(SS22) Application of digital visualization methods to advance paleobotanical studies

Date: August 29
Place: Room 5235 (oral)
Organizers: Selena Smith & Margaret Collinson
Contact email address: sysmith@umich.edu
Purpose: Tomography, or imaging by section, has a long history in paleobotany, especially in the reconstruction of plants preserved as petrifactions (e.g., coal balls).　The use of computers has improved visualization in long established methods such as serial-grinding, serial-sectioning and serial peeling. Further innovations have come from novel imaging techniques such as non-invasive and therefore non-destructive methods (e.g., synchrotron radiation x-ray microscopic tomography, microscopic x-ray computer tomography, confocal laser scanning microscopy, Raman imaging, laser scanning). These methods are of particular interest in researching fragile, unstable or unique specimens and microfossils and provide a novel way of visualizing fossil plants and understanding morphology. This symposium will provide a forum for a technical overview of a wide range of selected methods, highlighting recent technical advances, advantages and disadvantages, and the application of these methods to various types of preservation. Examples will be given to show how these 3D visualization techniques provide insight into structures and morphologies that would otherwise remain unknown – information that can be crucial to accurate taxonomic and paleoenvironmental interpretations.

Oral Presentation

Aug. 29 [AM2]　Room: 5235

Chair: Selena Smith

10:50-11:10　**Micro CT and 3D analysis reveal complex internal structure in silicified conifer cones from the Late Jurassic Morrison Formation, USA**　SS22-O01 (152)

Carole T. Gee, Armin Schmitt, Richard D. Dayvault

11:10-11:30　**Puzzling, configuring and simulating *Tobleria biscuspis*: Dynamic visualization of the digital 3D model of an Early Permian seed cone**　SS22-O02 (457)

Bodo Schütze, Isabel M. Van Waveren

11:30-11:50　**Tomography old and new: comparison of 3D reconstruction techniques for fossil plants**　SS22-O03 (570)

Zoe J. Wickens, Alan R.T. Spencer, Jason Hilton, Mark D. Sutton

11:50-12:10　**3D observation of fruit-like organs of two extinct gymnosperm groups from the Late Cretaceous of Hokkaido using MXCT**　SS22-O04 (371)

Harufumi Nishida, Yui Kotake

Aug. 29 [PM2]　Room: 5235

Chair: Selena Smith

14:30-14:50　**3D reconstruction of a coleopteran pupa in a reproductive organ of extinct gymnosperm from the Upper Cretaceous of Hokkaido, Japan**　SS22-O05 (358)

Arimasa Murata, Harufumi Nishida, Takeshi A. Ohsawa

14:50-15:10 **Three-dimensional modeling of termite galleries in Cretaceous silicified wood** SS22-O06 (45)

Lisa D. Boucher

15:10-15:30 **Reconstructing large plants from fossilized fragments: a laser scanning approach** SS22-O07 (234)

Paul Kenrick, John Needham, Jonathan Krieger, Lil Stevens, David Steart

15:30-15:50 **Digital visualisation of fossil fruits and seeds from the Eocene Messel oil shale** SS22-O08 (75)

Margaret E. Collinson, Selena Y. Smith, Steven R. Manchester, Volker Wilde, Lauren E. Howard, Brittany Robson, David Ford, Federica Marone, Julie L. Fife, Marco Stampononi

Aug. 29 [PM3] Room: 5235

Chair: Margaret Collinson

16:20-16:40 **Returning to old friends: reexamination of *Silvianthemum suecicum* using SXRTM** SS22-O09 (133)

Else Marie Friis, Kaj Raunsgaard Pedersen, Peter K. Endress

16:40-17:00 **Microscopy and the recovery of morphological information from pollen grains** SS22-O10 (306)

Luke Mander, Mayandi Sivaguru, Glenn Fried, Surangi W. Punyasena

17:00-17:20 **Seed morphology and evolution in Zingiberales: insights from SRXTM** SS22-O11 (485)

Selena Y. Smith, John C. Benedict, Margaret E. Collinson, Jana Skornickova, Volker Wilde, Federica Marone, Julie L. Fife, Marco Stampanoni, Xianghui Xiao

Chairs: Selena Smith, Margaret Collinson

17:20-17:40 **[General discussion]** SS22-O12

SS22-O01 (152)

Micro CT and 3D analysis reveal complex internal structure in silicified conifer cones from the Late Jurassic Morrison Formation, USA

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In many conifers, the structure of the seed cone is often crucial for identification and differentiation between species, and is reflected in both the gross morphology and internal anatomy of the cone. In fossil cones, compressions usually only show gross morphology, while permineralizations may yield more data on the cone's internal bauplan. Until now, the traditional approach with permineralized cones has been to produce serial sections by thin-sectioning with a rock saw, which results in the loss of information between sections and the ultimate destruction of the fossil. Because three dimensionally preserved cones are relatively rare, the use of a non-invasive and non-destructive technique that generates data on the internal construction of the cone is preferable. Micro CT is one technique that can be used to "see" into silicified cones and was applied to Late Jurassic cones from the Morrison Formation. While several taxa of conifer cones have been collected in Utah and Wyoming, some of the best preserved cones come from northeast Utah, west of Dinosaur National Monument. These well preserved cones—some of the first silicified cones to be described from the Morrison Formation—are slender and narrowly ellipsoid in shape. Their external morphology shows numerous overlapping cone scales, but it is not possible to discern the number of ovules per scale, nor any details of the vascular system. To study the cones's internal construction, one of these cones was scanned using a v|tome|x s by GE phoenix|x-ray (400 scans at a slice thickness of 51.8 µm). Orienting the cone in a perfectly upright position increased resolution in the scans, and it was necessary to scan the cone in only one direction (longitudinal). The data was processed and bundled into an image stack using VGStudio MAX 2.0 software. The different tissues in the cone were then color-coded using AVIZO 6.3® by VSG to produce a three-dimensional reconstruction of the internal cone structure, which shows very clearly the shape and angle of attachment of the cone scales, the size, shape, abundance, and arrangement of the seeds, and the net-like vascular system along the cone axis. Other parameters, such as cone volume or total seed volume, can also be calculated with the 3D analysis software. Hence, the combined use of the micro CT and 3D visualization software proves to be a powerful, nondestructive, and graphically innovative method of studying and reconstructing silicified conifer cones.

Keywords: GE phoenix|x-ray, Avizo, 3D visualization software, Utah, fossil conifer cone.

SS22-O02 (457)

Puzzling, configuring and simulating *Tobleria biscuspis*: Dynamic visualization of the digital 3D model of an Early Permian seed cone

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Compressed cones were found in association with dispersed material that previously was identified as *Tobleria biscuspis*, the seed scale complexes of a probable conifer. The dispersed and attached material, consisting of 224 paired fertile units, 158 bifid scales and 84 fertile units scale complexes, was measured systematically. Consistent relations between length, width, height of the point of attachment of the fertile units and apex length were used to establish the fertile scale variability, which indicated a gradual transition from small scales with short apices and small fertile units attached at their base, into large scales with long apices and bean shaped fertile units attached centrally. These relations were converted into parameters that served to make a 3D reconstruction. We relied on the phyllotaxy found in modern cones and used the Fibonacci polynomial to determine the position on the cone axis of each scale attachment point. Small scale complexes at the apex of the cone were considered to be arrested juveniles stages while the larger scales complexes at the base of the cone were considered mature. This allowed for the conception of the ontogeny of the fertile scale and for the translation of this information into a visual simulation using a software package for procedural animation, called SideFX Houdini. The procedural animation consisted of apical growth where smaller scales grew into larger. Three growth areas were defined in the cone (1) a basal area where scales would fully develop, (2) an apical area where the development was slowed down to arrested growth (3) a central transitional area. Both in the cones and in the dispersed material possible stacking of fertile scales was observed. This architecture was visualized in a second growth

model. After reducing the number of controllable parameters within the simulation tool to a minimum, a front end for enhanced accessibility was developed. The user can select a plant organ from a list of categories in the main menu and adjust the behavior of individual parameters over time, using Bezier type animation graphs with key frames.

Keywords: palaeobotany, reconstruction, animation, Early Permian, early conifer.

SS22-O03 (570)

Tomography old and new: comparison of 3D reconstruction techniques for fossil plants

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Seed plants appear in the fossil record during the Upper Devonian, but in many fossil floras they are only unequivocally represented by isolated seeds. The study of these seeds is hence of critical importance to studies of the origin and radiation of the clade, but previous investigations have typically been limited by the two-dimensional nature of the majority of specimens, and difficulties in visualising the complex three-dimensional nature of others. Our study has utilised new computerised three-dimensional reconstruction methods to re-evaluate anatomically-preserved seeds from the serial-peel collection of Albert G. Long, which represent the most complete dataset available on the early radiation of seed-plants. A number of early seed taxa including *Genomosperma* and *Stamnostoma* have been restudied using both existing serial-peel and new high-resolution serial-section datasets, reconstructed in to 3D models using a custom computer software suite (*SPIERS*). This work highlights the importance of sample interval, preparatory method and specimen registration; while reconstructions from existing peel datasets are possible, purpose-made serial preparations designed explicitly for three-dimensional reconstruction are considerably more informative. Study of these "virtual fossils" has better constrained the morphology of the specimens investigated, in particular by helping to identify ontogenetic and taphonomic components, and has hence facilitated the rigorous testing of existing developmental and functional models for these plants.

Keywords: 3D Reconstruction, *Genomosperma*, *Stamnostoma*, Serial-sectioning, virtual fossil.

SS22-O04 (371)

3D observation of fruit-like organs of two extinct gymnosperm groups from the Late Cretaceous of Hokkaido using MXCT

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Gymnosperms are highly diversified during the Cretaceous, reaching their zenith of diversity and dominance in terrestrial ecosystems. The Cretaceous gymnosperms consist of a wide array of taxa both extinct and extant today. From the Late Cretaceous (Santonian) of Hokkaido, two peculiar types of gymnosperm seed-bearing organs each of which would represent a new phylum have been known. These organs are fructifications that developed a thick seed-envelope analogous to the angiosperm fruit wall. One is an elongate follicle-like organ containing a single large seed often exceeding 3 cm in diameter within a conduplicate foliar structure with a prominent dorsal longitudinal crest. The foliar nature of the envelope, the gymnospermic features, and the whole morphology of the fossil were confirmed and reconstructed by observing and compiling vascular architecture and tissue compositions based on serial peel sections. Early reconstructions of these fructifications have been done before Microscopic X-ray CT (MXCT) started to be applied to paleobotany. MXCT could provide realistic 3D images for verifying the accuracy of earlier reconstructions, if the part of original specimens or other specimens of the same taxon existed. The MXCT is only applicable when the fossil preservation is suitable for X-ray use. The obtained images must be histologically compared with peeled tissues to identify their nature. The 3D images of the conduplicate fructification showed basic vascular configurations and tissue dimensions supporting the early reconstruction made by HN. The other morphology is a pome-like organ similar to the pentoxylalean *Carnoconites* fructification. Spiral series of axial ovules are embedded in thick fibro-parenchymatous tissue, but thin myclopylar tube extends from each ovule to the opening at envelope surface. Each ovule is encased in a round space in the “fruit wall”. Serial peels of the organ suggested that a nest of vascular bundles in the envelope tissue surrounds the space around the ovule. Each nest starts from a trace derived from a columnar central axis of the fructification, branching distally to form a cup-shape. The MXCT image also confirmed the peculiar cup-shape of vascular network. The evolutionary origin of the cup-shaped nest still remains uncertain. The resolution of MXCT varies basically according to its hardware performance, then the image quality relies on the software quality, and finally human ability to find the best rendering state on the display screen.

Keywords: 3D reconstruction, Cretaceous, fructification, gymnosperm, permineralization.

SS22-O05 (358)

3D reconstruction of a coleopteran pupa in a reproductive organ of extinct gymnosperm from the Upper Cretaceous of Hokkaido, Japan

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Terrestrial ecosystems and biodiversity mainly depend on primary production of land plants. Plant-animal interactions have evolved dramatically in response to the change of land plant communities. Cretaceous was one of the key periods in the evolution of plant-animal interaction, because the angiosperms started becoming dominant within earlier plant communities dominated by spore-producing plants and various phyla of gymnosperms including ones that became extinct afterwards. Permineralized plant tissues can preserve life traces and even bodies of animals that used the host plant in various ways, providing direct evidence for inferring the past plant-animal interactions. Here we report an anatomically preserved insect fossil found in a permineralized seed-bearing fructification similar to *Carnoconites* of Pentoxylales, but was collected from the Upper Cretaceous (Santonian) of Hokkaido, Japan. The fructification is an elongate globose structure containing numerous seeds embedded in thick tissues comparable to the angiosperm fruit wall. A slender micropylar tube extending out through the thick embedding tissue attributes the structure to the gymnosperm. The insect was reconstructed by overlaying images obtained from serial peel sections with 3D-reconstruction software, DeltaViewer. We identified different body parts and separated them in color to help recognize on the entire body reconstructed. The body shows the

antennae adhered around the body, the six articulated legs folded up on the underbody, and the elytra cowering to the ventral side. Based on these we concluded that the specimen is a pupa of the Coleoptera. We also presume that it is attributable to the Cerambycidae because of the whip-like antennae elongated to the ventral side, and the solid mandible. The insect larva probably fed mainly on the seeds, not the external envelope, because only seeds and the thin walls between the seeds are damaged. We have no report of seed predation in present Cerambycidae. This new finding demonstrates a unique relationship between the Cerambycidae and the extinct gymnosperm having developed a fruit-like structure during the Cretaceous prior to the establishment of a variety of angiosperm-insect relatioinship. Based on the comparison with a lifecycle of the present longhorn beetles, we infer that the long time-span for the maturation of the fossil fructification helped the fossil insect complete its lifecycle within the same plant organ. We took advantage of the 3D reconstruction in identifying the insect that made paleoecological study more vivid.

Keywords: 3D reconstruction, Coleoptera, Cretaceous, pupa, Upper Yezo Group, gymnosperm.

SS22-O06 (45)

Three-dimensional modeling of termite galleries in Cretaceous silicified wood

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Termite galleries and fecal pellets were identified in coniferous wood collected from the early Campanian Allison Member of the Menefee Formation in northwestern New Mexico, USA. Ichnofossils are important elements of fossil floras because they can contribute considerable paleoecological information that may not otherwise be preserved in the fossil record. Termites have been previously described from the Cretaceous as both trace and body fossils. This is the first description of termite borings in fossilized wood using high-resolution X-ray computed tomography. The advantage of using this technique is it enables a complete three-dimensional reconstruction of the galleries within the wood without destroying the original specimen. The wood is identified as *Cupressinoxylon* and is preserved as a silicified log embedded in sandstone. Geologic evidence supports a deltaic depositional environment and the presence of growth rings and interruptions in the wood indicate some short-term environmental disturbances and/or seasonality. Within the specimen are several areas of galleries and chambers containing fecal pellets. The coprolites are roughly hexagonal in mid-section and range from 0.45-0.65 mm in length to 0.25-0.45 mm in width. One piece of wood was scanned and image processed to construct a 3-D model of the burrows. Galleries are interconnected, with most predominantly oriented longitudinally through the trunk; some appear to be abandoned and filled with fecal pellets. Where the tunnels are interconnected and form chambers, they intersect rays and are not limited to a particular ring type. Termite burrowing and feeding most likely occurred prior to tree death or very soon after and prior to burial, as the wood is well-preserved and termite colony development within anoxic submerged logs is unlikely. Fungal remains are not evident. Coprolite size and morphology, burrow architecture, and other aspects of the depositional environment and preservation suggest that members related to the basal termite family Kalotermitidae created the galleries.

Keywords: Campanian, *Cupressinoxylon*, ichnofossil, paleoecology, X-ray computed tomography.

SS22-O07 (234)

Reconstructing large plants from fossilized fragments: a laser scanning approach

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Reconstructing large organisms from their fossilized remains is challenging because of the physical difficulties of excavation and the fragmentation of parts. Moreover, reassembling a whole plant for detailed study can be impractical due to its size, weight and number of parts. Here we take a laser scanning approach to reconstructing a large tree from numerous petrified fragments. The fossilised remains come from an *in situ* forest of Jurassic (Tithonian) age in southern England. The trunk was naturally fragmented due to brittle fracturing caused by minor earth movements following petrifaction, and in excess of 100 pieces were excavated by hand. Each of these fragments was numbered and its order in relation to the others was noted. Individually, they ranged in weight from as much as 350Kg (basal stump) to as little as 0.3kg. Following excavation, each piece was scanned using a portable colour laser scanner (VIUscan™) employing a landmark approach that only required aligning two consecutive pieces of petrified wood at any time. The surface was imaged in real colour at a resolution of 0.1mm, aiding identification of features such as the size and position of knots. The accompanying VIUscan software created virtual volumes, with all individually scanned pieces correctly aligned across the whole tree. Rapidform XOR processing software was used to repair holes and otherwise improve the 3D polygon mesh. Files can be exported in a variety of formats as an optimised polygon mesh in .obj, .stp and .igs, which can then be used for further reconstruction, finite element analysis or animation. The resulting virtual tree trunk exceeds 12m in length and comprises over 100 fully aligned pieces. This precision model enables the authors to develop an accurate reconstruction of the size and habit of the dominant tree in this ancient forest. The method is generally applicable to reconstructing large organisms that have become fragmented and also to the excavation of geological and archaeological sites.

Keywords: laser scanning, Jurassic, tree, virtual model.

SS22-O08 (75)

Digital visualisation of fossil fruits and seeds from the Eocene Messel oil shale

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X-ray tomographic methods have been evaluated for their suitability to visualise morphology and anatomy of compressed fruits and seeds preserved in the oil shale of the Middle Eocene Messel Formation (former lake Messel, near Darmstadt, Germany). Synchrotron radiation X-ray

tomographic microscopy (SRXTM) was undertaken at the TOMCAT beamline, Swiss Light Source, Paul Scherrer Institute, Villigen, Switzerland. MicroCT (micro computed tomography) was performed at the Natural History Museum, London, UK on a Metris X-TeK HMX ST 225 scanner. Specimens are stored in glycerol. Most are partly contained in small blocks of oil shale, but some are loose (free of oil shale). Shale blocks were trimmed and specimens rinsed in water. SRXTM trials were undertaken with specimens immersed in water, drained of water and surface-dried but still moist. Only the latter enabled visualisation of good tissue and cellular details so all specimens were surface dried (by absorption of water into a tissue) prior to study. For SRXTM specimens were imaged with the small blocks of oil shale immobilized at the base, sides and top (as needed) with foam (Plastazote™) in a plastic tube covered with a lid to reduce loss of moisture during scanning. Five Amp fuse wire wrapped around the block was used on one very flat specimen with some success to enable location of the area of interest once the specimen was in the beamline. For microCT specimens were wrapped in PVC cling film and stabilised with small blocks of Oasis™ or cotton wool in hand-made plastic containers. Both methods of study enable visualisation of parts of specimens buried in the oil shale. MicroCT has proven suitable for evaluation of tissue preservation whilst SRXTM enables visualisation of tissues and their detailed cellular structure. Of 30 taxa studied only four exhibit good cellular detail. The reason for lack of detail in other taxa is unclear but may be related to subtle variations in chemical composition or physical structure of their tissues. The tomographic datasets also allow 3D reconstruction of features such as locules. X-ray tomography has revealed important features of Messel specimens which have (i) provided key taxonomic characters and supported recognition of new taxa, some of which are the earliest fossil representatives of modern genera (*Pleiogynium*, Anacardiaceae; *Berchemia*, Rhamnaceae), (ii) demonstrated the absence of modifications for epizoochory in this flora, and (iii) revealed aspects of exceptional preservation relevant to mammal and bird diet (e.g., soft tissue in Vitaceae fruits).

Keywords: SRXTM (synchrotron radiation X-ray tomographic microscopy), microCT (micro computed tomography), angiosperm fossil, carpoflora, exceptional preservation.

SS22-O09 (133)

Returning to old friends: reexamination of *Silvianthemum suecicum* using SXRTM

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The study of Cretaceous flowers has greatly improved our knowledge of early angiosperm diversity and diversification. Systematic resolution highly depends on the quality and quantity of information that can be retrieved from the fossils. The floral structures are typically minute and fragile often represented by a single or few specimens and the study of organisation and structure by conventional methods such as serial sectioning are often not possible. The use of non-destructive synchrotron based X-ray tomographic microscopy (SXRTM) has therefore provides an excellent tool for reconstructing delicate and unique fossils. *Silvianthemum suecicum* is a fossil taxon based on fossil flowers from the Late Cretaceous of Sweden that has received much attention due it is possible relationship to the extant Southern Hemisphere taxon *Quintinia*. To improve our understanding of *Silvianthemum* and its phylogenetic position we recently re-analysed the holotype of *Silvianthemum suecicum* using SXRTM. Without further treatment internal features of this flower bud could be studied in detail and 3D reconstructions made of its androecial and gynoecial structure.

Keywords: fossil flowers, mesofossils, synchrotron based X-ray tomographic microscopy, SXRTM.

SS22-O10 (306)

Microscopy and the recovery of morphological information from pollen grains

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Research on the comparative morphology of pollen grains depends crucially on the application of appropriate microscopy techniques. Information on the performance of microscopy techniques can be used to inform that choice. We compared the ability of several microscopy techniques to provide information on the shape and surface texture of three pollen types with differing morphologies. These techniques are: widefield, apotome, confocal and two-photon microscopy (reflected light techniques), and brightfield and differential interference contrast microscopy (DIC) (transmitted light techniques). We also provide a first view of pollen using super-resolution microscopy. The three pollen types used to contrast the performance of each technique are: *Croton hirtus* (Euphorbiaceae), *Mabea occidentalis* (Euphorbiaceae) and *Agropyron repens* (Poaceae). No single microscopy technique provides an adequate picture of both the shape and surface texture of any of the three pollen types investigated here. The wavelength of incident light, photon-collection ability of the optical technique, signal-to-noise ratio, and the thickness and light absorption characteristics of the exine profoundly affect the recovery of morphological information by a given optical microscopy technique. Reflected light techniques, particularly confocal and two-photon microscopy, best capture pollen shape but provide limited information on very fine surface texture. In contrast, transmitted light techniques, particularly differential interference contrast microscopy, can resolve very fine surface texture but provide limited information on shape. Texture comprising sculptural elements that are spaced near the diffraction limit of light (~250nm; NDL) presents an acute challenge to optical microscopy. Super-resolution structured illumination microscopy provides data on the NDL texture of *A. repens* that is more comparable to textural data from scanning electron microscopy than any other optical microscopy technique investigated here. Maximising the recovery of morphological information from pollen grains should lead to more robust classifications, and an increase in the taxonomic precision with which ancient vegetation can be reconstructed.

Keywords: palynology, morphology, optics.

SS22-O11 (485)

Seed morphology and evolution in Zingiberales: insights from SRXTM

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The Zingiberales are a group of economically and ecologically important tropical to subtropical monocotyledonous flowering plants that today consist of eight families and ca. 2500 species. Understanding the fossil record of the group can provide us with details of their evolution and diversification, as well as information about paleoecology. Fossils attributed to Zingiberales extend from the late Cretaceous to the Pliocene of North America and Eurasia. Understanding leaf, fruit and seed morphology for the group is necessary for interpreting evolutionary and biogeographic patterns, especially as zingiberalean pollen is not preserved in the fossil record. Seeds in particular have the potential to be particularly taxonomically informative. Because zingiberalean seeds tend to have a hard, brittle seed coat with included phytoliths, standard histological techniques are more difficult, require the removal of silica bodies, and often yield gross morphological detail only. Here, synchrotron X-ray tomographic microscopy (SRXTM) has been used to study over 50 species from all eight families, plus the fossil *Spirematospermum* and an unnamed arillate seed from Messel, in order to identify and confirm informative seed characters that are phylogenetically significant and can be applied to the fossil record. SRXTM studies are complementary to other traditional methods of studying zingiberalean seeds. Both digital sections and 3D morphology are visualized with SRXTM, which allow us to simultaneously investigate gross morphology and more detailed features such as embryo morphology, seed coat structure and morphology of the complex micropylar and chalazal regions. A 'bright' layer is noticeable in the seed coats of all but Cannaceae, Lowiaceae, and most Zingiberaceae. Seed coats of Musaceae, Cannaceae, Costaceae, Marantaceae, Strelitziaceae are much more sclerified than those of Zingiberaceae, Lowiaceae and Heliconiaceae, which retain large parenchymatous cells in their testa. SRXTM clearly shows that, contrary to previous reports, a chalazal chamber is diagnostic of Musaceae, such a feature is also found in Costaceae and tribe Alpiniae (Alpiniodeae; Zingiberaceae) though it is constructed of different seed coat layers. In addition, the opercula can be digitally dissected and compared across the order. Initial results show that opercula in Marantaceae and Costaceae have a wider basal rim than those of Zingiberaceae, and the central protuberance varies in height and ratio of apical vs. basal width. Apart from demonstrating their value in zingiberalean systematics these results will also be applied to interpreting fossil seeds attributed to Zingiberales.

Keywords: carpology, Messel, *Spirematospermum*, synchrotron X-ray tomography, Zingiberaceae.