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An application of synchrotron based x-ray tomography in palaeontology: Investigating small, three-dimensional, exceptionally preserved fossil arthropods

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The fossil record is biased towards biomineralised elements (for example bones, shells and teeth) that usually retain their original three-dimensional shape. Non-biomineralised arthropods, often comprising only exoskeletal tissues such as cuticle, are comparatively rare and are usually preserved in two-dimensions (including examples inside early diagenetic concretions). Rarer still are exceptionally preserved fossils that contain replicated soft tissues; although tissues that are replicated during the initial stages of decay are usually three- dimensional and often preserved in detail, the fossil as a whole is almost invariably two dimensional. Fossil shrimp recovered from Upper Triassic (Rhaetian) unconsolidated clays at Frome, Somerset, England represent a low diversity, three-dimensionally preserved fauna, in which certain labile tissues and organs are routinely preserved in three dimensions in life position.

Initial SEM analysis of exposed, internal structures in unprepared specimens confirmed the presence of musculature (replicated in calcium phosphate) and a clay infilled gut. Due to the rarity of the material, and small size of the specimens (maximum length 12mm), non-destructive synchrotron radiation, x-ray microtomography was used to determine the extent, and fidelity, of preservation of the internal anatomy. Medium resolution (voxel size of 5.3µm) and high resolution (voxel size 0.7µm) imaging was carried out on selected specimens. This confirmed high fidelity replication of the following: limited volumes of abdominal, and more rarely, cephalothoracic musculature; the hepatopancreas; gonads and, in rare cases, blood vessels and antennal glands. Notably, these are all preserved in situ enveloped by structureless, fine-grained, authigenic carbonate. This carbonate precipitated inside the cuticle, but only at the periphery of the carcass and after, or during, the initial stages of decay; it infills voids created by the initial shrinkage of abdominal musculature (possibly due to dehydration) but not those created by its subsequent decay. The digestive tract is infilled with ingested clay material.

X-ray microtomographic imaging also revealed the presence of pyrite as framboids and polyhedra. The spatial distribution of framboidal pyrite, and tissue replicating calcium phosphate, indicates their precipitation is likely to be related to the original composition of the biological tissues. For example, although the pyrite framboids do not replicate tissues, they are found in association with the hepatopancreas. It is probably not coincidental that iron is especially abundant in this area in vivo. Notably, subtle differences in greyscale tone in the x-ray images are shown to correspond to authigenic phases of different composition. When calibrated against phases for which accurate compositions can be determined using other criteria (e.g. SEM-EDX), it is possible to identify the presence of particular authigenic mineral phases in such fossils.