Palaeogeography of the Lower Palaeozoic

Robin Cocks

COCKS, L.R.M. (2008). Palaeogeography of the Lower Palaeozoic. Proceedings of the Shropshire Geological Society, 13, 49–57. The chief purpose of this brief review is to describe how the disparate parts of the British Isles have come together, with particular reference to their amalgamation in the Palaeozoic. It is now known that, prior to the Caledonide Orogeny of the Silurian, Britain was divided between two major terranes and has thus only been united for less than 10% of geological time.

BACKGROUND

Based on the author’s address to the Geologists’ Association (Cocks, 2005) it is natural to assume that Britain has always been the sea-girt isle beloved of Shakespeare. However, as soon as one starts to look at British rocks and to understand her geology it becomes progressively obvious that, since the rocks contain numerous and varied fossils of marine origin, these islands have been under the sea for a very large part of geological time. For these reasons, Britain is one of the best places in the whole world in which to study geology, since the rocks represent a large proportion of the Earth’s history, with every period from the Precambrian to the Holocene represented by sediments and fossils. Shropshire emulates much of this within the compass of a single county.

However, it is also natural to assume that the area now occupied by the British Isles has always been together as a single unit, if not always at today’s latitude and longitude. Once again: a fallacy. It is the chief purpose of this relatively brief review to describe how the disparate parts of these islands have come together, with particular reference to their amalgamation in the Lower Palaeozoic.

Since the Palaeozoic, all the area of the modern British Isles has been joined together as a single unit and thus, although the seas have advanced and retreated many times in the Mesozoic to Recent, the changes in palaeogeography during the last 250 million years have been much less fundamental than in the previous aeons.

The past forty years have been a most exciting time for geologists: despite the preceding 200 years of steady progress in geological knowledge, it has only been since the 1960s that geology has possessed the unifying theory of plate tectonics, comparable to the understanding brought about by evolution for the biological sciences.

The effects of that global knowledge on our understanding of the geology and history of the British Isles have been astonishing. Most dramatically, we now know that Britain was divided between two major terranes until the Caledonide Orogeny of the Silurian, and has thus only been united for less than 10% of geological time.

Identifying Terranes

A terrane is a discrete piece of continental crust that is moving or has moved in relation to those blocks which surround it.

Methods of establishing the locations of individual terranes include:

- sea floor stripes and hotspot drift (applicable from the Jurassic, but not before due to the young age of oceanic crust)
- palaeomagnetism (gives latitude and terrane orientation, but not longitude and can suffer from an overprint problem)
- sediment distribution (cannot give longitude and is imprecise)
- tectonic alignments (dodgy, but the only technique for the Precambrian)
- palaeontology (only applicable from the Cambrian, and rather subjective)

Fossils of rapidly evolving free-swimming creatures such as graptolites are good for dating and thus for correlation, but not for identifying terranes (Figure 1). The opposite generally holds true for shallow water, bottom inhabiting creatures...
such as trilobites and brachiopods (Figures 2 & 3), but not always (Figure 4).

Figure 1. A graptolite (*Monograptus crispus*) useful for dating and thus correlation but not terrane recognition; collected by Cocks & Toghill (1973). © Copyright Natural History Museum, London

Figure 2. The trilobite *Asaphus*, indicative of Baltica. © Copyright Natural History Museum, London

Figure 3. The trilobite *Bathyurus*, indicative of Laurentia. © Copyright Natural History Museum, London

Figure 4. Trilobites are generally good facies indicators since many are bottom inhabiting creatures, and so restricted to terranes. However, this particular Welsh one, *Pricyclopyge*, has very large eyes and was a good swimmer, so is not good as a terrane indicator. © Copyright Natural History Museum, London

**Precambrian**

Northern Britain formed part of Laurentia, whilst Southern Britain was an amalgamation of several terranes which had become part of the huge supercontinent of Gondwana before 600 Ma.

The fabric of the Welsh Borderland is governed by its location on the margin of the Midlands Microcraton, evidence for which comes from the thickness of the continental crust revealed by deep geophysics (Figure 5).
Cambrian

With the caveat that they are restricted by facies, the similarity of fossils such as trilobites can be used as a general indicator of relative terrane location. For example, similarity of trilobites have been used to indicate the proximity of the Welsh Borderland continent (Avalonia) to Gondwana in the mid Cambrian (Figures 6 and 7).

Such evidence enables maps such as Figure 8 (for the Early Cambrian) to be compiled. Note that Baltica is here portrayed ‘upside down’, an orientation confirmed by its palaeomagnetism. Such continental masses have thus since rotated.

As time progressed through the Cambrian, so the Welsh mass of Avalonia separated from Baltica but remained close to Gondwana (Figure 9), separated by the narrow but widening Ran Ocean.

Figure 5. The Variscan Front in relation to the Midlands Microcraton, the remnant of an ancient terrane. © Copyright Natural History Museum, London

Figure 6. The trilobite *Solenopleuropsis* from Avalonia (Wales). © Copyright Natural History Museum, London

Figure 7. The essentially identical Cambrian *Solenopleuropsis* from Gondwana (collected in present day southern France), indicating that Wales was then part of Gondwana in the Cambrian. © Copyright Natural History Museum, London
Ordovician

Brachiopods have been successfully used to reconstruct the palaeogeography of Ordovician times, enabling terranes to be distinguished (compare Figure 10 with 11). This has revealed that Baltica was remote from Gondwana, and rotated compared to its current orientation (Figure 12).

Gondwana itself was still vast, and covered the full range of prevailing climatic belts (Figure 13).

By the Caradoc, significant continental drift had taken place, as shown by comparing Early with Late Ordovician palaeogeographies (Figure 14). The curved line to the left of the figure shows the palaeoequator; Laurentia (most of North America) straddled this at the time. Scotland and northwestern Ireland is the area shown to the east of Greenland; England, Wales and southeastern Ireland formed part of the Avalonia Terrane, originally part of Gondwana.

By the end of the Ordovician, southern England was 30 degrees south of the Equator and Avalonia was approaching Baltica (Figure 15). This period also saw a widespread glaciation, and the whole planet’s climate cooled significantly. Evidence exists in the form of glacial pavements (Figure 16) and decrease in carbonate sediments (Figure 17).
Figure 12. Baltica in Ordovician times was rotated compared to its present orientation and was quite separate from Gondwana. © Copyright Natural History Museum, London

Figure 13. Contrasting climates across the vast expanse of Gondwana in Arenig times. © Copyright Natural History Museum, London

Figure 14. Palaeogeography of the Iapetus Ocean area in Lower Ordovician times (480 Ma); a polar projection modified from Cocks & Torsvik (2002). The curved line to the left of the figure shows the palaeoequator. This map shows only the outlines of the various terranes present, with some modern geographical coastlines added to assist terrane recognition. © Copyright Noregs geologiske undersøking, Trondheim, Norway

Figure 15. Palaeogeographic map of southern Britain for the Caradoc (Late Ordovician). England was 30 degrees south of the Equator and Avalonia was approaching Baltica. © Copyright Natural History Museum, London

Figure 16. Hirnantian glacial pavement in Algeria, of Late Ordovician age [from Beuf et al. 1972 © Copyright Editions Technip, Paris]
Silurian

The Silurian Period saw a slow period of climatic amelioration, commencing with clastic sediments which became progressively more calcareous (Figure 17 & 20 from eastern Canada and Figures 18 & 19 from the Welsh Borderland).

Figure 17. At what was then the Equator, a section on Anticosti Island in the St Laurence river, Canada, showing warmer Silurian Becscie Formation sediments overlying the basal Llandovery above a much warmer Late Ordovician bioherm of the Ellis Bay Formation. © Copyright Natural History Museum, London

Figure 18. Hope Quarry, Shropshire, exposing Middle Llandovery carbonates – warming up was taking quite a time. © Copyright Natural History Museum, London

By the end of the Ordovician, Avalonia had collided obliquely into Baltica. By the end of the Silurian the combined Avalonia and Baltica subsequently bumped into Laurentia, with destruction of the Iapetus Ocean accompanied by the Caledonian orogeny. Warm climatic conditions now prevailed, with bioherms in eastern Canada and northern Greenland as well as the Welsh Borderland and the Urals.

Meanwhile the Rheic Ocean to the south was widening, evidenced by study of ostracods (e.g. Cocks & Fortey, 1982) (Figures 21 & 22).
The end of the Silurian saw jostling of terranes as the major continental masses came closer. Minor adjustments took place as ocean closure occurred. Studies of ostracods have been able to demonstrate these differences between the continental masses and reveal details of their evolution.

The Silurian in other parts of the world included the Siberian craton, which has the thickest and most stable continental crust in the world. Like Baltica, in the Lower Palaeozoic Siberia was ‘upside down’ and has since been rotated by plate movements (Figures 23 & 24).

Similar reconstructions have been compiled for the remnants of Gondwana, including the Middle East, the large adjacent continent of South China, Africa, India, Australia and Antarctica (Figures 25 & 26).
Summary

Scotland and northwestern Ireland were part of Laurentia, which today also makes up the greater part of North America. England and southeastern Ireland were parts, first of the Avalonian part of Gondwana until the earliest Ordovician and subsequently the independent Avalonia Terrane until its collision initially with Baltica in the latest Ordovician and, subsequently, with Laurentia in the Caledonide event. In addition, various much smaller terranes, which had existed in the various oceans surrounding the different parts of the British Isles, were accreted within the different phases of the Caledonide Orogeny, and are to be identified today along the closed Iapetus Ocean Suture Zone between Laurentia and Avalonia, which chances also to roughly coincide with the national boundary between England and Scotland.

The later Variscan Orogeny, in the Late Devonian and Carboniferous, also affected these islands, not only tectonically distorting their southern parts, but also in the accretion of the microterrane which is today exposed in the Lizard Peninsula of Cornwall. However, the Variscan and much later Alpine orogenies were not nearly so significant in the development of Britain as was the Caledonide Orogeny in the Silurian.

Subsequently, the unified British Isles were first part of Laurussia, secondly Pangaea and, finally today, after the Atlantic Ocean opened, at the northwestern margin of Eurasia.

The key dates for the evolution of the terranes comprising the Welsh Borderland are summarised in the following table.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>425 Ma</td>
<td>Mid-Silurian union of Avalonia-Baltica with Laurentia</td>
</tr>
<tr>
<td>443 Ma</td>
<td>End-Ashgill soft oblique docking of Avalonia with Baltica</td>
</tr>
<tr>
<td>ca. 490 Ma</td>
<td>Avalonia leaves Gondwana margin</td>
</tr>
<tr>
<td>550 – 490 Ma</td>
<td>“Avalonia” within Gondwanan margin</td>
</tr>
<tr>
<td>610 – 530 Ma</td>
<td>Transform system develops within “Avalonian” Gondwanan margin</td>
</tr>
<tr>
<td>635 – 570 Ma</td>
<td>Arcs develop uniting previous terranes</td>
</tr>
<tr>
<td>1.2 – 1.0 Ga</td>
<td>Varied terranes formed</td>
</tr>
</tbody>
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ACKNOWLEDGEMENTS

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REFERENCES


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