SEPTARIAN CONCRETIONS

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Septarian structures are former cracks, often filled with cement and are most commonly found in concretions hosted in mudrocks, although rare occurrences are known from siltstones and sandstones. Septarian structures occur in concretions or concretionary sheets, which may be chemically and mineralogically the same as non-septarian concretions in the same mudrock. The host concretions are most commonly calcite, dolomite or siderite dominated, although rare occurrences have been interpreted from silica concretions. Septarian concretions are predominantly a pre-Pleistocene phenomenon, although a potential 'proto' version has been described from the late Pleistocene (Duck, 1995).

Crack Morphology

Septarian structures were initially formed as open fractures, and are most often concentrated in the central regions of concretions and reduce in width and frequency towards the outer parts of the concretion, which may or may not be cracked. The fractures take a variety of forms, from lenticular cracks, which are widest towards the center of the concretion, to straight-sided cracks, to dense networks of hairline cracks. The orientation of the cracks can be diverse, but always include cracks which are predominantly sub-vertical to the bedding plane. Some sub-vertical cracks in sections perpendicular to the bedding plane may appear inclined, which is often due to the low angle of the crack and section intersection. Cracks can also be sub-horizontal or be curved, sometimes reflecting the shape of the concretion (Fig. 1). Within horizontal sections the cracks often demarcate approximately equidimensional blocks of the concretion (Fig. 1). Multiple generations of cracks are apparent in some septarian concretions, cross cutting early formed cracks. Cracks are mostly displacive and may cut body fossils, or occasionally cracks may show a component of shear displacement.

Crack filling cements

Cracks may range from largely unfilled to fully cement filled, often with a variety of distinctively colored spar cements. The fills may also include geopetal sediment, or sediment injected from the surrounding mudrocks, through cracks that reached the concretion surface. The cements grew on the fracture walls within a pore-fluid filled crack. This is evident by the preservation of partially unfilled cracks displaying crystal terminations in the voids. The cracks are usually filled with calcite, but sometimes include other carbonates, sulphide, sulphates or clay minerals, sometimes quite different to the mineralogy of the concretion body. In most occurrences the volume of the cracks make up less than 20% of the volume of the concretion body, although in rare occurrences the cement-filled cracks may constitute up to ~70% of the concretion body.

Timing of crack formation

The timing of the crack formation relative to the formation of the concretion body is indicated by the geochemistry of the body and crack cements. Detailed carbon and oxygen isotopic studies (see *isotopic methods, organic sediments*) indicate the central region of the concretion body generally formed first. The outside of the concretion body may have a similar cement chemistry to the earlier formed crack cements, hence for some concretions the outer part of the concretion formed at the same time as the inner cracks fills. The fracturing of some of the early cement fills by later cracking, and subsequent filling by later cements has indicated that some concretions have a repeated history of cracking and successive crack fills. The linkage of cement chemistry to likely changes in pore-fluid chemistry with sediment burial (see *diagenesis*) has also indicated that in some septarian concretions the crack-fills formed later than the concretion body.

Depth of formation

Estimates of the depth of formation of septarian cracks are closely linked to the origin of the body of the concretion. There are three main clues to the depth of formation. Firstly, the variation in the amount of cement in the concretion body has been used as a relative indicator of burial depth, through its assumed passive filling of the early sediment pore-space. This is not without its problems, due to the possible displacive or replacive growth of some concretion body cements. Secondly, the isotope geochemistry of the crack and body cements, linked to models of organic matter stimulated diagenesis (see *diagenesis*) has suggested estimates of likely burial depth, based on typical present-day depths of pore-water chemical boundaries. Thirdly, occurrences of septarian concretions exhumed at disconformities and subsequently re-buried, in which estimates of the amount of sediment removed can be ascertained (Hesselbo and Palmer, 1992). These three estimates suggest that some septarian cracking was initiated at a minimum of a few metres to a few 10's of metres depth. Maximum cracking depths are often not well constrained, but may extend to several Km's of burial, or occur during uplift.

Origin of cracks

Septarian structures have attracted debate since the late 19th century, when the accepted hypothesis was that they formed by shrinkage of the interior parts of the concretion. This idea has attracted many proponents since that time involving increasingly more complicated growth models (Pratt, 2000). However, a plausible model that explains this shrinkage process in firm physical terms has largely eluded its proponents. The physical process that may provide a comparable analogue for the shrinkage hypothesis is the production of syneresis cracks (see *syneresis*). The shrinkage model is also deficient in explaining the physical and chemical nature of the cementing medium which shrinks in the early-formed parts of the concretion, and deficiencies pertaining to the textural and geochemistry data about the relative timing of textural features (Astin, 1986). More recent hypotheses suggest the cracks are generated by tensional failure, either through stresses produced by excess pore pressure (see *compaction*; Astin, 1986; Hounslow, 1997) or shaking motions produced by earthquakes (Pratt, 2001). The essential differences between these models are that the Astin and Pratt models implicate formation-wide stresses, which are through unknown processes, localized to the concretion body. Without a process of tensional failure localization, both the Astin and Pratt models would also produce septarian cracks in rocks other than the concretion. The Hounslow model implicates stresses localized to the cementing concretion, whose cementation is the cause of the tensional stress. The driving motivation for tensional fracture physical models is the realization that large instantaneous tensional forces are needed to fracture rigid body fossils and the concretion body in its consolidated state. Tensional stresses applied over a long period of time (sub-critical crack growth) appear to provide a solution in lowering the threshold for fracture growth, and partially cemented concretions, as implicated in some growth models, may lower the tensional strength of the concretion body. A deficiency in the tensional fracture models are that in some concretions the tensional strains implied by the large volumes of crack-filling cement are far in excess of what could be expected. Hence, a hybrid shrinkage- tensional fracture model may be appropriate for some septarian concretions (Pratt, 2001).

Ultimately the origin of septarian cracks is tied to the debate about the origin of concretion bodies. One of the problems is the lower number of case studies linking the timing of concretion body and septarian cement formation, which utilize integrated and detailed geochemical, textural and mineralogical data. Study of hiatus septarian concretions could be a fruitful avenue for further study, since exhumation provides a relative timing and depth indicator (Hesselbo and Palmer, 1992). A second gap in knowledge is the physical properties of concretions when they first form, which is fundamental in dictating the likely processes of septarian crack formation. The absence of a present day analogue for septarian concretions either suggests the formation processes are absent or very rare at the present day, or that they take longer to form than current understanding suggests.

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Cross-references

Compaction

Diagenesis

Organic sediments

Isotopic methods

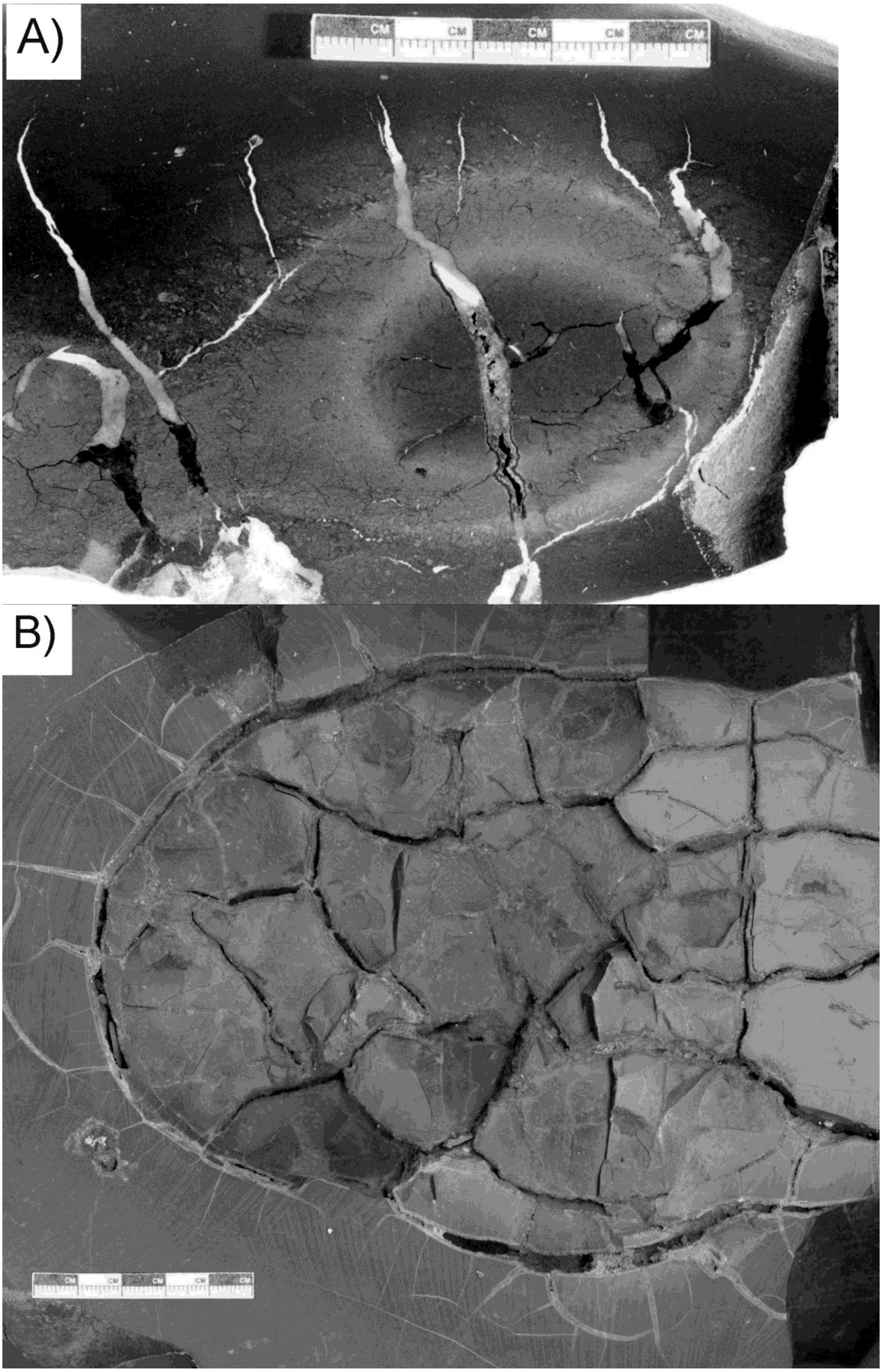
Concretions

Syneresis

FIGURE CAPTION

Figure 1. A) vertical section through a compound calcite (pale central part) and siderite (dark outer) septarian concretion. The lenticular and parallel-sided cement-filled cracks are

mostly vertical to bedding. Three generations of cement fill occur a clear calcite spar (dark) in the calcite concretion (large and small cracks), a pale brown spar (pale gray) and a barite (white), which mostly fills the later tapering terminations to cracks. Some crack voids are preserved in the inner calcite concretion (Ironstone shales, Lower Jurassic, UK). B) horizontal section through dolomitic septarian concretion with septarian cracks partially filled by dolomite (lower Carboniferous of Berwickshire, Scotland).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