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Research paper

Shapes of organic walled dinoflagellate cysts in early diagenetic concretions—markers for mechanical compaction

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ABSTRACT

Two species of organic walled dinoflagellate cysts: *Pareodinia ceratophora* Eisenack 1938 (Jurassic) and *Deflandrea phosphoritica* Deflandre 1947 (Palaeogene) are proposed as markers for determining the mechanical compaction ratio of fine-grained rocks. The near original shapes of these species are obtained from specimens preserved in siderite and calcareous concretions occurring in mudstone host rocks of various ages. An efficient and simple light microscopy examination method of the dinoflagellate cyst height along the microscope optical axis is presented and quantitatively tested on the available material. The differences of the cyst height measurements between specimens preserved in concretions and specimens preserved in the host rock deposits reflect the compression of dinoflagellate cysts most likely due to mechanical compaction of the rocks studied. The mechanical compaction ratios revealed are about 67% for Jurassic mudstones and about 64% for Palaeogene mudstones. Further marker investigations of samples from different outcrops and strata of different ages are recommended.

1. Introduction

Organic walled dinoflagellate cysts are composed of a macromolecular, highly resistant, viscoelastic organic compound called dinosporin, which is synthesized around the living cell (Fensome et al., 1993; Traverse, 2007; Mertens et al., 2009). This organic biopolymer has similarities to sporopollenin, but is specific to dinoflagellates.

The chemical nature of dinosporin in dinoflagellates has recently been broadly studied in a few modern (Kokinos et al., 1998) and fossil species (de Leeuw et al., 2006; Bogus et al., 2012; Versteegh et al., 2012).

Several recent studies focus on the changes in cyst morphology in response to environmental conditions both in modern species (Lewis and Hallett, 1997; Ellegaard et al., 2002; Mertens et al., 2009; Rochon et al., 2009) and palaeontological material (Pross, 2001; Dybkjær, 2004; Sluijs et al., 2005). Other physical issues of the studies on dinoflagellate cyst walls were focused mainly on the biometry of the length of processes as a proxy of salinity and temperature conditions (Mertens et al., 2009, 2010; Verleye et al., 2012).

Thermal and mechanical damages of dinoflagellate cyst assemblages from impact deposits were studied by Edwards and Powars (2003). They concluded that experimental work is needed to determine temperatures and pressures resulting in the cyst deformations observed.

The first attempts to correlate dinoflagellate cyst deformation with mechanical compaction were made by Munnecke and Servais (1996) and Westphal and Munnecke (1997), who analysed the deformations of thin-walled organic microfossils in fine-grained carbonates with a SEM. They discussed the shapes of dinoflagellate cysts in un-altered rocks of Pliocene age and of acritarchs in compacted rocks of Silurian age using samples with etched surfaces. They concluded that thin-walled organic microfossils are reliable indicators of mechanical compaction, particularly in fine-grained limestones lacking other compaction indicators.

The estimation of sediment compaction is an important input for seismic interpretation, depth conversion, and sedimentary basin modelling (Marcussen et al., 2009). This complex process, starting immediately after deposition, leads towards higher density of the sediments and their transformation into consolidated rocks. Mechanical compaction is usually followed by chemical compaction and controlled by thermodynamics and kinetics independent of the stress (Bjørlykke and Jaren, 2010). The main factors controlling both types of compaction processes are: grain size and mineralogy, sediment texture, pore fluid properties, effective stress, time and temperature (Puttiwongrak et al., 2013). The process of mechanical compaction affects all sediment components, including mineral grains, macrofossils, trace fossils, pelloids, ooids and microfossils (Bathurst, 1986; Ricken, 1986; Davaud et al., 1990; Zuschina et al., 2003). Finally, variable thickness reduction caused by compaction is an important issue for rock porosity and permeability considerations.

A number of indicators are commonly used to assess the mechanical compaction of various types of sediments. These consist of deformation of trace fossils, peloids or ooids, breakage of grains, orientation of elongated components, and deformation of fenestral structures and

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organic walled microfossils (Meyers and Hill, 1983; Bathurst, 1986; Gaillard and Jautée, 1987; Ricken, 1987; Lasemi et al., 1990; Westphal and Munnecke, 1997).

This study presents a new, light microscopy method for the assessment of the mechanical compaction ratio in mudstones by measuring the height of organic walled dinoflagellate cysts, a parameter which reflects the compression of the cyst body. The dinoflagellate cysts extracted from early diagenetic calcareous (Bojanowski, 2001) and siderite concretions (Majewski, 2000) revealed less compressed shapes than their counterparts from the neighbouring host rocks. Measurements of two common species of dinoflagellate cysts: *Pareodinia ceratophora* (Jurassic) and *Deflandrea phosphoritica* (Palaeogene) from different localities of different ages are presented as an example.

2. Material

Samples of siderite concretions (A, B) and the host rock (C, D) yielding specimens of P. *ceratophora* were collected from the Middle to Upper Bathonian dark grey mudstones (Matyja and Wierzbowski, 2006) in the Gnaszyn brick-pit near Częstochowa city (Central Poland). This area is situated in the Kraków-Silesia Homocline, which is a widespread geological structure dipping gently to the NE. In total, 131 measurements were made of the well preserved *P. ceratophora* specimens from this site.

The *D. phosphoritica* specimens were extracted from laminated calcareous concretions (samples E, F, G) and the host rock (samples H, I) collected from the Lower Oligocene (Barski and Bojanowski, 2010) grey to black mudstones of the Grybów Unit in the Outer Western Carpathians. This tectonised succession crops out along the banks of the Krokowy stream and generally dips at about 5–6° to the north. The material collected provided 92 specimens of well preserved *D. phosphoritica* specimens which were measured.

The taxonomic composition of the dinoflagellate cyst assemblages in siderite and calcareous concretions is not significantly different from that of the host rocks. Beside dinoflagellate cysts, the assemblages contained abundant pollen, spores, terrestrial debris and rare foraminiferal linings.

3. Dinoflagellate cysts height—the method

The rock material was processed following palynologic preparation including 37% HCL, 40% HF, 78% HNO3 and 5% KOH treatment. Finally, the organic residuum was concentrated by a 15 μm diameter sieve and heavy liquid (2.0 g/cm^3) separation. For observation, the palynological residues, stored in demineralised water, were mounted in warm glycerine jelly on a coverslip and subsequently cooled down and placed onto a microscope glass. The first, warm phase of glycerine jelly enabled the specimens to float and have time to fix in the right position for being measured. Measurements and photomicrophotographs were taken using a transmitted light Nikon Eclipse E-600 microscope equipped with a Nikon Plan 40×/0.65 objective and a Nikon CFI 10×/22 eyepiece.

Evaluation of the height of the dinoflagellate cyst, treated here as a three-dimensional object, was based on the linear measurements along the microscope optical axis in the light microscope. In order to measure the specimens, the objects were centrally positioned in the field of view, the microscope was focused on the uppermost detail on the cyst surface, and subsequently on the lowermost detail on cyst surface (high and low focuses, respectively) (Figs. 1 and 2A). The fine focus knob values (Fig. 2B) were recorded and calculated. According to Nikon's Eclipse-600 microscope instruction, one division of the fine focus knob scale corresponds to 1 μm of vertical stage movement, thus all measurements were easy transferred to metric units. To check the accuracy of this method, measurements were made of a coverslip with a known thickness that had been checked with a mechanics micrometre. The height of the coverslip was achieved by focusing the upper and lower felt-tip pen lines marked on both sides of the coverslip (Fig. 2C), respectively, and recording the fine focus knob values. The values encountered were comparable to the original manufacturer specification of about 1 μm.

Experimental measurements of the length and width of the specimens belonging to the two described species revealed no significant differences of these dimensions between the samples from concretions and the host rock, therefore such measurements were finally discounted. This procedure corresponds with the statement of Ricken

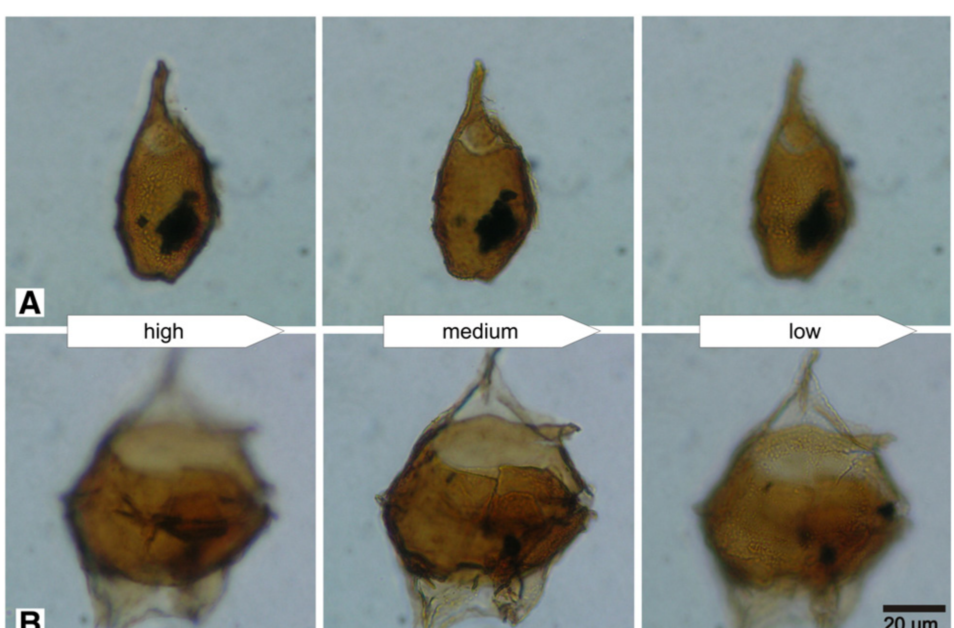

Fig. 1. High, medium and low focuses of specimens during axial linear measurements A. *Pareodinia ceratophora* Eisenack 1938, B. *Deflandrea phosphoritica* Deflandre 1947.