurangi Margin foraminiferal assemblages are consistent with modern and fossil seeps worldwide. Foraminiferal distribution, species richness, density and diversity were little different between seep and non-seep sites, though there were noteworthy exceptions. The non-seep reference core samples were greatly enriched in agglutinate species, which constituted 45% of the total assemblage of that core. By contrast, seep sites contained a maximum of 11% agglutinate foraminifera. Seep and non-seep sites were not separated by density or diversity, except for the single site beneath a bacterial mat that exhibited the lowest density and diversity of all sites. Assemblages at all sites were dominated by *Uvigerina peregrina*, a species known to inhabit fossil and modern seeps elsewhere, but that also is well documented from normal marine environments. Carbon isotope data significantly differentiates seep and non-seep sites through the greater ¹³C depletion and heterogeneity of $\delta^{13}\text{C}$ values in seep foraminifera. $\delta^{13}\text{C}$ values for *U. peregrina* were as low as -15.2% PDB. In addition, specimens of *Pyrgo depressa* and *Hoeglundina elegans* exhibited minimum $\delta^{13}\text{C}$ values of -29.8% and -35.7% PDB respectively, showing the influence of carbon that was derived from sulphate dependent anaerobic oxidation of methane. Authigenic carbonates and vesicomid bivalve shells from seep Station 198 also recorded depleted $\delta^{13}\text{C}$ values, with the lightest values (-55.4% PDB) clearly within the range of biogenic methane sources.

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1. Introduction

Cold hydrocarbon seeps are receiving a great deal of international attention for a number of reasons. The extreme high sulphide, low oxygen environments of cold seeps support luxurious and unique ecosystems that yield valuable insights into physiological adaptations in these environments and possibly the beginnings of life on Earth (Sassen and MacDonald, 1998; Levin, 2005). The gas hydrates that underlie cold seeps in some environments are implicated as initiating submarine slope instability as they form and dissociate, resulting in slumping, landslides, or frost-heave effects (Paull et al., 1996; Maslin et al., 1998). In addition, dissociation of methane hydrates on a global scale has been suggested as a possible cause of sudden climate change (Kennett et al., 2003; Hill et al., 2004). Finally, these deposits are of interest in the search for commercially viable and environmentally sustainable energy sources.

The study reported herein investigated the effects of methane-influenced pore waters on benthic foraminifera of the Hikurangi Margin, offshore eastern North Island, New Zealand. Specifically, the

study tested for discernible imprints on the foraminiferal assemblage and on mineralization of foraminiferal tests.

1.1. Geologic setting

The Hikurangi Margin is the southernmost section of the 3000 km long Tonga–Kermadec–Hikurangi subduction system where the Pacific plate is subducting beneath the Australian plate (Fig. 1). A plate boundary has existed here from ~40 Ma; however subduction only began ~21 Ma with a change from transtensional motion to convergence (Lewis and Pettinga, 1993; Faure et al., 2006). Convergence on this margin is strongly oblique, with anti-clockwise rotation up to 60°. At its southern end, the system ends with the intracontinental Alpine Fault and a mirror-image, west-facing subduction system in southern New Zealand (Lewis and Pettinga, 1993). Motion on this system varies greatly, from 100 mm/y in the Tonga–Kermadec section, to 40 mm/y in the northern part of the Hikurangi Margin, and 20 mm/y at the southern end. Large volumes of sediment derived from high mountains to the south and transported by channeled density currents have resulted in an anomalously thick (~3 km) accretionary wedge that is intricately deformed (Lewis and Pettinga, 1993).

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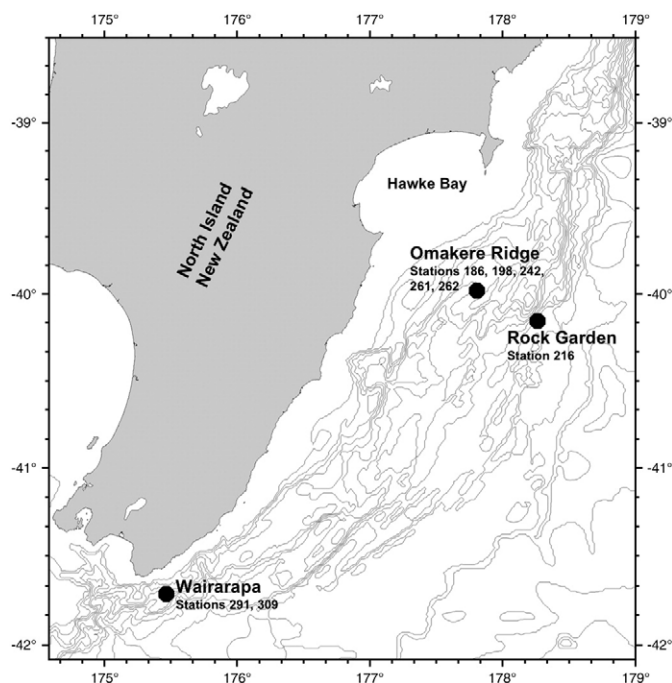


Fig. 1. Location of sampling areas used in this study.

Methane seepage on the Hikurangi Margin was first recognized in 1994 when fishermen dredged a *Bathymodiolus*-like mussel associated with a piece of carbonate chimney and observed a sonar plume in the water column (Lewis and Marshall, 1996). Subsequently, dredging recovered carbonates with attached chemoautotrophic fauna, including the bivalve *Calyptogena*. In addition, a prominent Bottom Simulating Reflector (BSR) implied the presence of gas hydrates in the sediments (Faure et al., 2006). All seep sites so far identified on the Hikurangi Margin are developed on the crests of thrust ridges, and are underlain by thrust faults that act as conduits for fluids (Barnes et al., 2010-this volume). In addition, beneath each site lie conspicuous breaks in the BSR, indicating discontinuous gas hydrate formation with accompanying fault/fracture development allowing migration of fluids (Barnes et al., 2010-this volume). The Rock Garden site (40°01.98'S, 178°09.65'E) differs from the other sites because it occurs directly above a subducting seamount, resulting in anomalous bathymetric elevation (Barnes et al., 2010-this volume).

1.2. Foraminifera in methane seeps

Foraminifera in modern cold seeps have been studied at locations on tectonically active and passive margins, including Blake Ridge, Atlantic Ocean (Robinson et al., 2004; Panieri and Sen Gupta, 2008); Gulf of Mexico (Sen Gupta and Aharon, 1994; Sen Gupta et al., 1997; Robinson et al., 2004); the North Sea (Jones, 1993); coastal California (Bernhard et al., 2001); Hydrate Ridge, eastern Pacific (Torres et al., 2003; Heinz et al., 2005); the Rockall Trough, the Irish Sea (Panieri, 2005); Japan (Akimoto et al., 1994); and the Barents Sea (Mackensen et al., 2006). Foraminifera from Cenozoic seeps have been investigated from the Miocene of Italy (Barbieri and Panieri, 2004) and the Eocene through Pliocene of the Cascadia Margin of the eastern Pacific (Martin and Nesbitt, 2005; Martin et al., 2007). All of these studies found that, unlike seep invertebrate fauna, there are no foraminiferal species that are endemic to seeps. In addition, foraminiferal densities and diversity in modern seeps do not show consistent trends. In some cases, density was low relative to comparable non-seep sites (Sen Gupta et al., 1997; Bernhard et al., 2001). In others densities were similar in seep and non-seep samples (Rathburn et al., 2003); whereas Wiedicke and Weiss (2006) found densities enhanced in seepage areas. In two

studies, statistical analyses resulted in the identification of diagnostic seep assemblages (Akimoto et al., 1994; Panieri, 2005).

Seep foraminifera respond to the presence of methane in pore waters by recording a depleted and variable $\delta^{13}\text{C}$ signal in their calcite tests (Hill et al., 2003; Rathburn et al., 2003; Hill et al., 2004). In non-seep sediments, the $\delta^{13}\text{C}$ value of foraminiferal tests varies within a narrow range: for example, in non-seep specimens of *Uvigerina peregrina*, $\delta^{13}\text{C}$ is typically between 0.2‰ and 0.4‰ PDB (Rathburn et al., 2003). In foraminifera from modern seeps, however, $\delta^{13}\text{C}$ values are considerably more variable. Single species bulk samples from Santa Barbara Channel seeps recorded $\Delta^{13}\text{C}$ ($=\delta^{13}\text{C}_{\text{max}}-\delta^{13}\text{C}_{\text{min}}$) between species ranging from -0.9% to -20.1% PDB (Hill et al., 2003). Single-individual analyses of foraminifera indicate that the isotopic variation is large even within a single species. For instance, from seeps in the Santa Barbara Channel, *Cibicides mckannai* varied between -0.37% and -2.28% PDB, and *Pyrgo* sp. recorded values between -0.01% and -25.23% PDB (Hill et al., 2003). It is unclear whether these variations reflect a primary biogenic signal or a post-depositional alteration effect. Nonetheless, foraminiferal carbonate is capable of recording excursions of depleted ^{13}C in ambient seawater and interstitial waters.

Complicating the interpretation of data from cold seep foraminifera is the mobility of these organisms. Most foraminifera are motile, capable of moving to new microhabitats within the sediment in response to environmental changes. The stimulus for foraminiferal migration is not clear. Linke and Lutze (1993) attributed it to food acquisition, while others (Moodley et al., 1998; Geslin et al., 2004) concluded movement was due to varying oxygen availability. Despite their mobility, foraminifera are generally categorized as epifaunal or infaunal based on the depth within the sediment at which they are most often reported alive (Corliss, 1985; Rathburn and Corliss, 1994; McCorkle et al., 1997). Analysis of data from cold seeps must, however, include cognizance of environmental factors other than methane seepage that might influence the isotopic results.

2. Methods

Sediment samples used in this study were retrieved during Leg 3 of RV SONNE cruise 191 (SO191-3) in February and March, 2007 using a TV-guided multicorer. Sample sites (Fig. 1) were identified by the presence of the vesicomyid bivalve *Calyptogena* spp., "raindrop" texture due to ampharetid worm burrows (Sommer et al., 2010-this volume) or active bubbles (Table 1). The samples represent the northern and southern ends of the Hikurangi Margin. From the northern end of the margin, one sample was taken from the LM3 seep (Station 216) in the Rock Garden area. From Omakere Ridge, two samples were recovered from the Kaka seep (Stations 242 and 261), and two from the Bear's Paw seep (Stations 186 and 198). Two additional samples were obtained from the southern Wairarapa area, one from the North Tower seep (Station 291) and one from Takahae (Station 309). A non-seep reference core was collected from near the Kaka 2 seep (Station 262) and was chosen based on surficial features, particularly bioturbation and lack of seep-specific biota and bubbles. All cores were sub-sampled at 0.5 cm intervals in the top five centimetres. Samples were preserved in 10% formalin with 1 g/L Rose Bengal added to stain living or recently dead individuals. Subsequently, samples were washed through a 63 mm sieve, air-dried and picked. Specimens used for isotope analyses were cleaned of organic material by soaking in a 15% hydrogen peroxide solution for 20 min, then rinsing and sonicating with methanol, and finally rinsing and sonicating in deionized water. In addition to foraminifera, a number of small pieces of carbonate slab, one carbonate nodule, and some *Calyptogena* sp. shells were recovered from Station 198 (Bear's Paw). One of these shells stained brightly in Rose Bengal, indicating it still contained cytoplasm when collected. The inorganic carbonates and stained and unstained shells also were analyzed for isotopes. Prior to analysis, shells were cleaned to eliminate organic material.

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