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# Preservation modes of exceptionally preserved fossils from the Early Ordovician Cabrières Biota, France

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The Cabrières Biota is a recently discovered Early Ordovician fossil assemblage from southern France, comprising a diverse range of organisms and recording a palaeopolar ecosystem. Despite its ecological significance and due to its recent discovery, research on this biota is still in its early stages, and the specific taphonomic pathway behind its preservation remains poorly understood. In this study, we use scanning electron microscopy to investigate the taphonomy of soft-bodied fossils from the Cabrières Biota. Our results show that soft-bodied fossils were predominantly pyritized under sulphate-reducing conditions during early diagenesis. This was accompanied by the dissolution of biogenic silicon in skeletal elements of organisms such as sponges, with the released silica likely contributing to the partial silicification of other soft tissues. In fossil soft parts where little to no pyrite or silica enrichment is present, carbon is observed. All exceptionally preserved fossils exhibit signs of significant post-early diagenetic weathering, which altered the taphonomic modes. Pyrite crystals have undergone dissolution and reprecipitation into poorly crystalline iron oxide phases, while carbon has often been partly leached away. Thus, the Cabrières Biota represents a rare case in which a highly reactive early diagenetic environment, coupled with a complex history of maturation and surface weathering, has produced a mosaic of preservation modes even within individual fossils. ☐ *Floian, exceptional preservation, taphonomy, Palaeozoic.*

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The Ordovician is widely known for experiencing two major events that profoundly shaped life on Earth: the Ordovician Radiation(s) or Great Ordovician Biodiversification Event, during which most animal phyla underwent a more or less rapid diversification; and the Late Ordovician Glaciation, which caused a sharp decline in biodiversity over a relatively short timespan (Harper *et al*. 2014; Servais & Harper 2018; Rasmussen *et al*. 2019; Stigall *et al*. 2019; Servais *et al*. 2021; Saleh *et al*. 2023a). For decades, our understanding of these biodiversification and extinction events has primarily relied on the fossil record of biomineralized, or 'shelly', organisms, such as brachiopods, which preserve well throughout geological timescales (e.g. Harper *et al*. 2015; Stigall *et al*. 2023).

However, shelly organisms represent only a fraction of ancient ecosystems. Many animals are either partially or entirely soft-bodied, having decay-prone tissues that do not fossilize easily (e.g. Parry *et al*. 2018; Purnell *et al*. 2018). Studying these soft-bodied organisms is crucial for capturing a more complete picture of ancient ecosystems and for accurately assessing biodiversity dynamics through deep time (Seilacher *et al*. 1985; Kimmig & Schiffbauer 2024). Soft tissues

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are only preserved in sites with exceptional fossil preservation, known as *Konservat-Lagerstätten* (Seilacher *et al.* 1985; Kimmig & Schiffbauer 2024). These sites provide invaluable glimpses into past ecosystems.

One such site for the Ordovician is the Fezouata Shale (Tremadocian–Floian, Morocco; Van Roy *et al.* 2010; Martin *et al.* 2016; Saleh *et al.* 2021a). This Lagerstätte has yielded critical palaeontological (e.g. Vinther *et al.* 2008, 2017; Polechová 2016; Van Iten *et al.* 2016; Gutiérrez-Marco *et al.* 2017; Saleh *et al.* 2018, 2020a, 2021b, 2022a; Lefebvre *et al.* 2019; Pérez-Peris *et al.* 2021; Drage *et al.* 2023; Dupichaud *et al.* 2023; Laibl *et al.* 2023a, b; Potin *et al.* 2023; Lustri *et al.* 2024), sedimentological (e.g. Vaucher *et al.* 2016, 2017; Saleh *et al.* 2019, 2020b, 2022b), and taphonomic (Saleh *et al.* 2020c, 2021c, 2023b, 2024a) insights that have reshaped our understanding of the Cambrian–Ordovician transition. Fossils from Fezouata revealed that many animal groups considered extinct by the end of the Cambrian survived well into the Ordovician (e.g. Van Roy *et al.* 2010; Laibl *et al.* 2023a). This discovery suggested that the Cambrian Explosion and the Ordovician Radiation(s) rather represent a continuous interval of diversification (Van Roy *et al.* 2010, Saleh *et al.* 2020c). The discovery of the Fezouata Biota underscored the significance of any new Early Ordovician site preserving soft-bodied organisms, as such discoveries have the potential to fundamentally advance our understanding of early animal evolution.

The recently discovered Cabrières Biota from southern France is an exceptionally preserved assemblage that includes a diverse array of organisms, such as algae, sponges, cnidarians, arthropods, vermiform organisms, molluscs, brachiopods, echinoderms, and hemichordates (Saleh *et al.* 2024b, c). Remarkably, this site lies closer to the palaeo-South Pole than any other known Ordovician *Konservat-Lagerstätte* (Saleh *et al.* 2024b). Its high fossil diversity amid elevated Early Ordovician sea-surface temperatures suggests that high-latitude regions may have served as refugia for marine life escaping more extreme equatorial conditions (Saleh *et al.* 2024b).

Despite its significance, research on the Cabrières Biota is still in its infancy owing to its recent discovery (Saleh *et al.* 2024b, c), and little is known about the taphonomy of this unique assemblage. Since taphonomic investigations are key for subsequent palaeontological interpretations, here we aim to comprehensively investigate the mode of preservation of soft-bodied organisms from the Cabrières Biota. This is complemented by other studies in this special volume investigating sedimentary processes, ichnological evidence, and palaeontological occurrences in this *Konservat-Lagerstätte* (Caillaud *et al.* this volume; Daley *et al.* in this volume; Gougeon *et al.* this volume; Gutiérrez-Marco *et al.* in this volume; Harper *et al.* this volume; Lefebvre *et al.* this volume; Li *et al.* this volume; Monceret *et al.* this volume; Polechová *et al.* this volume; Van Iten *et al.* this volume; Vannier *et al.* this volume; Vaucher *et al.* this volume; Vayda *et al.* this volume). The analyses presented here also complement the preliminary scanning electron microscopy and synchrotron X-ray analyses in Saleh *et al.* (2024b). Our findings demonstrate that the Cabrières Biota exhibits a wide range of taphonomic modes, including pyritization, silicification, and preservation of organic material. This diversity of taphonomic modes is likely linked to the unique geological history of Early Ordovician deposits in southern France.

## Material and methods

A field campaign was conducted in April 2024, during which hundreds of specimens were collected from the study area. All collected specimens were obtained from surface outcrops, as no drilling was conducted to obtain fresh rock samples. The material was then examined for fossil content, colouration, and general morphological features at the Institute of Earth Sciences of the University of Lausanne, using a standard optical microscope.

Preliminary observations revealed that some fossils exhibit little colour contrast relative to the surrounding sedimentary matrix while others display distinct hues, ranging from yellow, orange, brown, and occasionally, black (Fig. 1). From this initial screening, twelve representative fossils exhibiting varying types of preservation were selected for more detailed investigation using scanning electron microscopy (SEM)-based imaging and spectroscopy. More than 300 energy-dispersive X-ray spectroscopy (EDS) spectra were acquired across these twelve samples to characterize their elemental composition. Out of these, three specimens (sponge spicules UCBL-FSL717878; filamentous algae UCBL-FSL717888a, b; vermiform organisms UCBL-FSL717862) were chosen for detailed EDS mapping based on their contrasting spectral data.

SEM analyses were carried out using a Zeiss GeminiSEM 500 instrument operated under variable pressure conditions. The instrument is a joint facility of the École Polytechnique Fédérale de Lausanne (EPFL) and the University of Lausanne (UNIL), and is housed at the Géopolis building on the University

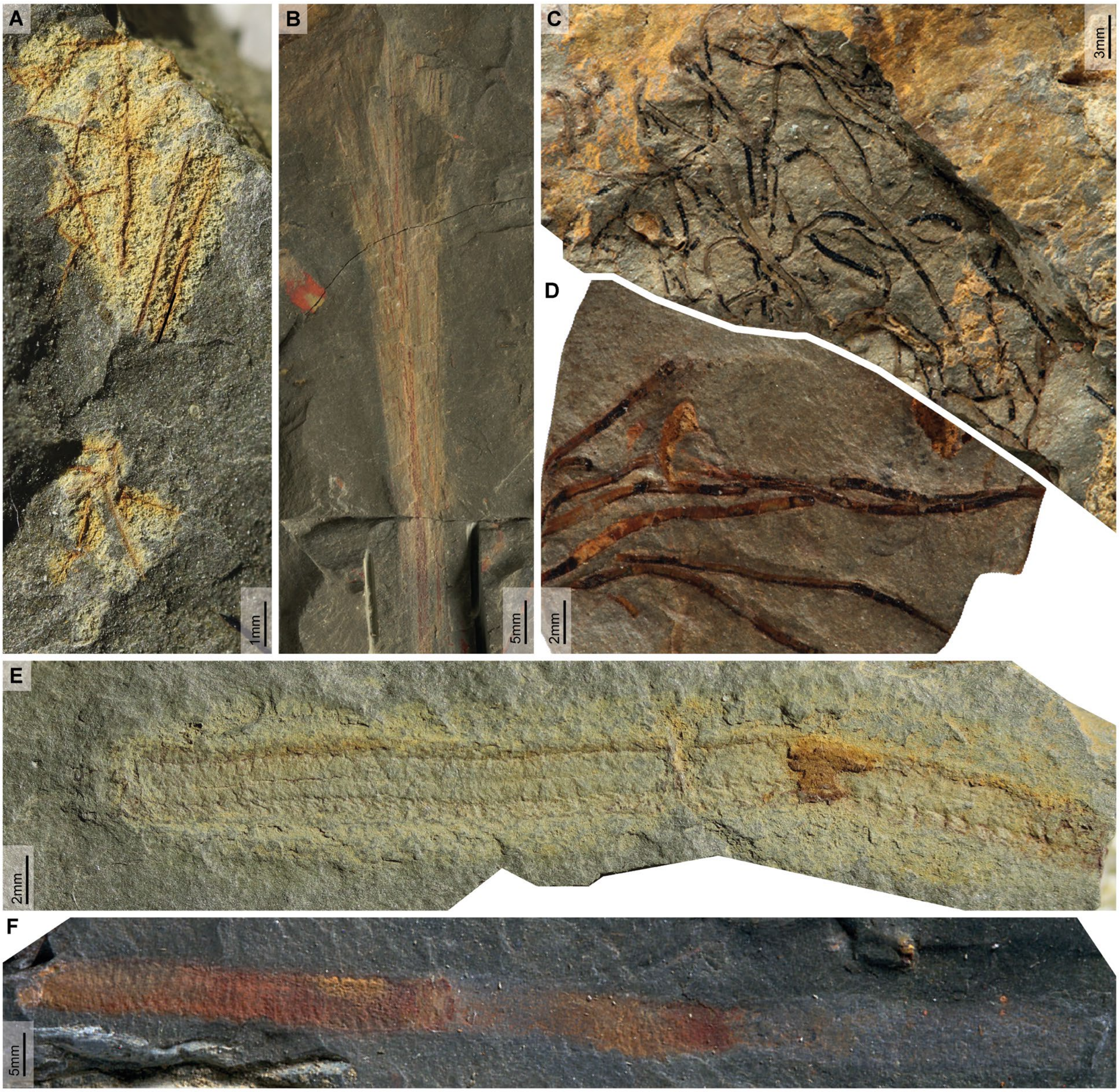

*Fig. 1.* Fossils from the Cabrières Biota: sponges (A: UCBL-FSL713619; B: UCBL-FSL717878), algae (C, D: UCBL-FSL717888a, b), and vermiform organisms (E: UCBL-FSL713622; F: UCBL-FSL717862). Note the variation in preservation, with specimen colours ranging from matrix-like green-blue to yellow, orange, red, brown, and even black. UCBL: University Claude Bernard Lyon 1 collections.

of Lausanne campus, Switzerland. Samples were mounted on standard SEM stubs using carbon adhesive tape and were not coated with any conductive metal layer to preserve surface integrity. Imaging and analysis were conducted in a chamber pressure of 40 Pa, using an accelerating voltage of 10 kV and a 30 µm aperture. A backscattered electron detector (BSD X-Max 150) was employed to enhance material contrast. EDS mapping was performed using the Oxford AZtec Microanalysis System, version 4.2 SP1.

All material is housed in the public collections of the Claude Bernard University Lyon 1 (France). The specimens were legally collected during the field campaign from public land owned by the Cabrières municipality, which signed an agreement authorizing palaeontological exploration and rock material collection on its land. This agreement was made with the Claude Bernard University Lyon 1, the University of Brest (France), and the University of Lausanne (Switzerland). The signed convention, along with the associated documentation and precise geographical coordinates of the collection sites, is stored with the fossil material at the Claude Bernard University Lyon 1.

## Results

The analysed algae from the Cabrières Biota (Fig. 1C) show an enrichment in carbon (Fig. 2A, C), particularly along their marginal parts (Fig. 3A). In some areas, the algae exhibit silicon enrichment compared to other regions, particularly in the central portions of the fossils (Fig. 3A). Note that the silicon enrichment in the fossils differs from that observed in the matrix, as silicon in the matrix is associated with aluminium, unlike in the fossils (Fig. 3A). Where no enrichment in silicon or carbon is observed, iron can be found instead (Fig. 3A, D). Hence, the algae exhibit multiple preservation modes, consistent with the data and taphonomic models for fossil algae presented by Vayda *et al.* (this volume).

The analysed sponge from the Cabrières Biota (Fig. 1B) shows no carbonaceous remains and, interestingly, no silicon enrichment, despite the siliceous nature of its spicules (Li & Reitner in this volume). The original siliceous material of these spicules has been replaced by iron oxide minerals (Fig. 2C–E). These iron oxide minerals are generally euhedral in shape and may be coated by smaller, poorly crystallized minerals on their surfaces (Fig. 2E). In some cases, the euhedral minerals were completely dissolved, leaving negative imprints where they were originally present (Fig. 2E). It is also possible for some of these iron-rich minerals to show some enrichment in elements like cobalt (Fig. 3C).

The analysed vermiform organism from the Cabrières Biota (Fig. 1F) also shows a comparable iron enrichment (Fig. 3F), manifested as small euhedral minerals and larger framboids (Fig. 2F–H). No carbonaceous material or silicon enrichment is associated with these vermiform fossils. Interestingly, in some cases, soft-bodied fossils from the Cabrières Biota show no visible contrast from the surrounding matrix, even to the naked eye (Fig. 1E), suggesting an extensive degree of weathering. Nevertheless, some specimens retain minute morphological details at the micron scale, as revealed by electron microscopy data (Vannier *et al.* in this volume).

## Discussion

The investigated fossils from the Cabrières Biota exhibit a variety of preservation modes (Figs 2, 3). While all fossils contain iron oxide minerals of varying morphologies (Fig. 2C–H), only a limited number also show evidence of carbon and silicon (Fig. 3A–C).

The presence of euhedral and framboid-like minerals (Fig. 2E, H) suggests that iron oxides might result from early diagenetic pyrite precipitation (Gabbott *et al.* 2004; Zhu *et al.* 2005; Farrell 2014; Ma *et al.* 2015; Saleh *et al.* 2020d). Pyrite precipitation is commonly induced by the decay of soft tissues under sulphate-reducing conditions, leading to the replication of organic matter by pyrite crystals that are geologically more stable than soft tissues (Farrell 2014). This mode of preservation is the principal mechanism at certain early Palaeozoic sites, such as the Cambrian Chengjiang Biota (China; Gabbott *et al.* 2004; Zhu *et al.* 2005; Lei *et al.* 2024), the Ordovician Fezouata Biota (Morocco; Saleh *et al.* 2020d; 2021a), and the Beecher's trilobite bed (USA; Briggs *et al.* 1991). It also occurs as an accessory preservation mode in other Lagerstätten, including the Cambrian Burgess Shale Biota (Canada; Gaines *et al.* 2008), and several Cretaceous deposits such as the Crato Biota (Brazil; Barling *et al.* 2023), and the Lagerstätten of Haqel, Hjoula, and Sahel Alma (Lebanon; George *et al.* 2024), amongst others. The replication of fossils by pyrite is even associated with some of the oldest known evidence of life on Earth (Palaeoproterozoic, Gabon; Marin-Carbonne *et al.* 2022; Baumgartner *et al.* 2024; El Khoury *et al.* 2025a, b).

Depending on the availability of organic matter, sulphate and iron, pyrite can form either as dispersed euhedral crystals or as aggregates in the form of framboids (Gabbott *et al.* 2004). Pyrite distribution and shape are often indicative of the biotic and abiotic conditions under which pyritization occurred (El Khoury *et al.* 2025b). For example, under most conditions, anatomical parts that resist decay (e.g. bone or shell) do not reduce sulphates and are unlikely to get pyritized in comparison to soft tissues (e.g. nervous and digestive tissues) (Gabbott *et al.* 2004; Farrell 2014). The incomplete pyritization observed in some fossils (Fig. 3A) could also reflect a closed system with a limited supply of the components necessary for pyrite formation, particularly iron or sulphates (El Khoury *et al.* 2025b). However, in marine settings such as those of the Cabrières Biota (Vaucher *et al.* in press), sulphate availability is generally not a limiting factor due to its abundance in seawater (Berner 2004; Algeo *et al.* 2015). Previous studies have suggested that carbonate cementation around decaying carcasses can inhibit the diffusion of sulphates to the decaying material, thereby preventing extensive pyritization (Gaines *et al.* 2012). However, no evidence of such carbonate cements is observed in the Cabrières Biota.

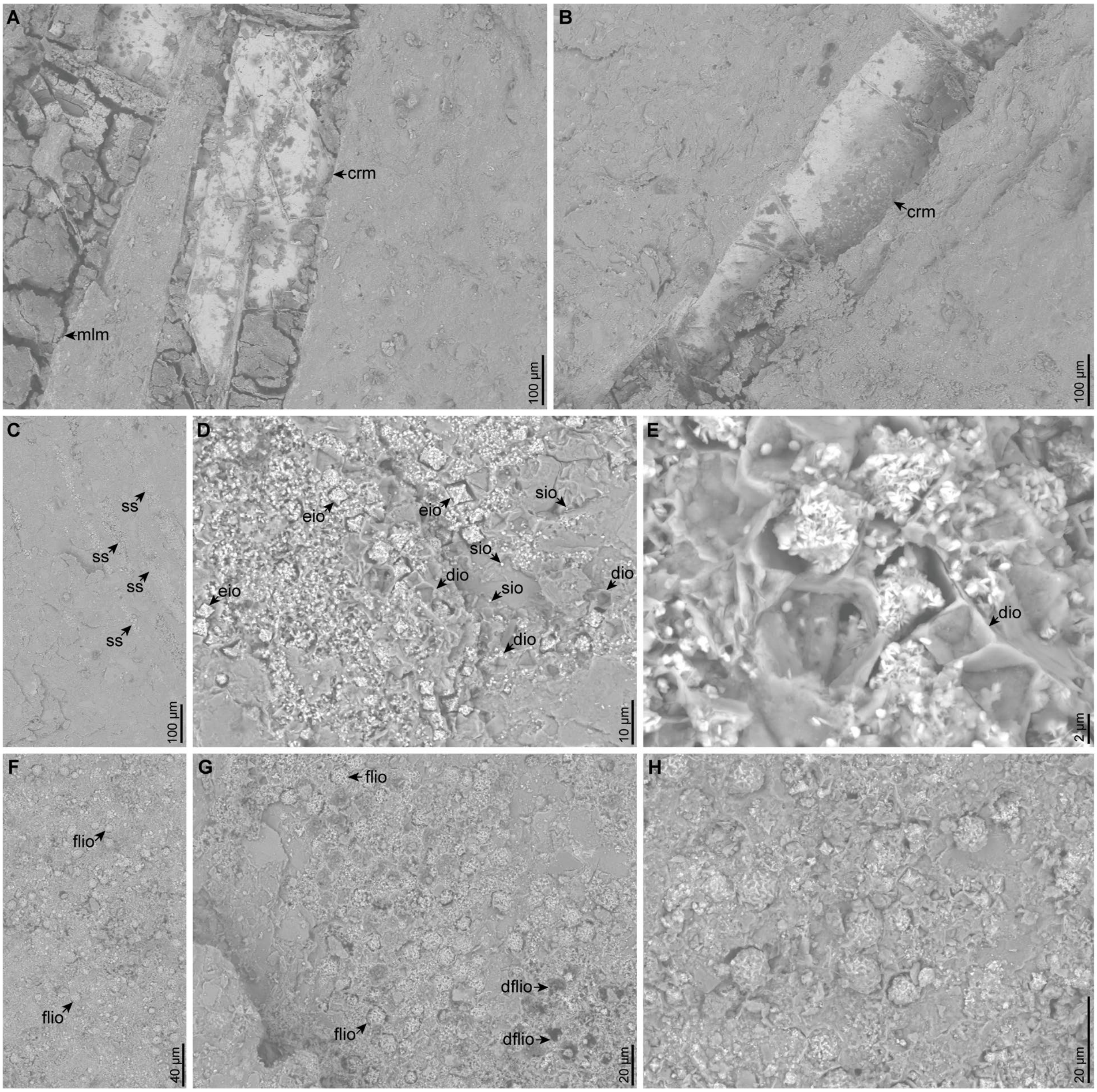

*Fig. 2.* BSE images of investigated fossils: algae (A, B), sponges (C–E), and vermiform organism (F–H). Fossil algae exhibit carbon-rich material (crm; A, B) and matrix-like material (mlm; A). The mlm lacks carbon and has a similar chemical composition to the surrounding matrix but a distinct texture. Longitudinal sponge spicules (ss; C) are enriched in euhedral iron oxides (eio; D). In some areas, dissolved iron oxides (dio; D, E) have left negative imprints where they were previously present. Euhedral iron oxides co-occur with small iron oxides (sio; D), which may also cover the surface of larger euhedral crystals (E). Vermiform organism fossils are extensively covered by euhedral, small, and framboid-like iron oxides (flio; F, G). Negative imprints are also observed where framboid-like iron oxides have dissolved (dflio; G). These framboid-like structures lack the typical framboidal morphology, characterized by aggregates of small euhedral crystals, and appear as spheres with irregular borders (H). The analysed algal filaments are those shown in Figure 1C; the analysed sponge is the one in Figure 1B; and the analysed vermiform organism is the one in Figure 1F.

Therefore, the limited pyritization (Fig. 3A) is more likely attributable to low environmental iron availability or a change in redox conditions. In such a scenario, anatomical features not replicated by pyrite retained their organic signatures. If decay was halted, due to increased burial rates (Schiffbauer *et al.* 2014) or other factors such as specific mineralogical signatures in the sediment (McMahon *et al.* 2016; Anderson *et al.* 2018; Corthésy *et al.* 2024; 2025a), these parts could be preserved in carbon, as observed in some Cabrières fossils

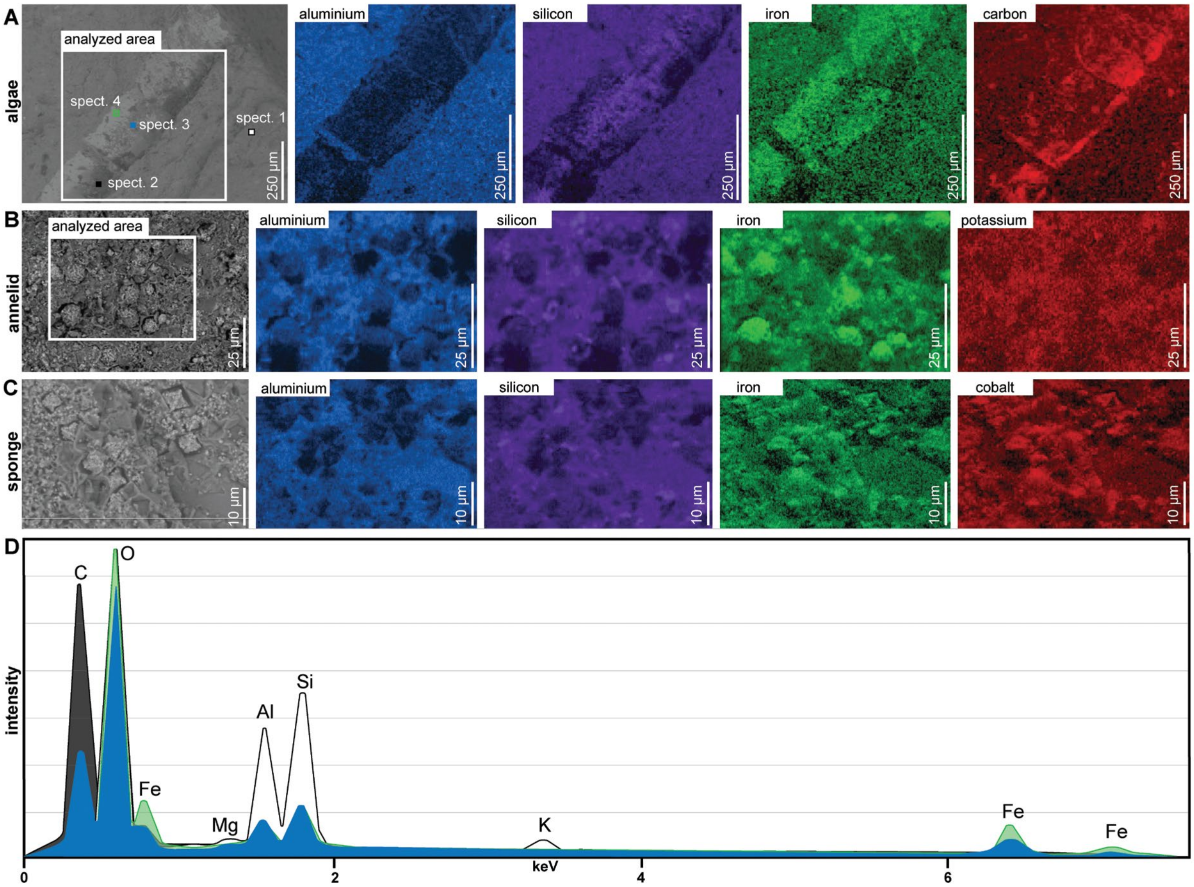

*Fig. 3.* Elemental composition of the investigated fossils: mapping of the algae (A), vermiform organism (B), and sponge (C), and spectra from the sponge specimen (D). Elemental mapping of fossil algae (A) shows that the surrounding matrix is enriched in aluminium and silicon, while the fossil itself is enriched in carbon and iron, with silicon in some places. Note that silicon within the fossil does not correlate with aluminium, unlike in the matrix. Framboid-like structures in the vermiform organism fossil are iron-rich (B), similar to the composition of euhedral minerals observed in the sponge fossil (C), which also show enrichment in trace elements such as cobalt. Overall, the matrix exhibits the highest concentrations of aluminium and silicon, while carbon and iron concentrations within the fossils vary depending on the analysed region (D). The spectra in (D) correspond to the boxed areas of similar colour labeled as 'spectrum' (spect.) in (A).

(Fig. 3A; refer to Vayda *et al.* (this volume) for further evidence of carbon enrichment). However, it is worth noting that the degree of compression in the carbon-rich material is not as pronounced as in Burgess Shale-type material (e.g. Butterfield 1990, 1995; Butterfield *et al.* 2007; Orr *et al.* 2009; Gaines *et al.* 2008); as the material still retains three-dimensionality (Fig. 2B) refer to Vayda *et al.* (this volume), for further information on the taphonomic pathways of algal filaments.

The presence of silicon in fossils (Fig. 3A; refer to Vayda *et al.* (this volume), for further evidence of local silicon enrichment in some algal filaments), together with pyrite crystals and carbon-rich material, is common in the fossil record. Similar associations are found in the Burgess Shale (Orr *et al.* 1998; Anderson *et al.* 2021), and experimental studies suggest that silicon can bind to organic material during early diagenesis (Newman *et al.* 2019; Slatger *et al.* 2024; Corthésy *et al.* 2025a). In fact, under highly reactive conditions, silicon may precipitate on the surfaces of decaying organisms in the shape of amorphous, poorly crystallized minerals, enhancing their resistance to decay (Corthésy *et al.* 2025a). These silicon-rich minerals can be distinguished from those in the surrounding matrix based on their chemical composition (Corthésy *et al.* 2025a). In the Cabrières Biota, for example, silicon is not associated with aluminium in fossils, unlike the surrounding aluminosilicate-rich matrix (Fig. 3A, D).

The presence of reactive conditions during early diagenesis in the Cabrières Biota is further evidenced by the replacement of originally mineralized structures, such as sponge spicules, by pyrite (Figs 2C–E, 3C). Sponge spicules contain silicon; however, Cabrières spicules have been entirely replaced by pyrite minerals (Figs 2C–E, 3C). Although sponge spicules are not among the most labile anatomical features, the pyritization of these elements is commonly observed in other exceptionally preserved biotas, such as the Ordovician Anji Biota (China; Wu *et al.* 2022). In the Anji Biota, it is suggested that the sulphate-reducing conditions favourable to pyrite precipitation promoted the dissolution of silicon within sponge spicules (Wu *et al.* 2022). This process resulted in the release of biogenic silica into the surrounding environment (Wu *et al.* 2022). Under these conditions, biogenic silica could have contributed, alongside environmental (abiotic) silica, to the silicon enrichment in other anatomical features and organisms, as observed in algae from the Cabrières Biota (Fig. 3A).

The proposed taphonomic scenario suggests that pyritization preceded silicification, whereas the alternative case, where silicification occurred first, is considered unlikely. If silicification had taken place prior to pyrite formation, the resulting mineral hardening of the organic matter (from the replication of organic matter by silica) would have inhibited decay, thereby preventing sulphate reduction (by decaying organic matter) and subsequent pyritization. As such, the most plausible sequence involves the dissolution of sponge spicules and their replacement by pyrite under sulphate-reducing conditions (Fig. 4A–C), followed by the rapid silicification of other fossils and anatomical features using the biogenic silica released during this process (Fig. 4D).

In this model, silicification occurs when conditions become non-permissive for pyrite precipitation (e.g. if the iron becomes limiting or following a change in redox conditions; Jauvion *et al.*, 2020; Odin *et al.* 2024; Corthésy *et al.* 2025b). The extent of silicification would then depend on the availability of silicon and the stability of environmental conditions that support this process (Maliva & Siever 1988; Moore *et al.* 2020). This sequence would result in a range of preservation modes (i.e. pyritized fossils that may also exhibit silicified parts, and carbon-rich material in areas lacking both pyrite and silicon; Fig. 4D) mirroring the diversity of preservation observed in the Cabrières Biota (Fig. 3A, D).

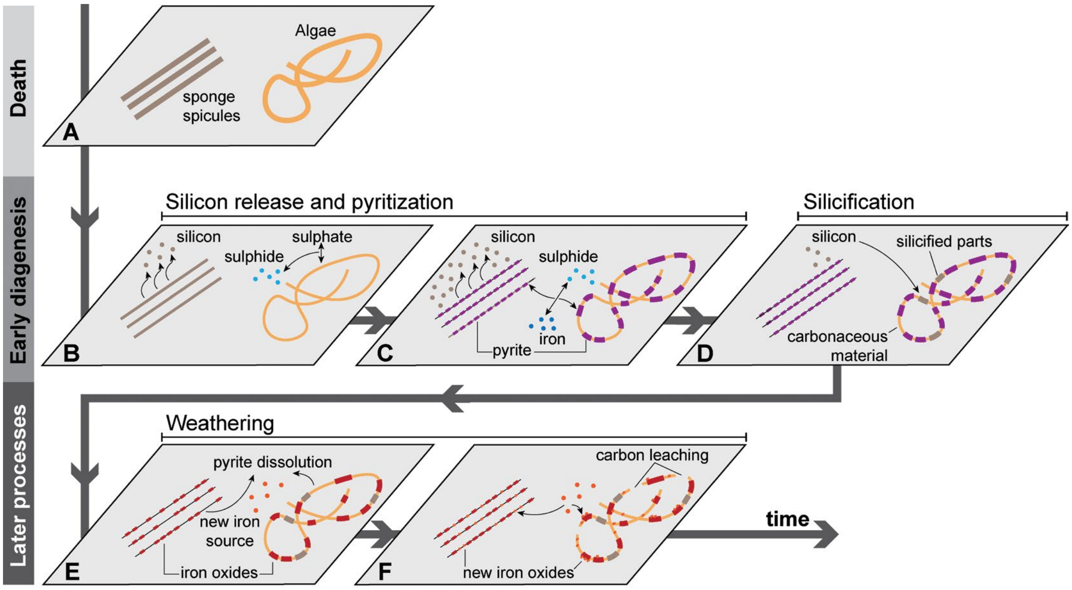

*Fig. 4.* Chemical taphonomic pathway for fossils from the Early Ordovician Cabrières Biota. Dead organisms from a single assemblage containing silica-rich sponge spicules and algae start decaying on the seafloor (A). During early diagenesis, reducing conditions are established, promoting the release of silicon from sponge spicules and the reduction of seawater sulphates into sulphides by decaying organic material (B). These sulphides react with iron from the environment, leading to the precipitation of pyrite (coloured purple) within organisms, as long as the conditions remain favourable (e.g. sufficient iron availability or stable redox conditions) (C). Biogenic silicon, when available, may contribute to the silicification (coloured grey) of previously non-pyritized parts of dead organisms; carbonaceous material may persist in regions that were not enriched in iron or silicon (D). During late diagenesis, and under metamorphic activity and surface weathering conditions, pyrite crystals dissolve to varying extents and become oxidized, releasing a secondary source of iron into the environment (E). This newly released iron can reprecipitate, even in areas that were not originally pyritized, as poorly crystalline iron minerals, and coat the surface of earlier-formed euhedral pyrite crystals. This stage can also involve the leaching or removal of some carbonaceous material (F). In such regions, the matrix beneath the fossil becomes exposed, showing no significant chemical difference from the surrounding matrix. Nonetheless, structural differences in mineral arrangement may still distinguish the fossil-bearing zone from the surrounding sediment (refer to Fig. 2A for further details).

Following pyritization and silicification, fossils from the Cabrières Biota underwent significant weathering. Sulphur was completely leached from pyrite crystals as no sulphur was detected in any of the obtained spectra (Fig. 3D). Some pyrite crystals were either partially dissolved, resulting in altered framboids that lack distinct individual crystals and appear as wrinkled spheres (Fig. 2H), or completely dissolved (Figs 2D, E, G, 4E). Iron was subsequently mobilized and reprecipitated as poorly crystallized iron oxides (Figs 2D, E, 4F). These can be distinguished from original pyrite crystals by their lack of defined shape and tendency to coat the surfaces of both euhedral and framboidal minerals (Figs 2E, 4F).

Similar patterns of pyrite dissolution are observed in other exceptionally preserved fossil sites, such as the Anji Biota (Wu *et al.* 2022). In the Fezouata Biota, abundant poorly crystallized iron oxides often cover fossil surfaces (Saleh *et al.* 2021a). The association of cobalt with some Cabrières Biota fossils (Fig. 3C) is also evidenced in the Fezouata Biota and is thought to reflect intense weathering processes (Saleh *et al.* 2020b). This extensive weathering may also explain the lack of carbon enrichment in certain fossil parts from the Cabrières Biota (Figs 2A, 4F). In some specimens, these areas are chemically indistinguishable from the surrounding matrix (Figs 2A, 4F), with fossil structures only discernible through the specific organization of underlying matrix minerals where carbon has been leached [Fig. 1E; refer to Vayda *et al.* (in this volume) for further examples]. In brief, the oxidation of pyrite results in fossils displaying orange and red colours. When carbon is still present (Fig. 3A), fossils appear black (Fig. 1C), while when carbon has been leached and no pyrite formed, fossil casts exhibit more or less the same colour as the surrounding matrix (Fig. 1E).

The pronounced alteration affecting the Cabrières Biota may be linked to the metamorphic history of the region, including multiple episodes of fluid circulation and relatively elevated burial temperatures (Álvaro *et al.* 2008; Roger *et al.* 2020). Present-day conditions at these forested outcrops further contribute to their weathering through continued fluid movement.

# Conclusion

Exceptionally preserved fossils of the Cabrières Biota result from a complex interplay of taphonomic processes. Pyrite precipitation, primarily driven by the decay of soft tissues under sulphate-reducing conditions, was likely the dominant initial preservation mechanism. Pyritization was followed by the partial silicification of the organisms, potentially facilitated by biogenically sourced silicon. Tissues that were neither silicified nor pyritized were preserved as carbon-rich material, suggesting that elements such as iron and silicon were limited in the early diagenetic environment. The complete leaching of sulphur, dissolution of pyrite crystals, and loss of carbon in some specimens point to a substantial alteration due to late diagenesis, metamorphic processes, and surface weathering conditions, which have obscured aspects of the original modes of preservation. Understanding the details of this taphonomic pathway and how it may have biased our knowledge of this unique ecosystem requires further high-resolution taphonomic analyses. For instance, it would be interesting in the future to investigate whether specific anatomical features are preferentially preserved through particular modes of preservation (e.g. pyritization or silicification). It would also be important to quantify the biological structures preserved in this Lagerstätte, in a manner similar to previous studies of other sites with exceptional fossil preservation (Saleh *et al.* 2022c, 2023c; Whitaker *et al.*, 2022). Elemental and isotopic analyses aimed at investigating the origin of elements such as iron, as well as broader depositional factors like redox conditions, are equally important (e.g. Gaines *et al.*, 2012; Schiffbauer *et al.*, 2014; Hammarlund *et al.*, 2017, 2019; Qi *et al.*, 2018). However, at this stage, the preliminary results presented here, which point to a complex preservation pathway behind the exceptional fossil record of this Early Ordovician polar ecosystem, represent a crucial first step toward achieving such an understanding.

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