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Computed reconstruction of spatial ammonoid-shell orientation captured from digitized grinding and landmark data ☆

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ABSTRACT

The internal orientation of fossil mass occurrences can be exploited as useful source of information about their primary depositional conditions. A series of studies, using different kinds of fossils, especially those with elongated shape (e.g., elongated gastropods), deal with their orientation and the subsequent reconstruction of the depositional conditions (e.g., paleocurrents and transport mechanisms). However, disk-shaped fossils like planispiral cephalopods or gastropods were used, up to now, with caution for interpreting paleocurrents. Moreover, most studies just deal with the topmost surface of such mass occurrences, due to the easier accessibility. Within this study, a new method for three-dimensional reconstruction of the internal structure of a fossil mass occurrence and the subsequent calculation of its spatial shell orientation is established. A 234 million-years-old (Carnian, Triassic) monospecific mass occurrence of the ammonoid *Kasimlarceltites krystyni* from the Taurus Mountains in Turkey, embedded in limestone, is used for this pilot study. Therefore, a $150 \times 45 \times 140\ mm^3$ block of the ammonoid bearing limestone bed has been grinded to 70 slices, with a distance of 2 mm between each slice. By using a semi-automatic region growing algorithm of the 3D-visualization software Amira, ammonoids of a part of this mass occurrence were segmented and a 3D-model reconstructed. Landmarks, trigonometric and vector-based calculations were used to compute the diameters and the spatial orientation of each ammonoid. The spatial shell orientation was characterized by dip and dip-direction and aperture direction of the longitudinal axis, as well as by dip and azimuth of an imaginary sagittal-plane through each ammonoid. The exact spatial shell orientation was determined for a sample of 675 ammonoids, and their statistical orientation analyzed (i.e., NW/SE). The study combines classical orientation analysis with modern 3D-visualization techniques, and establishes a novel spatial orientation analyzing method, which can be adapted to any kind of abundant solid matter.

1. Introduction

1.1. Mass occurrences and their internal orientation as key to paleoenvironments

Abundant marine fossils, especially with elongated shapes (e.g., belemnites), are useful indicators to draw conclusions about influencing factors (e.g., sea floor paleocurrents and transport mechanisms) of paleoenvironments. Since Hall (1843) regarded the orientation of brachiopod valves as current induced, a series of studies have been conducted concerning fossil orientation measurements (Potter and Pettijohn, 1977). Orthocone cephalopods (e.g., nautiloids like *Orthoceras*; Wendt et al., 1984; Wendt, 1995), gastropods (e.g., Seilacher, 1959, 1960; Wendt, 1995; Cataldo et al., 2013), bivalves (Kelling and Moshrif, 1977), foraminifers (King, 1948), tentaculite shells (Hladil et al., 1996), trilobites (Seilacher, 1959, 1960) and vertebrate bones (e.g. Vasiļkova et al., 2012) have been used so far in field-based spatial orientation studies (Flügel, 2004). Kidwell et al. (1986) analyzed two-dimensional geometries of skeletal accumulations with focus on their preferred orientation. However, the indication of current patterns is not only restricted to fossils with elongated basic shape and their nature to be reoriented by any kind of current. Planispirally coiled (disk-shaped) forms like gastropods, but also cephalopods such as ammonoids can also provide such depositional information (e.g., Futterer, 1982; Wendt, 1995; Lukeneder, 2005; Olivero, 2007; Seilacher, 1971; Wani, 2006, 2007).

The main aim of this study is to present a novel method for analyzing spatial orientation, which can be adapted to all kinds of

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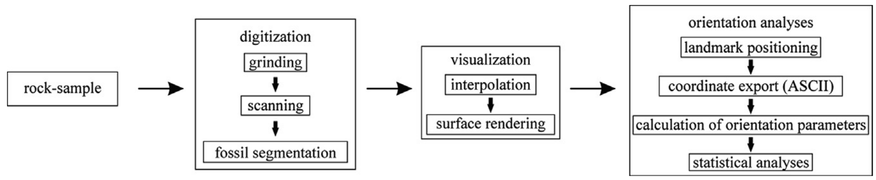

Fig. 1. Steps used for digitization and visualization of the ammonoids as well as for subsequent calculation and evaluation of their spatial shell-orientation.

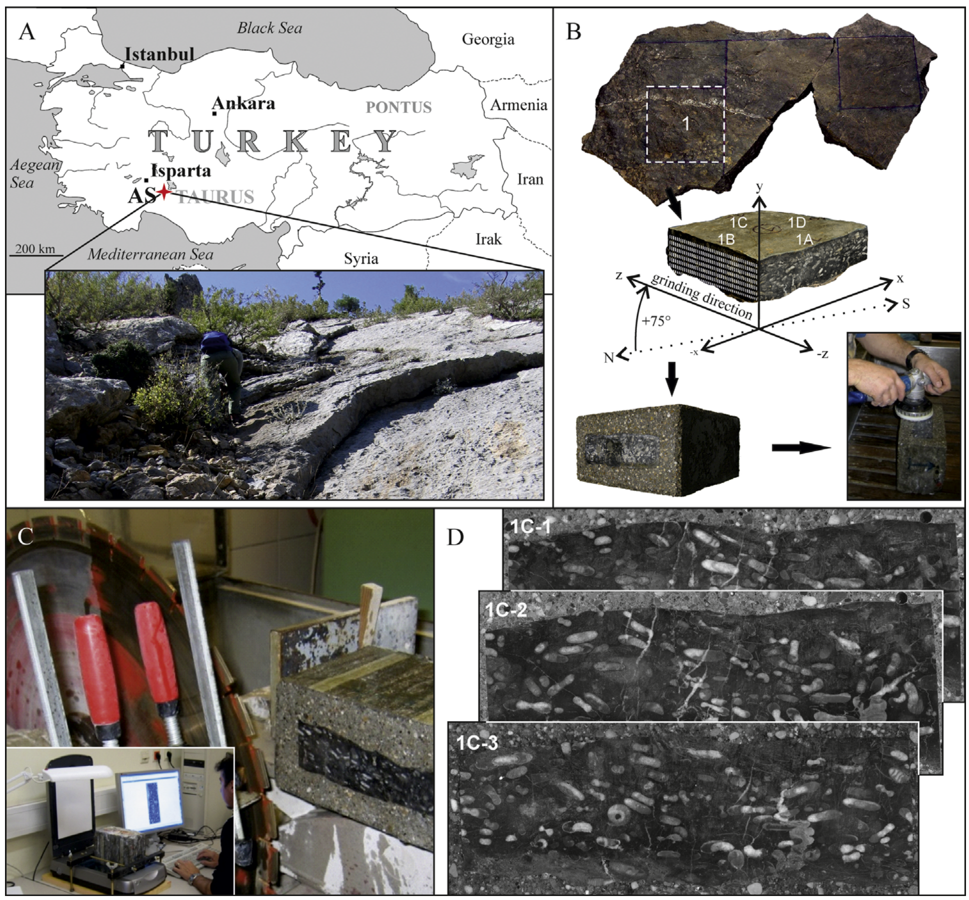

Fig. 2. Explanation of the grinding and digitizing method of the ammonoid mass occurrence from Aşağiyaylabel. (A) Geographic location of the limestone bed. (B) The recovered limestone bed and the $150 \times 45 \times 140$ mm^3 limestone sample, which was geographically adjusted and set into concrete. (C) Grinding, polishing and scanning of the slices. (D) Three examples of the 70 scanned slices, with a distance of 2 mm.

abundant solid matter such as fossils and particles or to geological features such as faults, folds or rock core analyses.

1.2. *Serial-grinding as possible alternative to computed tomography*

The application of 3D-visualization on different kinds of objects and in different scientific fields has increased enormously. Since Sollas (1903) introduced the method of serial sectioning within his work on Therapsida and Lysorophia (Camp and Hanna, 1937), 3D-visualization has been adapted for a wide field of paleontological studies (e.g., VanderHoof, 1931; Simpson, 1933; Koslowski, 1932; Stensiö, 1927; Fourie, 1974; Conroy and Vannier, 1984; Ketcham and Carlson, 2001; Marschallinger, 2001, 2011; Dockner, 2006; Sutton, 2008; Garwood et al., 2010; Briguglio et al., 2011; Kruta et al., 2011; Lukeneder, 2012). The most obvious method used for digitization today is computed tomography (CT) with all its derivatives (e.g., macro-CT, μ-CT, nano-CT, etc.). However, CT is not always successful, particularly when the density contrast of the involved materials is too low. This is exactly the case for the herein presented ammonoid mass occurrence, caused by the almost equal density of the ammonoid shells (i.e., secondary calcite shells, 2.6–2.8 g/cm^3) and the embedding source rock (limestone, 2.8 g/cm^3). Therefore, we applied the classic method of serial-grinding, despite its invasive and (partially or entirely) destructive character. If samples are large enough to sacrifice fractions of it, serial grinding represents a good alternative in cases when digital recording methods fail, because in addition to a good resolution, color information (not available in CT-scans) can be obtained as well.

In our approach, we focus on the three-dimensional reconstructions of the ammonoids from the entire bed, instead of focusing on the fossil orientation on the surface of a sedimentary horizon. This and the spatial analysis of their orientation within a stereographic projection plot are the main innovations of this study compared to other conventional fossil-orientation-studies. An overview over the entire approach, from fossil collection to orientation analyses, can be gleaned from Fig. 1.