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The connection between iron ore formations and "mud-shrimp" colonizations around sunken wood debris and hydrothermal sediments in a Lower Cretaceous continental rift basin, Mecsek Mts., Hungary

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ABSTRACT

In the Early Cretaceous, the continental rift basin of the Mecsek Mts. (Hungary), was situated on the southern edge of the European plate. The opening of the North Atlantic Ocean created a dilatational regime that expanded to the southern edge of the European plate, where several extensional basins and submarine volcanoes were formed during the Early Cretaceous epoch. Permanent seaquake activity caused high swell events during which a large amount of terrestrial wood fragments entered into submarine canyons from rivers or suspended woods which had sunk into the deep seafloor. These fragments created extended wood-fall deposits which contributed large-scale flourishing of numerous burrowing thalassinid crustaceans. Twelve different thalassinid coprolite ichnospecies can be found in the Berriasian–Hauterivian volcano-sedimentary formations.

According to the seladonitic crustacean burrows which associated with framboidal pyrite containing Zoophycos and Chondrites ichnofossils (i.e. a "fodinichnia" trace fossil association), the bottom water was aerobic and the pore water was anaerobic; in the latter sulfate reduction occurred. The preservation of wood fragments around thalassinid burrows can be explained by rapid sedimentation related to turbidity currents.

Due to the low temperature hydrothermal circulations of seawater, large amounts of iron were released from intrusive, pillowed basaltic sills; these sills intruded into soft, water-saturated sediments containing large amounts of thalassinid excrement. In the coprolites can be found idiomorphic mineral particles originating from the basalts, and coprolites can often be found in peperitic interpillow sediments. This indicates that the life-activity of the decapoda crustaceans in many Lower Cretaceous occurrences initially preceded the first magmatic eruptions. The paroxysm of the rift volcanism took place during the Valanginian age, when some submarine volcanoes emerged above sea level, reaching a maximum height of 300 m (above sea level); from these volcanoes further terrestrial plant debris got into the basin. Hydrothermal vents, which periodically occurred around basaltic bodies until the Hauterivian, could have contributed to the creation of favourable temperature or nutritional conditions for some decapoda crustaceans – e.g the recently described new callianassid (*Nihonotrypaea thermophila*), which is known only from hydrothermally infuenced habitats.

Around the intrusive pillow basalts, hydrothermal circulation of oxygenated seawater occured and thick seladonitic and goethitic fills formed along the cracks and cavities of pillowed basalts. When oxidized, sulfate-rich fluids passed into the crustacean coprolite-rich, reductive and anaerobic interpillow sediments, these fluids underwent an intensive sulfate reduction. This was primarily due to termophil sulfate reducers which as proved by the negative sulfur isotope values ($-35.9‰$ and $-28.0‰$ $\delta^{34}S$) of sulfidic hydrothermal chimneys which contain framboidal pyrite and which were formed between the pillow basalts. The largest chimney structure reached a height of 1 m, with a mass of about 150 kg. The sulfide phase is characterized by Mo enrichments up to 511 ppm. The fluid inclusion measurements from the calcitic precipitations of the sulfide chimneys indicate low temperature (~129 °C) hydrothermal activity, and the salinity of the primary fluid inclusions proves the seawater origin of the hydrothermal fluids. In some thalassinid crustacean coprolite rich interpillow sediments and in the cracks of some hydrothermal calcite, there is the presence of black, lustrous bitumine (gilsonite) which is the distillation product of hydrothermal petroleum formed mainly by the coprolites. Hydrothermal circulations

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of oxygenated seawater caused subsequent oxidation of the sulfidic, interpillow sediments and chimneys; these were altered to form goethite. Due to the short-period of the hydrothermal activity among the intrusive pillowed basalts, sulfidized interpillow sediments could not be oxidized completely.
The texture of the goethitic iron ore (as an interpillow sediment) is network-like and dentritic, which is very similar to the iron-oxidic and microbial textured sediments of the Juan de Fuca Ridge. The dendritic iron-oxide-hydroxide particles which were involved in this study are not hollow and exceed the size-domain characteristic for bacterial products. However, in some cases hollow- and tube-like particles having a diameter of 1.2–1.5 μm can refer to the activity of the *Sphaerotilus–Leptothrix* iron-oxidizer bacterial group.

1. Introduction

In the Lower Cretaceous, mainly deep water volcano-sedimentary sequences of the Mecsek Mts., thalassinid burrows and coprolites (up to 12 ichnospecies) can be found. Each one of these is associated with wood debris, but the sediments themselves often suffered hydrothermal alterations around Lower Cretaceous magmatic sills. Heterotrophic macrofaunal assemblages present in some hydrothermally active sediments exhibit higher densities and biomass relative to inactive sediments: for example, in the Manus Basin, South Su, Papua New Guinea, Southwestern Pacific Ocean, and in the Middle Valley near the Juan de Fuca hydrothermal vents, Northeastern Pacific Ocean (Levin et al., 2009). Furthermore, in the sediment-covered areas of the East Pacific Rise and which surround magmatic sills (e.g. Guayamas Basin, Gulf of California; Escanaba Trough, Middle Valley in the North-Eastern Pacific), as well as in such environments in the Bransfield Strait and Atlantis II Deep of the Red Sea, hydrothermal systems transform the organic matter of the sediments into hydrocarbons from methane to asphalt (Simoneit, 1988; Simoneit et al., 1996, Gieskes et al., 2002; Simoneit and Rushdi, 2002). These hydrocarbons contribute to the development of the heterotrophic bacterial community (Simoneit, 1990; Venkatesan et al., 2003). In some lakes, formed along continental rifts, hydrothermal activity has also been observed in association with chemosynthetic bacterial strenuousness. Examples include Lake Baikal (Crane, 1991), Lake Baringo (Renaut et al., 2002), and Lake Tanganyika (Tiercelin, et al., 1993).

“Mud-shrimp” infraorders, which were at one time considered together as forming a single group of “thalassinideans”, have recently been separated into two major clades and infraorders (Axiidea and Gebiidea). Molecular and morphological evidence (Dworschak et al., 2012) has reinforced this separation but, based on the mainly collective ecological requirements and burrowing strategy, in this study the Thalassinidea designation is used.

Until recently, Thalassinid shrimps had only very rarely been reported from hydrothermally-influenced sediments and from wood fall or whale fall deposits. A callianassid mud shrimp, *Callianassa truncata*, was identified around shallow water vents from the lower temperature region of the sediment (<40 °C) near the islands of Milos and Santorini in the Hellenic Volcanic Arc of the Aegean Sea (Dando et al., 1995). Türkay and Sakai (1995) described *Paraglypturus calderus*, a new genus and species of a callianassid from an active submarine volcano (at 63–114 m) in the Mariana Arc. Sakai and Türkay (1999) described the new genus and species of a callianassid, *Bathycalliax geomar*, from the deep water cold seeps of Oregon. Dworschak and Cunha (2007) described the pale white *Vulcanocalliax arutyunovi*, a new genus and species of the callianassidae from chemoautotroph communities of the deep water mud volcanoes in the Gulf of Cádiz. Lin et al. (2007) reviewed a new callianassid, *N. thermophila* from deep water hydrothermal vents of Taiwan; and Komai and Fujiwara (2012) identified *N. thermophila* from the hydrothermally influenced field in Kagoshima Bay, Japan, concluding that this species occurred only in association with hydrothermalism. Komai and Fujiwara (2012) also described a new callianassid genus (*Cheramus cavifrons*) collected from the reducing area around artificially implanted whale carcasses.

The oldest record of decapods from the fossil chemosynthetic communities seems to come from the Jurassic of France (Peckmann et al., 1999; Campbell, 2006; Senowbari-Daryan et al., 2007). The callianassids from fossil chemosynthetic communities are also known from the Oligocene of Washington and Alaska (Goedert and Campbell, 1995; Peckmann et al., 2002). Peckmann et al. (2007) reported two unnamed species of a callianassid associated with the ichnofossil *Palaxius* from the methane-seep limestone included in the Eocene Humptulis Formation of Washington. Buchs et al. (2009) found paleocene thalassinid coprolites from interpillow sediments of a deep water seamount near South Costa Rica, and raised the possibility that these shrimps were members of a chemosynthetic community. Most recently, Karasawa (2011) reported a new callianassid, *Callianassa hayano*, from a Lower Cretaceous cold-seep related siltstone from Hokkaido, Japan.

Along with hydrothermal vents and cold seeps, wood falls are regarded as sulfide-rich reducing environments (Smith et al., 2003), where wood debris is released from the coastal zone during high swell events (Duggins et al., 1989). In this form it can be concentrated and transported to depths in submarine canyons to create vast accumulations of organic material in the deep ocean (Vetter, 1994; Vetter and Dayton, 1998, 1999; McLeod and Wing, 2007). This process is of fundamental importance to the nutritional ecology of deep waters (Cayré and Richer de Forges, 2002, Smith et al., 2003, Palacios et al., 2006). It is recognized that wood-falls on the deep sea floor contribute to the beta diversity in the deep sea by creating patches of organic enrichment and chemical or physical disturbance (Stockton and DeLaca, 1982; Smith and Hamilton, 1983; Smith, 1985, 1986; Grassle and Morse-Porteous, 1987; Snelgrove and Smith, 2002). Thalassinid crustaceans have been recorded from hypoxic and sulfidic sediments, where the shrimps are highly tolerant of hypoxia and are able to maintain aerobic metabolism down to very low oxygen partial pressures; moreover, some species are able to survive anoxic conditions for several days (Atkinson and Taylor, 2005). Thalassinid and Galatheid crustaceans associated with sunken woods were collected during exploration cruises of the Tropical Deep Sea Benthos cruises program (TDSP) (Samadi et al., 2010); furthermore, analysis of the diet of a Galatheid crab, *Munidopsis andamanica*, showed that this species effectively feeds on wood (Hoyoux et al., 2009).

Fossil wood fall occurrences in hydrothermally active volcano-sedimentary basins have never been studied until now, and fossil hydrothermal chimneys on paleo-oceanic or continental rifts are less known too. Occurrences around the world are rare, and are usually poorly-preserved (Larter et al., 1981; Boyce et al., 1983; Haymon et al., 1984; Hannington and Scott, 1988; Crane, 1991; Vearncombe et al., 1995; Zaykov et al., 1996; Little et al., 1997, 1998, 1999a,b; Li and Kusky, 2007; Chen et al., 2009). A fossil “black smoker”, developed in a continental rift-system, has been found at only one place, in the North-China Craton, along a synsedimentary fault (Li and Kusky, 2007).