

# The Silurian Herefordshire Konservat-Lagerstätte: a unique window on the evolution of life

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SIVETER, David J. (2008). The Silurian Herefordshire Konservat-Lagerstätte: a unique window on the evolution of life. *Proceedings of the Shropshire Geological Society*, **13**, 58–61. The Herefordshire (Silurian) Konservat-Lagerstätte is emerging as an exciting palaeontological discovery of global importance. It contains a variety of small marine invertebrates such as worms, molluscs, starfish, and brachiopods, together with a range of arthropods, plus many intriguing forms of yet unknown affinity.

All of the fossils are beautifully preserved with extraordinary fidelity and, in three dimensions, complete with details of their soft anatomy. They occur as calcite in-fills within nodules entombed in an ancient volcanic ash that fell onto a moderately deep sea floor some 425 million years ago. The soft-bodied animals that became preserved are unknown elsewhere. The specimens are recovered from the rock as “virtual fossils”, by the use of micro-grinding, digital imaging and computer reconstruction techniques.

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## BACKGROUND

The Welsh Marches are internationally renowned for the Silurian sedimentary sequence exposed there and the record this contains of the evolution of life, including a critical phase in the early colonisation of the land. The earliest well-known description of the fossils of the Silurian within the Welsh Marches is provided in Murchison's *The Silurian System* (1839). Of necessity, this work was concerned almost exclusively with specimens that were visible to the naked eye. Microscopically small creatures were mostly unknown at the time.

Much study followed in the succeeding century and a half, progress in Silurian geology and palaeontology being presented at an international gathering at Keele in 1989 – The Murchison Symposium – under the auspices of the Palaeontological Association, the papers from which were summarised (Bassett *et al.*, 1990) and subsequently published (Bassett *et al.*, 1991). At about the same time the stratotypes for the international series of the Silurian, two of which are in the Marches (the Wenlock and the Ludlow), were detailed in a ‘global standard’ book on the system (Holland & Bassett 1989). The most comprehensive account of Silurian sites in Britain is provided in a volume of the Geological Conservation Review series (Aldridge *et al.*, 2000).

## KONSERVAT-LAGERSTÄTTEN

Our understanding of the history and biodiversity of life on Earth relies on the fossil record, and importantly on information gained from rare cases of exceptional preservation, where the soft parts of animals and even entire soft-bodied animals are preserved; such horizons are known as *Konservat-Lagerstätten*. The importance of such deposits is that they provide key windows on the palaeobiology and palaeoecology of life in the past. The fossils that they contain can also often provide a better indication of biological affinity and insight into questions of evolution than can ‘typical’ fossils where only the hard shelly parts are preserved.

The recently discovered Herefordshire (Silurian) Konservat-Lagerstätte is one such deposit (Briggs *et al.*, 1996). Its global palaeogeographic setting, on the micro-continent of Avalonia in the southern subtropics, is documented elsewhere (see Cocks 2008, *this volume*). Utilising studies on the sedimentary facies and the co-occurring macro-faunas, such as those documented by Ziegler *et al.* (1968), the sediments containing the Herefordshire biota can be shown to have formed on the outer shelf or upper slope area of the Welsh sedimentary basin at a water depth of 150–200 metres in mid-Silurian times, some 425 million years ago.

The Herefordshire biota is emerging as an exciting palaeontological discovery of global

importance. World-wide there are only 20 or so key Konservat-Lagerstätten known, with hardly any from the Silurian. It thus provides a missing palaeobiological window between the more numerous Konservat-Lagerstätten known from the older Cambrian, such as the famous Burgess Shale fauna of British Columbia, and those in the Devonian.

The Herefordshire Konservat-Lagerstätte contains a variety of small marine invertebrates such as worms, molluscs, starfish, and brachiopods, together with a range of arthropods, plus many intriguing forms of yet unknown affinity. Its age can be determined from macrofossils (graptolites and brachiopods) and microfossils (chitinozoan palynomorphs and radiolaria): it corresponds approximately to the level of the Sheinwoodian-Homerian stage boundary, within the Lower Silurian Wenlock Series.

All of the fossils are beautifully preserved in extraordinary detail in three dimensions (Orr *et al.*, 2000), and are unknown from elsewhere in the world. Even completely soft-bodied animals, such as worms (Sutton *et al.*, 2001a), have survived intact. This is somewhat surprising, and indicates that certain factors very early in the fossilization process mitigated to preserve the physical integrity and three-dimensionality of the animals within the nodules in which they occur.

The fossils occur as calcite in-fills within the nodules which themselves are entombed in a volcanic ash (bentonite) that fell onto a moderately deep sea floor some 425 million years ago. Clay was apparently crucial to the preservation of the animals, surrounding the carcass almost immediately after burial and providing sufficient support to help maintain three-dimensionality until sparry and fibrous calcite precipitated in the void that resulted from the decay of internal soft tissues. It seems that calcium sourced from the volcanic ash during early diagenesis combined with the bicarbonate released from the decaying carcass, to produce calcium carbonate. The calcite in-fill, together with the surrounding protective nodule, ensured the long-term preservation of each fossil.

It remains to be determined where the volcanic ash responsible for this remarkable preservation actually came from. The Dingle Peninsula in South-Western Ireland is a contender. There was Wenlock volcanic activity in the Mendips, but not at exactly the right time. Bohemian volcanoes

were also active, at about the right time, but the palaeogeography shows the region to have been considerably further away from the Welsh Basin than it is at present.

## SPECIMEN PREPARATION

A small team from Oxford (Professor Derek Siveter and Dr Mark Sutton, now London; and Dr Paddy Orr, now Dublin), Yale (Professor Derek Briggs) and Leicester (Professor David Siveter) universities has been working on these remarkable fossils since the discovery of the biota. The Herefordshire fossils cannot be extracted from the rock by conventional physical or chemical methods. Instead, each specimen is ground down 20 microns (i.e. 0.02 mm) at a time and digitally photographed after each grind. For a single fossil this provides hundreds of images that can be stacked together as a series of closely spaced slices that can then be rendered in 3-D as a 'virtual fossil' by use of computer software, facilitating study, measurement and analysis (Sutton *et al.*, 2001b). The computer reconstructions can even be turned into physical models of the animals through the use of rapid prototyping technologies.

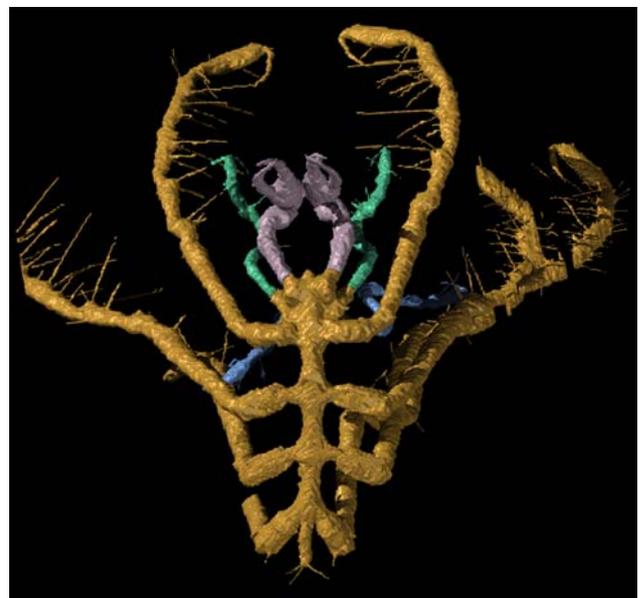


Figure 1. A pycnogonid (sea spider) from the Herefordshire Konservat-Lagerstätte (Siveter *et al.*, 2004). © copyright David Siveter and colleagues.

Certainly the most remarkable aspect of the Herefordshire fossils is that they have soft part anatomy preserved in detailed 3D. This has enabled verification of their similarity (or not) with living species, as in the case of a complete sea

spider (Siveter *et al.*, 2004) (Figure 1), a brachiopod with its pedicle and other soft parts preserved (Sutton *et al.*, 2005) (Figure 2), and even certain microscopic organisms such as two ostracod crustacean specimens, one a male, and the other a female with eggs *in situ* (Siveter *et al.*, 2003, 2007a) (Figure 3). Other forms include a trilobite-like arthropod (Siveter *et al.*, 2007b) and a phyllocarid crustacean (Briggs *et al.*, 2004) with complete sets of appendages, and even specimens illustrating metamorphosis in a barnacle (Briggs *et al.*, 2005). Almost unbelievable as fossils, such material has caught the imagination of scientists and the general public alike.

## CONCLUSIONS

The Herefordshire animals are from a period of geological time for which we have hardly any information about soft-bodied faunas. This quite remarkable fauna from the Welsh Borderland is therefore crucial in helping to fill a gap in our knowledge of the history of life and is fundamental to resolving issues about the relationships and evolution of various groups of animals.

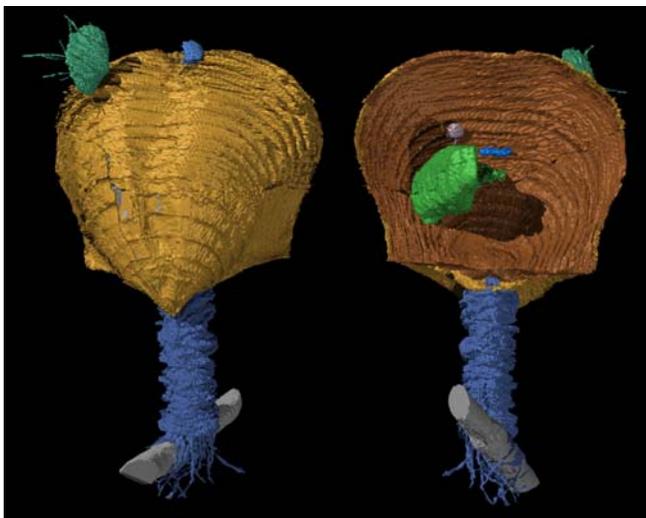


Figure 2. A brachiopod from the Herefordshire Konservat-Lagerstätte, complete with its pedicle attachment structure projecting from the shell, and also other, tiny, attached brachiopods (Sutton *et al.*, 2005). © copyright David Siveter and colleagues.

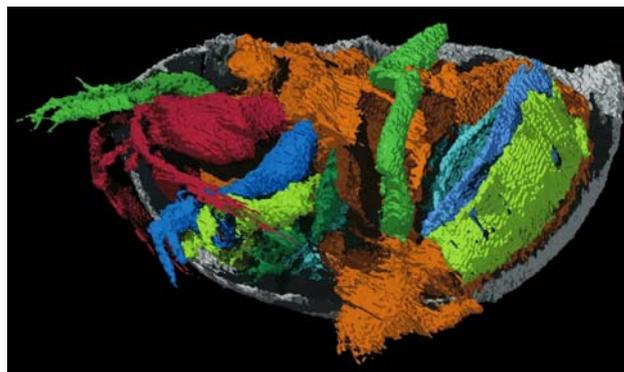


Figure 3. A male ostracod crustacean from the Herefordshire Konservat-Lagerstätte. One of its two valves has been removed to show its remarkably detailed internal soft-part anatomy (Siveter *et al.*, 2007a). © copyright David Siveter and colleagues.

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