Palaeogeography, Palaeoclimatology, Palaeoecology 462 (2016) 41–56

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Paleocene methane seep and wood-fall marine environments from Spitsbergen, Svalbard

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ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 25 August 2016
Accepted 27 August 2016
Available online 30 August 2016

Keywords:
Chemosynthesis-based environments
Conchocele
Ecology
Hydrocarbon seeps
Paleocene
Svalbard

ABSTRACT

Here we describe a Paleocene-aged methane seep locality and an associated layer of sunken wood, from Fossildalen on Spitsbergen, Svalbard, hosted in offshore to prodelta siltstones of the Basilika Formation, Van Mijenfjorden Group. The fossiliferous seep carbonates were first identified in museum collections from expeditions in the 1920s and 1970s, and subsequently sampled as *ex-situ* blocks in the field in 2015. The isotopically light composition ($\delta^{13}C$ values approaching −50‰ V-PDB), and characteristic petrographic textures of the carbonates combined with the isotopically light archaeal lipids are consistent with their formation at fossil hydrocarbon seep environment. The invertebrate fauna within the carbonates is of moderate diversity (17 species) and has a shallow water affinity. Wood specimens within the carbonates contain the borings and shells of wood-boring bivalves. The seep fauna is dominated by a species of the thyasirid genus *Conchocele*, common to other seeps of similar age. The data shed new light onto the history of methane seepage on Svalbard, and the evolution and ecology of seep and wood-fall faunas during the latest Cretaceous–earliest Paleogene time interval.

1. Introduction

Hydrocarbon seeps are sites of submarine hydrocarbon emission, common in shallow to deep marine settings in all oceans (e.g. Hovland, 1992; Fujikura et al., 1999; Domack et al., 2005; Dando, 2010). A high concentration of reduced compounds results in seeps hosting dense communities of invertebrates relying primarily on chemosynthetic primary production, unlike 'normal' marine benthic faunas, which largely depend on organic matter produced through photosynthesis (Sibuet and Olu, 1998; Levin, 2005). Similar communities relying on chemosynthetically-produced organic matter have also been recognized around hydrothermal vents and deep-marine organic enrichment sites associated with sunken animal and plant material (e.g. Smith and Baco, 2003; Bernardino et al., 2010). The dominant animal groups at modern oceanic chemosynthesis-based communities consist of solemyid, lucinid, thyasirid and vesicomyid clams, bathymodiolin mussels, abyssochryssoid gastropods and siboglinid tubeworms (e.g. Dando et al., 1991; Sibuet and Olu, 1998; Southward et al., 2001; Sahling et al., 2002, 2003; Taylor and Glover, 2010; Sasaki et al., 2010). Although palaeontological evidence supports the antiquity of some of these groups, especially solemyid bivalves and siboglinid tubeworms (e.g. Little et al., 1999; Little et al., 2004; Peckmann et al., 2005; Hryniewicz et al., 2016), several important seep taxa (vesicomyids and bathymodiolins) have currently their earliest records in the Eocene (Little and Vrijenhoek, 2003; Kiel and Little, 2006; Amano and Kiel, 2007; Vrijenhoek, 2013; Kiel and Amano, 2013; Kiel, 2015; Kiel and Hansen, 2015). Seep communities from the latest Cretaceous and the earliest Paleogene are therefore very important for constraining the age of origin of modern seep faunas. There are, however, just a handful of sites from this time interval, including some of the youngest aged Tepee Buttes seeps from the Maastrichtian of the Western Interior

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http://dx.doi.org/10.1016/j.palaeo.2016.08.037
0031-0182/

Seaway, USA (Metz, 2010); the Sada Limestone from the Campanian–Maastrichtian of Shikoku Island, Japan (Nobuhara et al., 2008); Maastrichtian seeps from the James Ross Basin, Antarctica (Little et al., 2015) and the Paleocene Panoche Hills seeps from California, USA (Schwartz et al., 2003). Possible chemosynthesis-dependent communities associated with sunken wood have also been described from the Paleocene of Hokkaido (Amano and Jenkins, 2014; Amano et al., 2015a, 2015b). This paper describes fossiliferous methane seep carbonates and wood-fall occurrences from Paleocene marine sediments from Fossildalen, Spitsbergen, Svalbard. The fauna from the seep carbonates is of moderate diversity and is dominated by the large thyasirid bivalve *Conchocele conradii* Rosenkrantz, 1942, with subordinate protobranch and lucinid bivalves, "naticiform" gastropods and other invertebrates. We present petrographic and geochemical evidence supporting our interpretation of the carbonates as fossil hydrocarbon seep deposits, and discuss the geological, ecological and evolutionary significance of the seep and wood-fall communities.

2. Geological setting

The material studied herein comes from the Central Cenozoic Basin of Spitsbergen (subsequently CCB; Fig. 1). The CCB is a NNW–SSE trending synclinorium, formed in the Paleogene during the strike-slip movement between Greenland and the Barents Sea shelf related to the opening of the Northern Atlantic (Steel et al., 1981; Dallmann, 1999). The basin encompasses nearly 2000 m of Paleocene and Eocene transitional to marine sediments of the Van Mijenfjorden Group, comprising fine- to coarse-grained clastics and subordinate coals (Dallmann, 1999). The fossiliferous carbonates and associated sunken wood layer described in this paper come from the late Paleocene deposits of the Basilika Formation (Major and Nagy, 1972; Manum and Throndsen, 1986; Dallmann, 1999). This represents offshore siltstones and subordinate sandstones, up to 350 m thick, with several thin volcanogenic clay layers (Dypvik and Nagy, 1978). The benthic foraminiferal fauna of the Basilika Formation indicates restricted offshore shelf to prodelta conditions and oxygen depletion, possibly related to water column stratification (Nagy et al., 2000). The Basilika Formation contains numerous glendonites – pseudomorphoses after carbonate hexahydrate mineral ikaite (Suess et al., 1982) – indicative of cold-water conditions in Spitsbergen during the late Paleocene (Spielhagen and Tripati, 2009).

3. Materials and methods

3.1. Locality information

A proportion of the fossils treated in this paper was previously described by Hägg (1925), Gripp (1927) and Vonderbank (1970). Chronologically the first work dealing with fossiliferous carbonates from the Paleocene of Fossildalen is that of Hägg (1925), material from which is curated at the Naturhistoriska Riksmuseet, Stockholm, Sweden. The specimens were collected at Colesbukta on the southern coast of Isfjorden by the Norwegian mining engineer Arthur Lewin during the summers of 1923 and 1924, and subsequently handed over to Hägg the following winter. The consequence is that Hägg's (1925) locality description is second-hand and rather general, indicating the western side of Colesbukta, 150 m above sea level and about 300–400 m above the base of the Cenozoic. A hand-drawn map of Arthur Lewin stored in Stockholm together with the appearance of the material suggests that Lewin's locality is somewhere around the small valley of Fossildalen. The material of Gripp (1927) was stored in the palaeontological collections of the Universität Hamburg, but was most likely destroyed during WWII (U. Kotthoff, 2015, personal communication). However, Gripp's locality description is helpful for the Fossildalen seep locality identification as he participated in the German 1925 Spitsbergen Expedition and collected the material himself. Gripp states that the

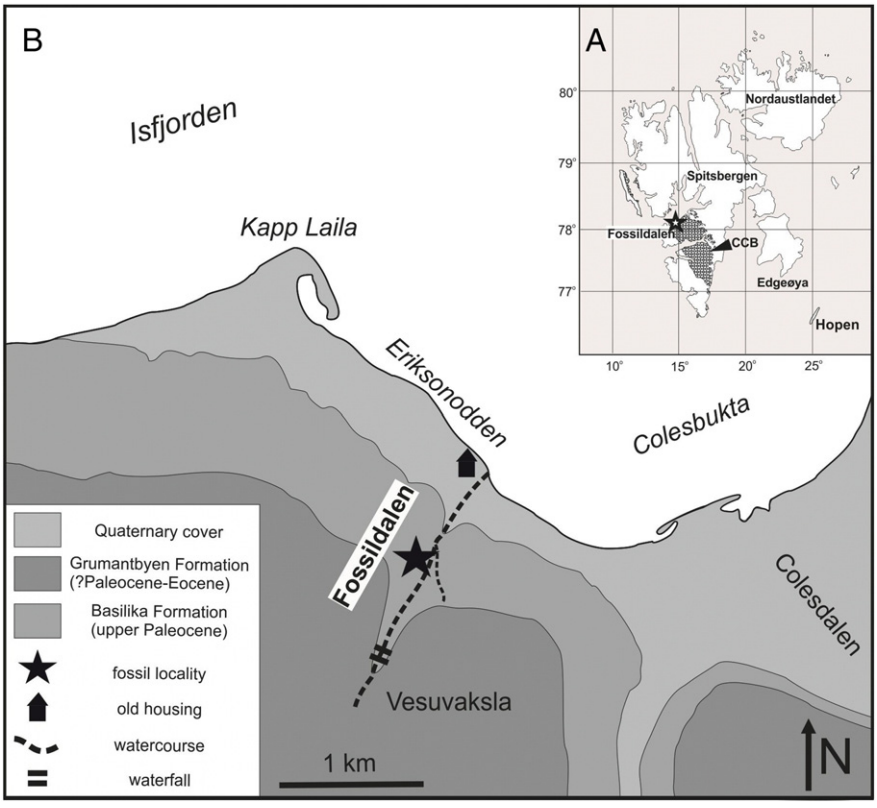

Fig. 1. A) Map of Svalbard with Cenozoic outcrops indicated, CCB stands for Central Cenozoic Basin; B) simplified geological map of the Fossildalen area with the approximate position of the study site and reference points of Gripp (1927) indicated; A) after Nagy et al. (2013); B) after Ohta et al. (1992), litostratigraphic unit names after Dallmann (1999).