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ABSTRACT

In a recently-published paper, Galasso et al. (2022) interpreted relatively high levels of unseparated spore tetrads and some darkened miospores which occur immediately below the Toarcian Oceanic Anoxic Event (~183 Ma) in southwest Germany as resulting from enhanced levels of UV-B radiation due to high levels of volcanism at this time. The present authors consider that this teratological interpretation is unlikely, and more plausible explanations of these phenomena are rapid sedimentation and short transport durations, and reworking respectively.

Keywords: Germany; Lower Jurassic; pollen and spores; reworking; sedimentology; teratology

1. Introduction

Galasso et al. (2022) is a comprehensive study on the marine and terrestrial palynology of the Lower Toarcian (Lower Jurassic) Posidonia Shale Formation (*Posidonienschiefer*) at Dormettingen, ~70 km southwest of Stuttgart in Baden-Württemberg, southwest Germany. The succession studied by these authors, based on 59 samples, is independently dated by ammonites, and its geochemistry and sedimentology are very well studied. It includes the

Toarcian Oceanic Anoxic Event (T-OAE) which is a geologically short-lived hyperthermal interval which occurred at ~183 Ma. The T-OAE is associated with extremely high rates of organic-carbon burial, sea level rise and elevated rates of extinction. It has been linked to the prodigiously rapid release of methane into the atmosphere from destabilised marine gas hydrates (Hesselbo et al. 2000).

The authors of the present comment warmly congratulate Francesca Galasso and her two co-authors on this well-illustrated, well-structured and well-written work which consummately documents the palynology of this iconic reference section. The succession studied is 12 m in thickness and comprises the uppermost Amaltheenton Formation (uppermost Pliensbachian) and the Posidonia Shale Formation (Lower Toarcian); it spans the four ammonite zones *Pleuroceras spinatum*, *Dactylioceras tenuicostatum*, *Harpoceras falciferum* and *Hildoceras bifrons*, and their constituent ammonite subzones.

2. Comments on two aspects of Galasso et al. (2022)

The present authors wish to comment specifically on two aspects of Galasso et al. (2022), namely, the nature and interpretations of a spike in unseparated spore tetrads, and some darkened pollen and spores from stratigraphically immediately below the pronounced negative carbon isotope excursion (CIE) of the T-OAE (i.e., subsections 4.2.1. and 4.2.2. of Galasso et al. 2022 respectively). These phenomena were both observed in the interval DJ1 covering samples D50 to D92, representing the uppermost part of the Amaltheenton Formation (uppermost Pliensbachian, *Pleuroceras spinatum* ammonite zone) and the lower part of the Posidonia Shale Formation (Lower Toarcian, *Dactylioceras tenuicostatum* ammonite zone).

2.1. Unseparated spore tetrads immediately pre-dating the T-OAE

Galasso et al. (2022, fig. 4) noted relatively common tetrads of cryptogam spore species such as *Kraeuselisporites reissingeri* and *Leptolepidites equatibossus* in the *Dactylioceras tenuicostatum* ammonite zone in interval DJ1 below the CIE which indicates the T-OAE. These tetrads were interpreted as “aberrant forms” by Galasso et al. (2022, subsection 4.2.1.), and these authors attributed this phenomenon as being indicative of a failure of the primary tetrads to separate during meiosis as proposed by Visscher et al. (2004).

Galasso et al. (2022) contended that this spike in unseparated spore tetrads in this interval was caused by severe environmental stress related to enhanced volcanic activity from the Karoo-Ferrar Large Igneous Province, and the associated thinning of the ozone layer. This led to increasing biologically destructive UV-B radiation, in addition to severe chemical pollution for example by mercury. These authors offered no *prima facie* evidence of enhanced volcanism proxied for by, for example mercury spikes, or any other environmental stressors at this time, although enhanced mercury levels have been recorded close to the Pliensbachian–Toarcian transition (Percival et al. 2016, Al-Suwaidi et al. 2022). We strongly believe that the increased volcanism proxied by the high levels of mercury was most likely not responsible for the increase in unseparated spore tetrads. It is far more plausible that factors such as rapid sedimentation and short transport durations were the principal causal factors in this case (Tyson 1995). Sedimentological phenomena related to the acceleration of the hydrological cycle such as these offer a far simpler, and much more credible, explanation for this spike in unseparated tetrads than unsubstantiated speculation about high level of volcanic pollutants and UV-B radiation.

This contention is supported by recent findings on the occurrences of unseparated tetrads of the pollen genus *Classopollis* due to preferential hydrodynamic deposition (Stukins 2022), which are shown in Galasso et al. (2022, fig. 5) to match the abundance trends of the cryptogram spore tetrads throughout interval DJ1. Furthermore, it should be noted from the data of Galasso et al. (2022, fig. 4.) that, other than three extremely minor occurrences of *Kraeuselisporites reissingeri*, the significant proportion of all these occurrences are within DJ1. This therefore allows no scope for a coherent background trend to be established. These authors rely on only two parochial references for their value of background malformations (Wilson 1963, Foster et al. 2005). There are very few, if any, publications that comprehensively cover background levels of aberrancy in different floral groups, and place them in context with their environment of deposition.

2.2. Darkened pollen and spores prior to the T-OAE

We also wish to comment on the nature and interpretation of darkened sporomorphs, also in the DJ1 interval below the CIE associated with the T-OAE, reported by Galasso et al. (2022, subsections 3.1. and 4.2.2.). These authors noted that in the uppermost *Pleuroceras spinatum* ammonite zone and the *Dactylioceras tenuicostatum* zones, the pollen and spore assemblages comprise a mixture of light and dark specimens (Galasso et al. 2022, pls I–V). The significant minority of darkened miospores were said to be “unrelated to changes in thermal maturity” (Galasso et al. 2022, p. 4) on the basis that the same taxa are present in normal colours, i.e. yellow/orange, in the same samples. Furthermore, Galasso et al. (2022, fig. 4, pl. 2) interpreted the dark miospores as being additional evidence for ecological stress prior to the negative CIE of the T-OAE.

On the first point above, apparently to strengthen their view that there is a teratological explanation for the darkened sporomorphs, Galasso et al. (2022, p. 23) claimed that darkened/mature and yellow/immature specimens of the gymnosperm pollen grain *Callialasporites* are present in the same samples. These authors did not figure any immature specimens of this genus, however, they illustrated a darkened specimen of “*Callialasporites* sp.” from sample D59 (Galasso et al. 2022, pl. II/15). This is clearly a misidentification. *Callialasporites* is a large, subcircular monosaccate pollen grain with considerable separation of the layers of exine, the outer one of which is relatively thin (e.g. Correia et al. 2018, fig. 14/4, 5). The specimen figured by Galasso et al. (2022, pl. II/15) appears to be a highly ornamented cryptogam spore in oblique lateral view.

We also believe that the second point above is also flawed. This is the interpretation by Galasso et al. (2022, fig. 4, pl. II) that the dark miospores represent additional evidence for substantial syndepositional ecological pressure. Throughout the DJ1 interval, the majority of the palynomorphs are yellow/light orange in colour which indicates low levels of thermal maturation (Galasso et al. 2022, pls I, and III–V). This would be deemed immature (e.g. Staplin 1969, Batten 1981, Marshall 1991) which is entirely compatible with the Lower Jurassic succession of Germany which has not been deeply buried and is far from major igneous intrusions, thick successions of volcanic rocks or major faults.

Despite stating that reworking is the “most intuitive explanation for the observed heterogeneous colouration” of the miospores, Galasso et al. (2022, subsection 4.2.2) invoked two teratological hypotheses to explain why some of the miospores are darkened. The first of these is that the concentration of flavonoids (radiation-absorbing phytocompounds, see Grotewold 2006) in some of the dark pollen and spore specimens was not sufficient to resist the high levels of UV-B radiation caused by the supposed volcanically-driven thinning of the ozone layer. This phenomenon therefore darkened them, in other words ‘burning’ these grains. The second explanation offered by Galasso et al. (2022) was that the supposed higher levels of UV-B radiation at this time increased the production of flavonoids, and that the quantity of these biomolecules caused the walls of some of the miospores to become substantially darkened.

As with the unseparated spore tetrads (see subsection 2.1 above), and despite reports of enhanced mercury levels at the Pliensbachian–Toarcian transition (Percival et al. 2016, Al-Suwaidi et al. 2022), we submit that the presence of the minority of darkened pollen and spores (in comparison to the majority of relatively immature miospores) in the uppermost Amaltheenton Formation and the lower Posidonia Shale Formation immediately below the T-OAE at Dormettingen is not a result of major environmental stress. There are no reports of darkened palynomorphs at the Paleocene–Eocene Thermal Maximum (PETM), another major hyperthermal event associated with high levels of mercury (Kender et al. 2012, Kender et al. 2021). By contrast, the Dormettingen scenario simply represents the reworking of Carboniferous strata during this lowstand interval. The reasons we take this view are three-fold and are expounded below.

Firstly, the assemblage illustrated in Plate II of Galasso et al. (2022), appears to be dominated by Upper Palaeozoic spores. Specifically, there are several specimens which are of Carboniferous age. Photographs 6, 16 and 17 in Plate II are all specimens of the genus *Densosporites*. Specimens 6 and 16 are possibly *Densosporites sphaerotriangularis,* while 17 is most likely to be *Densosporites anulatus*. While the species assignments are tentative without having studied the actual material, our assignment of the genus agrees with that of Galasso et al (2022). 'Densospores' is the collective term for species of the miospore genera *Cingulizonates*, *Cristatisporites, Densosporites* and *Radiizonates* following Butterworth (1966). These are all the spores of lycopods, occur in high abundances in Carboniferous coal seams and range stratigraphically from the Devonian to the Permian (Smith and Butterworth 1967, Traverse 2007). This puts beyond doubt that the palynological assemblage studied by Galasso et al. (2022) contains reworked Upper Palaeozoic material which is probably of Carboniferous age. Furthermore, we believe that photographs 7 and 10 in Plate II are illustrations of the same specimen, even though the caption suggests they are of different specimens originating from two separate samples. This triangular spore with rounded angles and rugulate ornament is reminiscent of *Savitrisporites nux*, a miospore entirely restricted to the Carboniferous. It is recovered abundantly from coal seams in western Europe (Clayton et al. 1977). However, as above, this species assignment is tentative without having studied the actual material; it should probably be referred to as spore indet. aff. *Savitrisporites nux*.

Another factor which points to reworking is that the darkened spores exhibit very little damage due to the growth of pyrite crystals (Galasso et al. (2022, pl. II). By contrast, the immature spores and pollen grains show considerable mechanical damage caused by pyrite grains (e.g. Galasso et al. 2022, pl. V/14).

The reworking of Carboniferous spores is a well-known and widespread phenomenon. They are abundant, often superabundant, as autochthonous grains in siliciclastic Carboniferous strata (Riding 2021). Carboniferous densospores have thick, robust walls and hence are readily stratigraphically recycled into younger strata. For example, Windle (1979), Riding (2005), Riding et al. (1991) and Hesselbo et al. (2020) documented the reworking of Carboniferous spores into the Jurassic of Skye, northwest Scotland and Yorkshire in northern England. Especially where a Mesozoic or Cenozoic depocentre is closely bounded by Carboniferous strata, the reworking of spores of this age is extremely widespread (Riding et al. 1999). These palynomorphs are very refractive and prone to reworking; they even may be recycled more than once, and are also extensively stratigraphically recycled into Quaternary deposits (e.g. Riding et al. 2003, Busfield et al. 2015, Hodkin et al. 2016).

Secondly, previous research has clearly established that there was a major reworking event prior to the T-OAE in Germany. Prauss et al. (1991) recognised several distinct intervals recognisable using vitrinite reflectance and mentioned recycled vitrinite in the Posidonia Shale Formation of southern Germany. Song et al. (2015) also studied the Posidonia Shale Formation throughout northwest Europe, including the area studied by Galasso et al. (2022). These authors also found that reworked vitrinite particles are more abundant than autochthonous vitrinite, clearly indicating the presence of considerable reworked material in this succession. A reworking event immediately below the T-OAE is entirely consistent with the lowstand conditions at this time and the rapidly increasing intensity of the hydrological cycle and weathering as global temperatures increased (Hesselbo et al. 2000).

The third point which strongly mitigates against a teratological explanation for these darkened spores is the fact that this phenomenon is selective in that only some of the cryptogam spores are affected. The gymnosperm pollen and all the marine palynomorphs are entirely immature (i.e., relatively light in colour). Galasso et al. (2022, p. 23) explicitly stated that no aberrant bisaccate gymnosperm pollen grains were recorded from Dormettingen. Why would high levels of UV-B radiation only affect the spores and not the pollen, dinoflagellate cysts and other palynomorph groups?

3. Summary

It is the contention of the present authors that the explanation for a spike in unseparated spore tetrads and the presence of some darkened miospores noted by Galasso et al. (2022) in the uppermost Amaltheenton Formation and the lower Posidonia Shale Formation immediately below the T-OAE at Dormettingen, southwest Germany are due to rapid sedimentation and short transport durations, and reworking respectively. Using the well-known principle of parsimony, often termed Occam's razor ('the simplest solution is most likely'), a teratological explanation for the unseparated tetrads and the darkened miospores is deemed to be highly unlikely. Galasso et al. (2022) did not present any evidence, such as geochemical data, to support their hypothesis that these two spore phenomena were caused by unusually high levels of UV-B radiation. In fact, they explicitly stated "to date, evidence of increased UV-B radiation and/or ozone layer depletion is unknown for the Toarcian" (Galasso et al. 2022, p. 23). In terms of the darkened spores, herein interpreted as allochthonous, what Galasso et al. (2022) described, perfectly matches the published narrative of a reworking event in Germany at this time.

Declaration of Competing Interest

All the authors declare that they have no financial interest or benefit in the direct application of the research documented herein.

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