Palaeogeography, Palaeoclimatology, Palaeoecology 437 (2015) 165–180

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Disentangling the history of complex multi-phased shell beds based on the analysis of 3D point cloud data

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ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form 14 July 2015
Accepted 20 July 2015
Available online 1 August 2015

Keywords:
Terrestrial laser scanning
Oyster biostrome
Miocene
Taphonomy
Tsunami

ABSTRACT

We present the largest GIS-based data set of a single shell bed, comprising more than 10,280 manually outlined objects. The data are derived from a digital surface model based on high-resolution terrestrial laser scanning (TLS) and orthophotos obtained by photogrammetric survey, with a sampling distance of 1 mm and 0.5 mm, respectively. The shell bed is an event deposit, formed by a tsunami or an exceptional storm in an Early Miocene estuary. Disarticulated shells of the giant oyster *Crassostrea gryphoides* are the most frequent objects along with venerid, mytilid and solenid bivalves and potamidid gastropods. The contradicting ecological requirements and different grades of preservation of the various taxa mixed in the shell bed, along with a statistical analysis of the correlations of occurrences of the species, reveal an amalgamation of at least two pre- and two post-event phases of settlement under different environmental conditions. Certain areas of the shell bed display seemingly significant but opposing shell orientations. These patterns in coquinas formed by densely spaced elongate shells may result from local alignment of neighboring valves due to occasional events and bioturbation during the years of exposure. Similarly, the patchy occurrence of high ratios of shells in stable convex-up positions may simply be a result of such "maturity" effects. Finally, we document the difficulties in detecting potential tsunami signatures in shallow marine settings even in exceptionally preserved shell beds due to taphonomic bias by post-event processes.

1. Introduction

Shell beds are key features in sedimentary records throughout the Phanerozoic. The interplay between burial rates and population productivity is reflected in distinct degrees of shelliness (Tomašových et al., 2006; Patzkowsky and Holland, 2012). Consequently, shell beds may provide information on various physical processes that led to the accumulation and preservation of hard parts. Many shell beds pass through a complex history of formation being shaped by more than one factor (Kidwell, 1986, 1991; Fürsich and Oschmann, 1993; Mandic et al., 2004a; Zuschin et al., 2005, 2007). In shallow marine settings, the composition of shell beds is often strongly influenced by winnowing, reworking and transport. These processes may accumulate specimens that lived thousands of years apart (Kidwell and Tomašových, 2013 and references therein). A major obstacle in interpreting shell beds is the amalgamation of several depositional units in a single concentration, as is typical for tempestites and tsunamites. Disentangling such mixed assemblages requires understanding the ecological requirements of the taxa involved – which is achievable for geologically young shell beds with living relatives – and a statistical approach to quantify the contribution by the various death assemblages. Furthermore, it requires understanding the sedimentary processes potentially involved in their formation.

Here we present the first attempt to describe and decipher such a multi-phase shell bed based on a high-resolution digital surface model

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http://dx.doi.org/10.1016/j.palaeo.2015.07.038

(DSM) with a resolution of 1 mm combined with orthophotos with a nominal resolution of 0.5 mm per pixel. The shell accumulation covers an area of 27 × 17 m (459 m^2) with about 54,000 specimens, which were excavated at Stetten in Lower Austria (Fig. 1). Formed in an Early Miocene estuary of the Paratethys Sea, the shell bed is mainly composed of shells of the giant oyster *Crassostrea gryphoides* along with numerous other bivalves, gastropods and barnacles. This *Crassostrea* shell bed is the world's largest excavated fossil oyster biostrome and is a highlight of the geo-edutainment park "Fossilienwelt Weinviertel" (www.fossilienwelt.at/).

The term oyster reef is well established in estuarine ecology (e.g.: Powell et al., 2006; Thomsen et al., 2007; Lejart and Hily, 2011; van der Zee et al., 2012). Herein, we prefer to use the term biostrome of Lahee (1932) because many intertidal oyster bioconstructions lack a strong vertical growth component.

2. Geological setting and paleoenvironment

The Stetten site (48° 22′ 03.33 N, 16° 21′ 33.22 E) is part of the small Austrian Korneuburg Basin (KB), which is a half graben that formed within the Alpine-Carpathian thrust belt. This basin is about 20 km long and attains a maximum width of 7 km, but it is strongly narrowed in its northern extension (Wessely, 1998). The investigated oyster biostrome is the upper part of an about 600-m-thick siliciclastic succession of the Korneuburg Formation in the southern basin, which is tilted ca. 25° in the western direction (Fig. 2). Sand packages with trough cross-bedded sets are interpreted as tidal sand waves of the shoreface. Pelitic sediments mostly show even lamination to wavy bedding or thinly alternating sandy and muddy layers, indicative of tidal flat deposits (Zuschin et al., 2014). These deposits were dated into nannoplankton zone NN4, paleomagnetic chron C5C and mammal zone MN5 (Harzhauser and Wessely, 2003) corresponding to the latest Early Miocene (Burdigalian; Karpatian regional stage, ~16.2 Ma.).

A comprehensive data set on the fauna and flora of KB was published by Sovis and Schmid (1998, 2002). Additional details on ecology, climate and water chemistry were provided by Latal et al. (2005, 2006), Kern et al. (2010), Zuschin et al. (2004, 2014) and Harzhauser et al. (2007, 2010). A popular synthesis of the paleoenvironment is given in Harzhauser et al. (2009). According to these paleontological and geochemical data, the southern part of the basin was an estuarine ecosystem that existed for more than 700,000 years due to its peculiar tectonic setting and significant subsidence (Harzhauser et al., 2002; Latal et al., 2005, 2006; Zuschin et al., 2014). The foraminifera and mollusc faunas were partly adapted to brackish water conditions and indicate a very shallow water environment, with a maximum water depth of about 30 m (Rögl, 1998; Harzhauser et al., 2002). Along the seaward fringe, an *Avicennia* mangrove was established. Tidal mudflats and sandbars were settled by vast *Crassostrea* biostromes. These "reefs" became established in the mixohaline shallow subtidal to lower intertidal zone of the estuarine bay. Brackish marshes, shallow lakes, oxbows and rivers developed as the typical wetland types of the southern Korneuburg Basin (Harzhauser et al., 2002; Kern et al., 2010). A diverse mammalian fauna lived in the swamps and forests (Daxner-Höck, 1998). Palynological analyses by Kern et al. (2010) revealed a subtropical climate with mean annual temperatures between 15.7 and 20.8 °C.

Fig. 2. The shell bed in the geo-edutainment during the terrestrial laser scanning campaign, showing the post-sedimentary tilting in the western direction.

3. Taxonomic inventory and autecology

During the excavations of the biostrome in 2005 and 2008, a detailed taxonomic survey of the macrofauna (>5 mm) was conducted, yielding an inventory of 46 molluscan species, comprising 23 gastropod, 1 cephalopod and 22 bivalve species (Table 1). The abundances of these taxa were categorized semi-quantitatively as *rare* (<10 specimens), *common* (10–100 specimens) and *frequent* (>100 specimens) in relation to the total excavation area of 459 m^2 (each bivalve shell counted as an individual). The most frequent gastropod species are the neritid *Nerita plutonis* (Basterot, 1825), the potamidid *Ptychopotamides papaveraceus* (Basterot, 1825), the calyptraeids *Calyptraea depressa* Lamarck, 1822 and *Calyptraea irregularis* (Cossmann and Peyrot, 1919), the naticid *Polinices pseudoredemptus* (Friedberg, 1911–28) and the nassariid *Nassarius edlaueri* (Beer-Bistrický, 1958). Among the bivalves, only 5 species are common to frequent: *C. gryphoides* (Schlotheim, 1813), *Perna aquitanica* (Mayer, 1858), *Ostrea digitalina* Dubois de Montpereux,

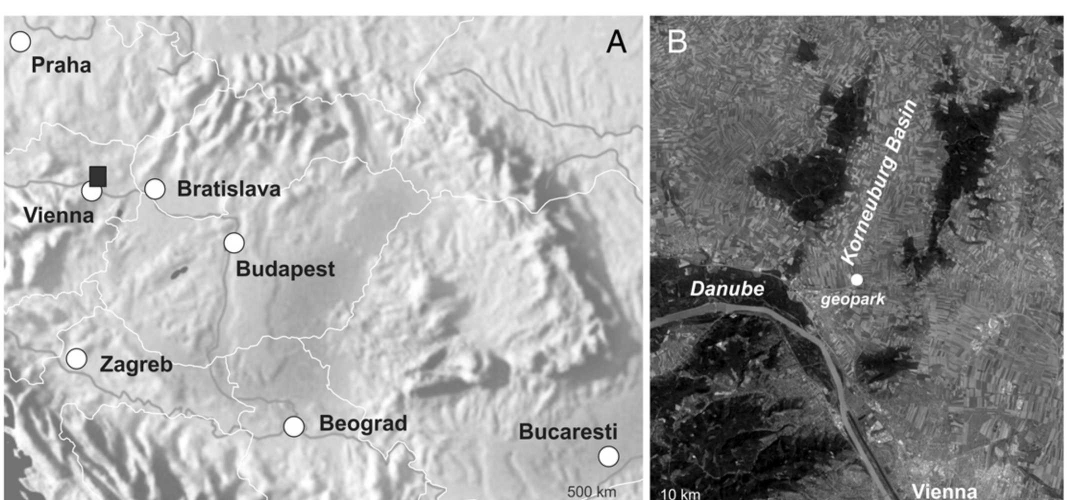

Fig. 1. Geographic setting of the Korneuburg Basin in Austria at the junction between the Alps and the Carpathians (A) and position of the site north of Vienna (B); map corresponds to black rectangle in A.