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Methane seepage along the Hikurangi Margin, New Zealand: Overview of studies in 2006 and 2007 and new evidence from visual, bathymetric and hydroacoustic investigations

J. Greinert [a,b,*], K.B. Lewis [c], J. Bialas [b], I.A. Pecher [d], A. Rowden [c], D.A. Bowden [c], M. De Batist [a], P. Linke [b]

[a] Renard Centre of Marine Geology (RCMG), Ghent University, Krijgslaan 281 s.8, B-9000 Gent, Belgium
[b] IFM-GEOMAR, Leibniz Institute of Marine Sciences at the University of Kiel, Wischhofstraße 1-3, 24148 Kiel, Germany
[c] National Institute of Water and Atmospheric Research, Private Bag 14 901, Kilbirnie, Wellington, New Zealand
[d] GNS Science, 1 Fairway Drive, Avalon, Lower Hutt 5010, New Zealand

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ABSTRACT

This paper is an introduction to and an overview of papers presented in the Special Issue of Marine Geology "Methane seeps at the Hikurangi Margin, New Zealand". In 2006 and 2007, three research cruises to the Hikurangi Margin at the east coast of New Zealand's North Island were dedicated to studying methane seepage and gas hydrates in an area where early reports suggested they were widespread. Two cruises were carried out on RV TANGAROA and one on RV SONNE using the complete spectrum of state-of-the-art equipment for geophysics (seismic, sidescan, controlled source electromagnetics, ocean bottom seismometers and hydrophones, singlebeam and multibeam), seafloor observations (towed camera systems, ROV), sediment and biological sampling (TV-guided multi-corer, gravity-corer, grab, epibenthic sled), deployment of in-situ observatories (landers) as well as water column sampling and oceanographic studies (CTD, moorings). The scientific disciplines involved ranged from geology, geophysics, petrography, geochemistry, to oceanography, biology and microbiology.

These cruises confirmed that a significant part of the Hikurangi Margin has been active with locally intense methane seepage at present and in the past, with the widespread occurrence of dead seep faunas and knoll-forming carbonate precipitations offshore and on the adjacent land. A close link to seismically detected fluid systems and the outcropping of the base of the gas hydrate stability zone can be found at some places. Pore fluid and free gas release were found to be linked to tides. Currents as well as density layers modulate the methane distribution in the water column.

The paper introduces the six working areas on the Hikurangi Margin, and compiles all seep locations based on newly processed multibeam and multibeam backscatter data, water column hydroacoustic and visual data that are combined with results presented elsewhere in this Special Issue. In total, 32 new seep sites were detected that commonly show chemoherm-type carbonates or carbonate cemented sediment with fissures and cracks in which calyptogenid clams and bathymodiolid mussels together with sibloglinid tube worms live. White bacterial mats of the genus *Beggiatoa* and dark gray beds of heterotrophic ampharetid polychaetes typically occur at active sites. Bubble release has frequently been observed visually as well as hydroacoustically (flares) and geochemical analyses show that biogenic methane is released. All seep sites, bubbling or not, were inside the gas hydrate stability zone. Gas hydrate itself was recovered at three sites from the seafloor surface or 2.5 m core depth as fist-sized chunks or centimeter thick veins. The strong carbonate cementation that in some cases forms 50 m high knolls as well as some very large areas being paved with clam shells indicates very strong and long lasting seep activity in the past. This activity seems to be less at present but nevertheless makes the Hikurangi Margin an ideal place for methane-related seep studies in the SW-Pacific.

1. Introduction

1.1. Cold seeps

Submarine cold seeps are sites where fluids, both pore water and free gas, migrating from deeper sediment horizons, are expressed

* Corresponding author. Now at Royal Netherlands Institute for Sea Research, P.O. Box 59 , NL-1790 AB Den Burg, The Netherlands.
E-mail address: greinert@nioz.nl (J. Greinert).

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from the seabed into the overlying water column (Suess, 2010). They are often inferred to be associated with gas hydrates in the underlying sediment, which can act as time-variable sources or sinks for methane, the dominant gas component at most seeps. Methane, together with hydrogen sulphide that is expelled at some seep sites, allow chemoautotrophic faunas to thrive, and cause precipitation of methane-derived authigenic carbonates at the sea floor, which can locally build into massive chemoherm complexes (Bohrmann et al., 1998; Greinert et al., 2001). Methane seeps occur globally and represent a substantial component of the carbon and methane cycles; the material turn-over may be of similar importance to that at the hydrothermal vent systems of mid-ocean ridges. Nevertheless, relatively little is yet known about the ecological variability and lifespans of seeps, about the variability in fluid-flow activity in space and time and about their overall impact on the global carbon cycle and hence on climate. For a better understanding of the nature of cold fluid seepage and associated gas hydrates it is necessary to study these phenomena in different tectonic and biological environments globally.

While cold seep systems have already been documented at many places in the northern hemisphere (e.g., North Sea, Baltic Sea, Black Sea, North Atlantic, Gulf of Mexico, NW Pacific, Indian Ocean; Judd and Hovland, 2007; Suess, 2010), detailed investigations in the SW Pacific region are still sparse. Indications of methane seepage have been reported from around New Zealand, being particularly numerous along the subduction margin off eastern North Island's Hikurangi Margin (Lewis and Marshall, 1996). Fossil and modern seeps have also been widely documented on the adjacent land (Campbell et al., 2008). However, despite the Hikurangi Margin appearing to be an ideal location for a detailed multi-facetted study of seepage processes, no such study had been proposed for nearly a decade after Lewis and Marshall's (1996) original paper.

To start closing this knowledge gap, a number of independent but closely linked research cruises took place in 2006 and 2007. They were organized and conducted by the Institute of Geology and Nuclear Sciences (GNS Science; Lower Hutt, New Zealand), the National Institute for Water and Atmospheric Research (NIWA; Wellington, New Zealand) and the Leibniz Institute of Marine Sciences (IFM-GEOMAR, Kiel, Germany) using the New Zealand research vessel RV TANGAROA (Cruises TAN0607, TAN0608, TAN0612, TAN0616, and TAN0711) and the German RV SONNE (Cruise SO191). In this paper we give an overview of three cruises (TAN0607, TAN0616, and SO191) and their interrelated scientific programs. We introduce six seep areas with different biological and geological environments and summarise information that is the context of the various more specialized papers in this Special Issue. Furthermore we give evidences of individual seep sites and seep activity that are not presented elsewhere.

1.2. Background to seep studies at the Hikurangi Margin

The Hikurangi Margin is at the southern end of the 1000 km long Tonga-Kermadec-Hikurangi subduction systems, where the Pacific Plate subducts increasing obliquely towards the south beneath the Indo-Australian Plate (Fig. 1). At the southern end of the Hikurangi Margin, the plate boundary through New Zealand continues as a dextral intra-continental transform system to link with an almost mirror-image subduction system, where the Indo-Australian crust is subducted beneath the Pacific Plate southwest of South Island (Walcott, 1978). Rates of convergence along the Hikurangi Margin range from 45 mm/a at the northern end off East Cape to about 38 mm/a at the southern end near Kaikoura, although rotation of the forearc increases the rate of convergence to 54 mm/a at the slope-toe off East Cape with obliquity of about 40° (Collot et al., 2001). The subducting oceanic plate is the anomalously shallow, 12–15 km thick Hikurangi Plateau (Davy, 1992; Wood and Davy, 1994), consisting of ocean crust being covered by turbidites up to 5 km thick. Subduction takes place along the 3000 m deep, infilled structural trench of the Hikurangi Trough, along the toe of the slope (Lewis et al., 1998).

The central part of the margin is characterized by a particularly well defined accretionary prism of imbricated, offscraped Plio-Pleistocene “trench” turbidites from the Hikurangi Trough (Lewis, 1980; Davey et al., 1986a, b; Barnes and Mercier de Lepinay, 1997; Barnes et al., 2010-this issue). The offscraped trench sediments form margin-parallel ridges and basins on the lower slope and the same style of deformation and topography continues across the upper slope and coastal ranges. This upper deforming margin is not formed by offscraped trench sediments but by a “deforming backstop” of late Cretaceous and Palaeogene passive margin sediments that predate subduction (Lewis and Pettinga, 1993). The boundary between offscraped sediments and deforming backstop was inferred to be significant in defining the location of many of the previously reported cold seep sites (Lewis and Marshall, 1996).

New research described by Barnes et al. (2010-this issue)) considerably redefines the boundary between the deforming backstop and frontally accreted sediment, and sheds new light on how this boundary influences the location of cold seep sites. The frontally accreted trench sediments, the deforming backstop and back-tilting cover beds in slope-parallel basins (Lewis, 1980), together form an actively imbricating frontal wedge that is up to 150 km wide. They are deforming, with increasing dextral strike-slip motion as they approach the backstop of Mesozoic “greywacke” meta-sediments that form the main axial ranges of North Island (Walcott, 1978; Barnes et al., 1998).

The nature and width of the Hikurangi frontal wedge varies considerably along the margin, largely due to changes in plate boundary processes, which include a major northward increase in both the velocity of convergence and number of seamounts on the subducting plate, with a corresponding southward increase in obliquity of convergence and thickness of trench sediments (Lewis and Pettinga, 1993; Collot et al., 1996; Lewis et al., 1998; Henrys et al., 2006; Barnes et al., 2010-this issue). At the northern end of the margin, the thin trench-fill and rapid subduction of numerous seamounts results in little or no frontal accretion and tectonic erosion of a steep margin (Collot et al., 1996). The majority of the historical seep sites (Lewis and Marshall, 1996) as well as the newly discovered ones discussed here occur in the central zone of slower convergence with few seamounts, thick trench sediments and gently tapering, classic frontal accretion.

Townend (1997) estimated that more than 20 m^3 of fluids are being squeezed from accreted and subducted sediments along each meter of the Hikurangi Margin every year, which results in abundant evidence of escaping gas both offshore (Faure et al., 2010-this issue; Naudts et al., 2010-this issue; Linke et al., 2010-this issue) and onshore (Campbell et al., 2008; Nyman et al., 2010-this issue). Small seeps of light hydrocarbons are widespread on the adjacent land (Kvenvolden and Pettinga, 1989). Fossil submarine seep-carbonates up to 10 m thick and 200 m across, with preserved methane signatures, chemoautotrophic palaeocommunities and near-seabed plumbing systems occur in Miocene bathyal mudstones that outcrop in the coastal hills (Campbell et al., 2008). In addition, mud “volcanoes” have erupted “spectacularly” onshore (Ridd, 1970) and, on the continental shelf, pockmarks have been interpreted as evidence of gas expulsion (Nelson and Healy, 1984). Further seaward, bottom simulating reflectors (BSR), generally inferred to indicate free gas beneath gas-hydrate infused sediment, occur extensively on the mid and lower slope (Katz, 1981; Townend, 1997; Henrys et al., 2003; Pecher et al., 2004) with the signal of the BSR being strongest where geological structures favour fluid migration such as anticlines, layer outcrops and fault systems (Pecher and Henrys, 2003).

Slide scars are widespread on all scales along the offshore Hikurangi Margin and at least some slope failures, including the giant Ruatoria Avalanche deposit, have been partly attributed to