INTRODUCTION

The Welsh Marches along the western side of the Midland Platform have been the focus of stratigraphic study since the seminal work of Murchison, who defined the Silurian System (1835). Traditionally this has been based on rock succession exposed in the field (“lithostratigraphy”) and the evolution of fossils (“biostratigraphy”).

The middle portion of the Silurian is ascribed to the Wenlock Stage. This traditionally has been considered a relatively shallow marine series in this area, with shallow water facies top and bottom separated by a deeper water facies in the middle. This gives rise to a tripartite succession of:

- Much Wenlock Limestone Formation
- Coalbrookdale Formation (formerly called the Wenlock Shales)
- Buildwas Formation

This sequence represents a period of some 6 million years during which in excess of 400 m of sediment accumulated. However, it is now known that during this time there were at least two glacial episodes. The associated sea-level change would have been expected to have generated a somewhat more complex sequence of sediments. Furthermore, this was a time of active plate tectonics in the Midland Platform region and volcanic eruptions have added thin but regionally extensive sheets of ash to the sedimentary pile.

It is therefore now timely to reconsider the correlation of the middle Silurian in the light of recent evidence for development of its stratigraphy.

VOLCANIC ASH

Within the marine Wenlock of the Welsh Marches there are a number of thin clay bands. These comprise the swelling clay montmorillonite and is frequently referred to as “bentonite” (although strictly this is the sodium variety commercially used in the oil industry rather than the calcium variety that is usually encountered in the UK).

Some bentonites are locally thick, e.g. 150 mm in Whitman’s Hill Quarry northwest of the Malverns, but 10 mm is more common. These offer the potential to act as time markers provided the same ash bands can be recognised in different exposures. Identification can be on the basis of colour, texture, supported vegetation (particularly as they are impermeable), and geophysics (notably resistivity detected in wire-line logs). Series of ash bands within a sequence, notably for closely spaced exposures and boreholes, are more readily recognisable than ash bands in isolation.

Refinement of the ash sequence can be resolved using sieved samples to extract sand-grade crystals. These can be identified using a microscope and thereby reveal a characteristic mineral suite comprising crystals of biotite, apatite and plagioclase, for example. This can be refined by using the apatite since this mineral contains small quantities of rare earth elements (REE) which are diagnostic of the host magma. As plates move so the source magma changes and this is reflected in the REE signature.

The utility of this approach can be demonstrated at the top of the Wenlock in East Shropshire across into South Staffordshire. Here the sediments are very varied, with the Much
Wenlock Limestone reef tract and both off reef and back reef environments recognisable either side of the main reef zone.

Specific bentonite bands can nevertheless be recognised and correlated across considerable distances. For instance, WHN13 at Wren’s Nest can be traced as far as Wenlock Edge and WHN7 as far as Whitman’s Hill Quarry close to the Malverns. The stratigraphy can also be tied down using diagnostic fossils, notably in the off-reef sediments exposed in the Longville-Stanway road cutting below Wenlock Edge (Scoffin, 1971; Ray, 2010). Furthermore, the bentonites can be traced from the Midland Platform right across to the Baltic, although there they are much thinner. REE studies reveal how the source magma has evolved, with the more acidic character generating more highly explosive eruptions that have enabled the ash to travel further afield (Fisher & Schmincke, 1984; Cramer, 2012; Marshall, 2012).

SEQUENCE STRATIGRAPHY
As already noted, sea-level change is frequently global in extent and yet locally the sediment sequence is very sensitive to water depth. By recognising such sediment changes it is possible to identify still stands of water depth (low and high) and changes, whether deepening or shallowing. A comprehensive picture of sea-level change can thereby be compiled. Such changes have been known for a considerable time (e.g. Grabau, 1936) and become accepted in the last few decades, since the work of Vail (1977).

The speed with which sea-level changes can be quite rapid (Miller, 2005). It is now known that decay of a continental glacial ice sheet could cause global rise in sea-level by some 200 m at a rate of 20 m per thousand years, and is thus potentially able to resolve changes an order of magnitude smaller than the conventional tools of lithostratigraphy and biostratigraphy (Simmons, 2007).

Thus sediment builds out into the basin and sea-level decreases in a Highstand (regressive) Systems Tract. As sea-level rises, sediment builds out but reflects deeper conditions as one goes out into the basin.

The Wenlock of the Midlands does not expose the basin floor during periods of sea-level fall, nor does the basin become completely infilled as sea-level rises. However, progradational parasequences (building out during high stands) can be recognised, for example at Wren’s Nest where shallow deposits become progressively deeper within a metre or so of sediment.

Similarly, aggradational parasequences characterise small scale infilling for the accommodation space. Such details of Silurian sequence stratigraphy can be compared with the system established globally (e.g. Johnson, 2006). Although the broad details are now agreed, there are a number of detailed differences. An independent marker is needed, for which carbon isotopes can be utilised.

CARBON ISOTOPES
The heavy carbon isotope, carbon 13, is a measure of sea temperature. Deviation of the carbon 12 to 13 ratio from the normal, known as an “excursion”, can be used as a measure of sea-level and thus excursions represent changes in sea-level (Saltman, 2005; Cramer, 2010).

WENLOCK PALAEOGEOGRAPHY
Integrating studies of regional stratigraphy have enables the palaeogeography of the Midland Platform to be constructed within a global context (Bug Plates, 2009; Woodcock, 2000). Locally the distribution of facies has been related to a continental shelf environment by Scoffin (1971). His reconstruction has shallow water environments stretching through eastern Shropshire and Worcestershire, with coastlines in South Staffordshire and North Gloucestershire, running out to deeper water facies in western Shropshire and into Powys.

The Wenlock of this region is internationally important because of the early acceptance of the middle Silurian stratigraphy and its adoption worldwide. The GSSPs for the base of the Wenlock, Homerian and Ludlow are all within the Marches (at Hughley Brook, Whitwell Coppice and Pitch Coppice respectively) and their utility and interpretation are critical for correct application for correlation elsewhere.

However, there are correlation issues:

- the GSSPs are small and geographically isolated
- the detailed biostratigraphy is mostly restricted to the type areas
good exposures are restricted to the upper
and lower part of the Wenlock

The work reported herein has therefore focussed
on creating a high resolution correlation that is
robust.

**HIGH RESOLUTION CORRELATION**

Using the techniques outlined above, high
resolution correlation can be attempted for the
Midland Platform.

The process begins by establishing the detailed
stratigraphy from deep boreholes. Two drilled on
behalf of the BGS have been particularly useful:
Lower Hill Farm near Much Wenlock and Eastnor
Park in North Gloucestershire. These are some 50
km apart; Lower Hill Farm is within the marine
shelf whereas Eastnor Park is close to shore.

Within some 40 m of the lowest unit, the
Buildwas Formation, sediments contain no less
than 31 bentonites. REE signatures have been
established on sieved samples and these enable
correlation between the two boreholes (Ray,
2007). Correlation can then be extended to the
Silurian inliers (May Hill, Woolhope, Abberley,
etc.) using just basic lithologies (Ray & Butcher,
2010):

- sandstone (indicating shallow marine, close
to shore)
- bedded limestone (indicating shallow
  marine, shelf)
- nodular limestone (indicating somewhat
deeper marine, shelf)
- shale (indicating deep marine, off the shelf)

Logs of boreholes have enabled parasequences to
be established within the lithological sequences.
Examples of sea-level change of early Wenlock
age can be deduced at Scutterdine Quarry
(Woolhope) and Brinkmarsh Quarry (Tortworth),
the latter close to shore.

Both quarries show considerable variety, more
so in Scutterdine, yet both demonstrate comparable
upward shallowing parasequences. *Pycnactis* is a
solitary rugose coral and is found in the same
shallow water situation on both localities.

Furthermore, carbon isotope values show a
decay upwards through the same sequence. This
compares with the well-known sections at Götland
in the Baltic off the Swedish coast, corresponding
to the upward deepening trend of the Woolhope
Limestone Formation. Indeed, the same sequence
can also be demonstrated in the Carnic Alps of
Austria, thus correlation can be achieved over very
large distances.

Wenlock sediments are also found across the
Atlantic in the Niagara Falls area. Even though the
North Atlantic did not exist at the time, carbon
isotope studies initially seemed to suggest that
correlation may not possible. However, it turns out
that the whole of the Niagaran succession falls
within the Ireviken episode and in fact the
correlation tools have been shown to be applicable.

**CONCLUSIONS**

Correlation of the Silurian across the Midlands has
been established for nearly two centuries but the
basis is considered somewhat simplistic in the
context of current understanding of sea-level
change.

Consideration of new methods of correlation is
presented in the context of Wenlock sediments in
the vicinity of the Midland Platform.

Bentonites may be used as a geochemical event
horizon and thereby establish magmatic settings
and absolute age.

High resolution sequence and event
stratigraphy facilitates basin-scale correlation.

Carbon isotope excursions can be used to
supplement biostratigraphic data.

The stratigraphy of the Midland Platform has
thereby been resolved to a much greater level of
detail than has been possible hitherto and the
continental shelf model of Scoffin (1971) upheld.

Even apparently incongruous sequences, such
as the Niagaran succession, can be successfully
correlated provided a number of correlation tools
are applied rather than relying solely on one or
two.

**DRAFT**

**ACKNOWLEDGEMENTS**

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REFERENCES

Please could you add the full references for each of the relevant items – possibly a figure from each would be appropriate, to illustrate the points you make in the text.

Bug Plates, 2009
Cramer, 2010
Cramer, 2012
Fisher & Schmincke, 1984
Grabau, 1936
IGCP 591
Johnson, 2006
Marshall, 2012
Miller, 2005
Murchison, 1835
Ray, 2007
Ray, 2010
Ray, 2011
Ray & Butcher, 2010
Saltzmann, 2005
Scoffin, 1971
Simmons, 2007
Vail, 1977
Woodcock, 2000