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Methane in shallow cold seeps at Mocha Island off central Chile

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ABSTRACT

We studied for the first time the intertidal and subtidal gas seepage system in Mocha Island off Central Chile. Four main seepage sites were investigated (of which one site included about 150 bubbling points) that release from 150 to 240 tonnes CH_4 into the atmosphere per year. The total amount of methane emitted into the atmosphere is estimated in the order of 800 tonnes per year. The gases emanated from the seeps contain 70% methane, and the stable carbon isotopic composition of methane, $\delta^{13}C–CH_4$ averaged $-44.4 \pm 1.4‰$ which indicates a major contribution of thermogenic gas. Adjacent to one of the subtidal seeps, rocky substrates support a diverse community of microbial filaments, macroalgae, and benthic organisms. While stable carbon isotopic compositions of marine benthic organisms indicate a dominant photosynthesis-based food web, those of some hard-substrate invertebrates were in the range $-48.8‰$ to $-36.8‰$, suggesting assimilation of methane-derived carbon by some selected taxa. This work highlights the potential subsidy of the trophic web by CH_4–C, and that its emission to the atmosphere justifies the need of evaluating the use of methane to support the energy requirements of the local community.

1. Introduction

Methane is a powerful greenhouse gas, third in importance to water and carbon dioxide, and is the most abundant hydrocarbon in the atmosphere. Sources of atmospheric methane are found on both land and sea. Marine sources include methane produced microbially in the seawater, methane transported by coastal runoff, and methane released from the seafloor. In the third case, methane enters the water column by way of coastal runoff, diffusion, and advection from sediments, seeps, vents, and mud volcanoes, which may be related to gas leakage from subsurface petroleum (gas and/or oil), and by destabilization of clathrates (Judd and Hovland, 2007). In spite of the enormous size of the reservoirs and fluxes of methane into the ocean, the water column remains for the most part undersaturated with respect to this gas when compared to the atmosphere (Bates et al., 1996). This is mainly because microbial oxidation in the water column reduces the concentrations to the low nanomolar range observed in the ocean (Reeburgh, 2007). Methane represents a source of carbon and energy for an important group of aerobic bacteria known as methanotrophic bacteria. These bacteria produce a membrane-bound or particulate form of the enzyme methane monooxygenase, which generates methanol from methane as the first enzymatic step in the oxidation of methane (Hanson and Hanson, 1996). Under anoxic conditions, methane is oxidized by a consortium of methanotrophic archaea and sulphate-reducing bacteria (Hoehler et al., 1994; Hinrichs et al., 1999, 2000; Boetius et al., 2000) in a process called anaerobic methane oxidation (Hinrichs and Boetius, 2002). In spite of the numerous sinks, there are several processes where methane is transported to the atmosphere with minimal opportunity for microbial oxidation (Reeburgh, 2007), indirectly by diffusion from methane-saturated waters or directly through the escape of bubbles (a form of gas advection) from seeps, especially those located at depths shallower than 200–300 m (Judd, 2004).

Conspicuous metazoan communities thrive in deep methane seeps, which are highly specialized (e.g., vesicomyid clams, siboglinid tube-worms) and develop symbiotic relationships with chemosynthetic bacteria (Paull et al., 1984; Kennicut et al., 1985). At these sites, methane fuels or facilitates directly or indirectly local food webs (Levin, 2005, and references therein). Part of this evidence has been obtained by tracing the fate of chemosynthetic production through stable isotopic analysis of the local food webs (Levin and Michener, 2002). Although these processes are well

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documented for deep water sites, examples from intertidal sites are much scarcer and lack convincing evidence of the effect of the seeping carbon (such as methane) on the local biology. Indeed, among the few reports on the effects of intertidal methane seepages on local fauna, Dando et al. (1994) concluded that microbial methane oxidation does not constitute an input to the local heterotrophic food chain at a site in the Kattegat (Denmark). However, they pointed out that rock formation by carbonate cementation favors sessile fauna to settle, thus indirectly enhancing local abundance and biomass.

A series of intertidal (beach) and shallow subtidal (5 m depth) gas seeps were detected in Mocha Island off Central Chile (Fig. 1), where the Chilean Gas Company (Empresa Nacional del Petroleo, ENAP) had surveyed the area in the early 1980s for natural gas exploration. The island is a mountainous structure that covers an area of 53 km^2 and corresponds to the top of a mountain range

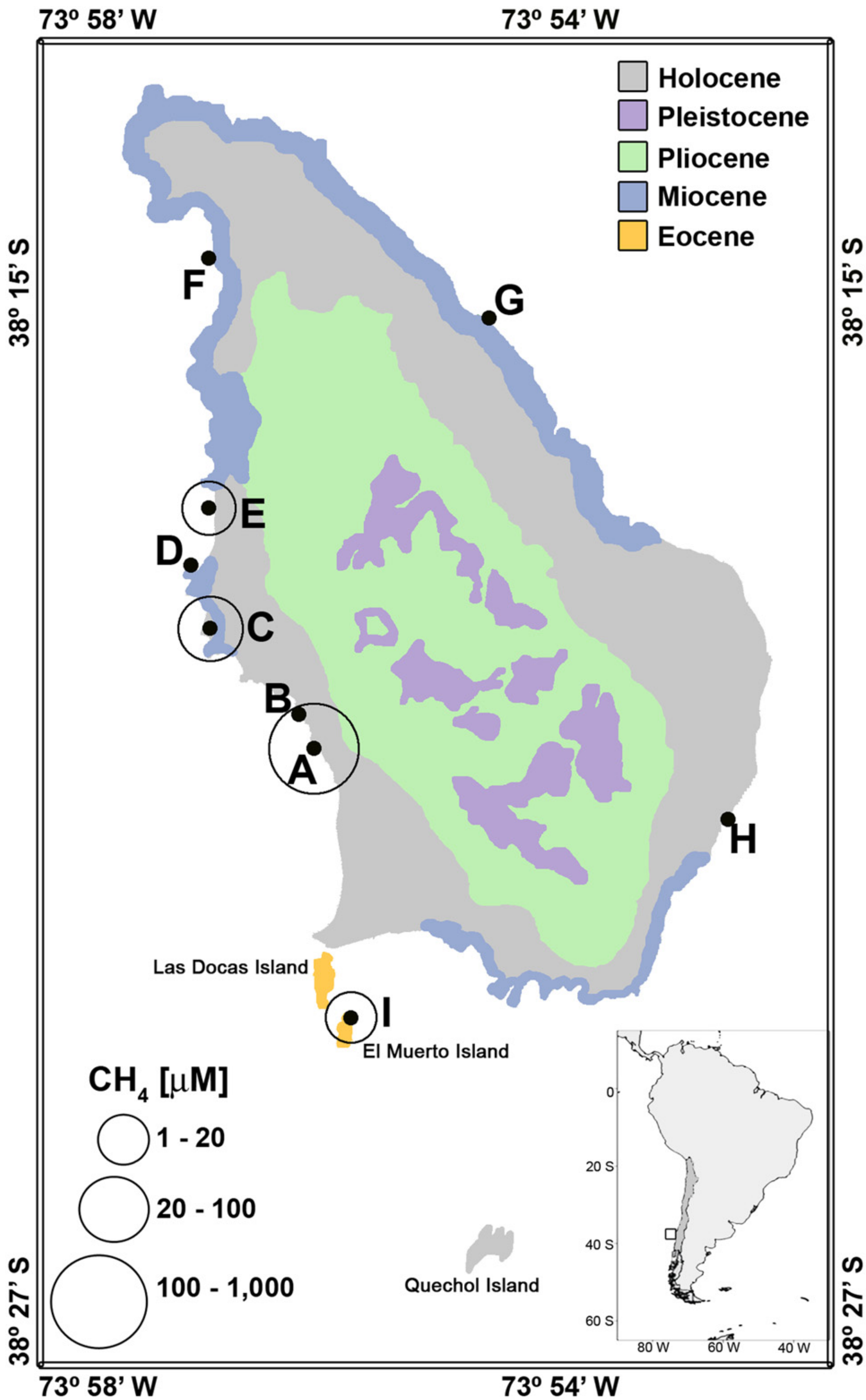

Fig. 1. Simplified geologic map of Mocha Island (adapted and modifed from Tavera and Veyl, 1958 and Sánchez, 2004) showing the sampling sites. Circles show methane concentration in water overlying the seeps.