Herefordshire & Worcestershire
EARTH HERITAGE TRUST

Journey from the south pole

a geological history of Herefordshire and Worcestershire

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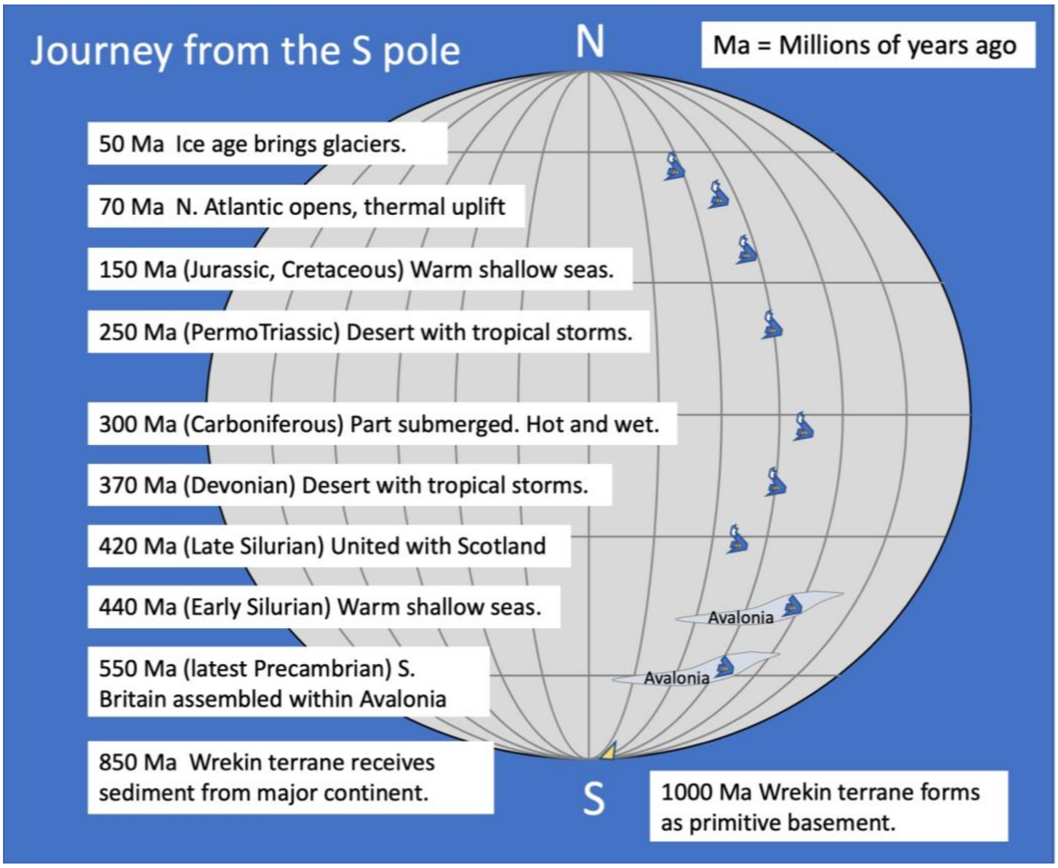
Introduction

This story starts near the South Pole where, for many millions of years, Herefordshire and Worcestershire developed on separate pieces of crust, or 'terranes', before colliding and combining with a number of similar crustal fragments to form the microcontinent of Avalonia. Over the ensuing half a billion years Avalonia, which included all of Southern Britain, drifted northwards to unite with Scotland close to the Tropic of Capricorn. It continued the northward drift crossing the equator, traversing the northern tropics and eventually reaching the cool temperate climes where it is today. During its journey it endured bumps and skirmishes, union and division involving a number of crustal blocks, large and small, and in recent times, a combination of uplift and intense erosion by ice and water have exposed the many different rocks that formed during this eventful journey.

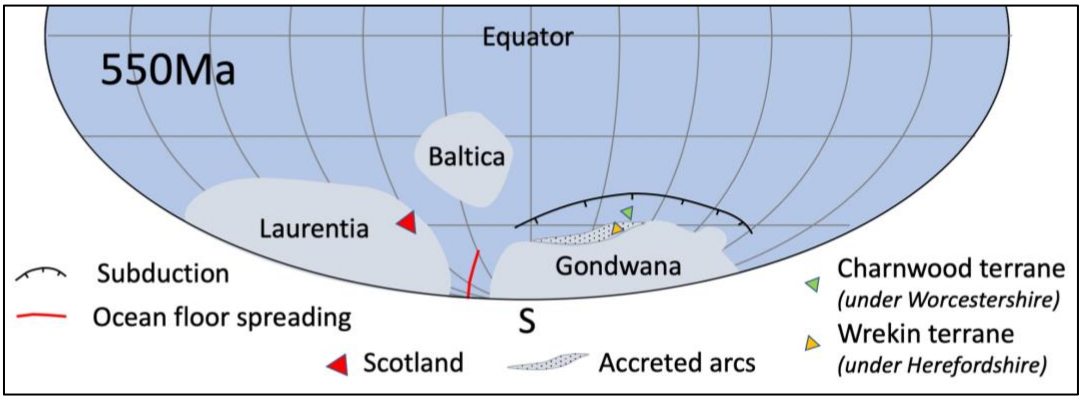


The details of this adventure can be read to a great extent in the rocks and landforms of Herefordshire and Worcestershire. This account provides a short overview.

Down in the basement

The origins of the Wrekin terrane, underlying Herefordshire

The Precambrian basement of Herefordshire appears at the surface on either side of the county: in the Malvern Hills to the East and in the Stanner-Hanter rocks just outside the county in Wales, as well as to the North in Shropshire. It is part of the Wrekin terrane, which underlies the Welsh borderlands. Analysis of Malvern Hills rocks has revealed some of the details of how, where and when this basement was formed. The coarse-grained rocks that make up the bulk of the hills cooled 677 Million years ago (677 Ma) in chambers several kilometres underground. Rock formed from crystallization of magma (molten rock and dissolved gas) underground in this way are referred to as plutonic. In the Malverns, this rock intruded through existing bedrock. By analysing radioactive isotopes in the Malverns plutonic rocks, geologists estimate that the basement rock through which they intruded had formed in a primitive island arc[1] about 1,200 to 1,000 Ma. On top of this early basement, sedimentary rock had formed and some of this was brought up with the magma. It can be found near Gullet Quarry in the Malvern Hills as sedimentary gneiss, and zircon (zirconium silicate) crystals within it match those of the ancient rocks of the Amazon. The dating of these crystals has shown they are 1,900 million years old, having cooled within rocks in a deep Amazonian magma chamber. Those rocks were then heated, folded, faulted and eventually brought to the surface, eroded and transported as sand grains to the continental edge, where around 800 Ma the crystals were deposited in sediment.



The intrusion and cooling of the Malvern plutonic rocks at 677 Ma was followed about 25 million years later by continental collision on the edge of Amazonia. This was the Cadomian Orogeny[2] and caused intense heating and shearing of the Malverns Complex rocks, followed in the next 40 million years by lower temperatures and chemical alteration by watery fluids. It is thought that at this time, the Wrekin terrane was thrust against and accreted onto the continental margin. As a result, the original minerals of the plutons have largely been converted to metamorphic minerals[3]. The shape and orientation of crystals shows how shearing of the rocks at depth has squashed and distorted them during this time. In addition, magma of various compositions has intruded the rocks at different times forming numerous dykes with complex cross-cutting relationships.

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[1] Earliest stage of continent formation as one ocean plate subducts under another.

[2] Mountain-building episode

[3] In the Malverns Complex rocks, the pyroxenes and alkali feldspar minerals that are normally found in the plutonic rocks of a volcanic arc have been replaced, with the addition of water, by the metamorphic minerals hornblende and mica.

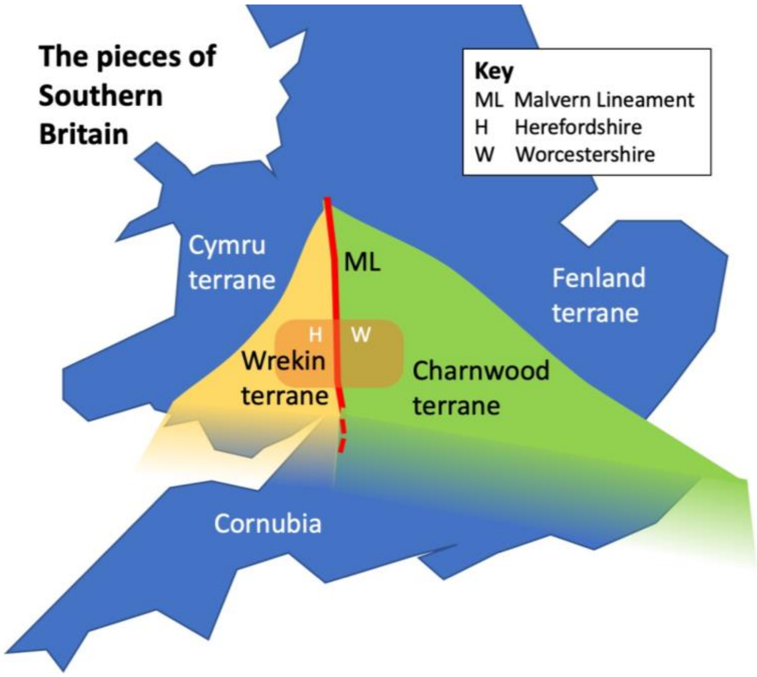
The Charnwood terrane, underlying Worcestershire

Meanwhile, not far away, the basement underlying Worcestershire was starting to develop as a 'primitive' island arc, created as one piece of ocean crust was subducted under another, forming an area of thicker crust that was to become the Charnwood terrane.

Around 566 Ma subduction and volcanic activity resumed on the edge of Amazonia, now a part of the supercontinent of Gondwana. Basalt was extruded onto the sea floor and lighter volcanic material was ejected and settled as volcanic sediment. This Charnwood basement can be found on the eastern side of the Malvern Hills as the Warren House formation. It has also been found several kilometres down in the borehole at Kempsey as well as in the Charnwood rocks in Leicestershire. Its chemistry is a close match to that of the Wrekin terrane but not identical, and indicates that they developed in close proximity, but at different times.

Terrane amalgamation: the counties come together at around 60^o south

Within the next 30 million years or so, the basements of Herefordshire (the Wrekin) and Worcestershire (the Charnwood) were brought together. Several volcanic arcs on the edge of the continent of Gondwana were thrust against each other in haphazard fashion and welded together.



The Wrekin and Charnwood terranes were joined along a suture that we call the Malvern lineament, extending from the Bristol Channel in the south through the Malvern, Suckley and Abberley hills to at least the Cheshire plain in the north. Further uplift accompanied this tectonic activity. Erosion of the uplifted rock ensued, so that by around 520 Ma the ancient, much modified magma chambers, which we see today as Malverns Complex rock had become exposed at the surface. We know this, because coarse marine sandstones and conglomerates of the mid Cambrian Period have been deposited directly on top of the eroded surfaces, creating what geologists call an unconformity.

Building on the basement

By 500 Ma, the assemblage of terranes that was to become Southern Britain was located at around 60° south of the equator, on the northern edge of the continent of Gondwana by the side of the Iapetus Ocean. It was a low-lying area, partially submerged and receiving sediment from the rivers of Gondwana. Cambrian and early Ordovician sandstones, mudstones and shales can be found around the south west of the Malvern Hills and in North Worcestershire. These Cambrian and early Ordovician rocks contain numerous fossils, so they can be compared in space and time with other rocks around the world. In the mid to late Cambrian, Scotland lay at warmer latitudes some distance away on the edge of the Laurentian continent, and their fossils of similar age are markedly different. This, however, was about to change.

Renewed volcanism, rifting and shifting: Avalonia breaks away

By early Ordovician times, subduction of the Iapetus ocean crust under the edge of Gondwana had resumed, resulting in major volcanic activity in Wales and northwest England. The Midland Platform, consisting of the English midlands and Welsh borders was uplifted above sea level and middle to late Ordovician deposits are not found here.

At the same time, a major rift valley started to form between the newly accreted terranes and the Gondwanan continent. After about ten million years a new ocean opened up and a sliver of crust broke away completely, forming the micro-continent that we call Avalonia, with Southern Britain in the eastern part of it.

Rift valleys usually start at a 'triple point' where the upwelling of hot mantle rock causes the crust to fracture in three directions. Initially, all three fractures open up, but over time, rifting focusses on two of them along which the rift valley continues to widen, while the third is the 'failed arm' and remains as a line of weakness in the crust. The Worcester Basin, lying between the Malvern Lineament and the Cotswolds may have been that 'failed arm' at the time Avalonia broke away from Gondwana. If so, it has been an important British geological feature for more than 450Ma.

Avalonia was drawn northwards across the shrinking Iapetus Ocean, as subduction continued under both sides of Iapetus and the new Rheic Ocean expanded to the south. The late Ordovician to earliest Silurian periods though were far from peaceful, as three important events affected our micro continent.

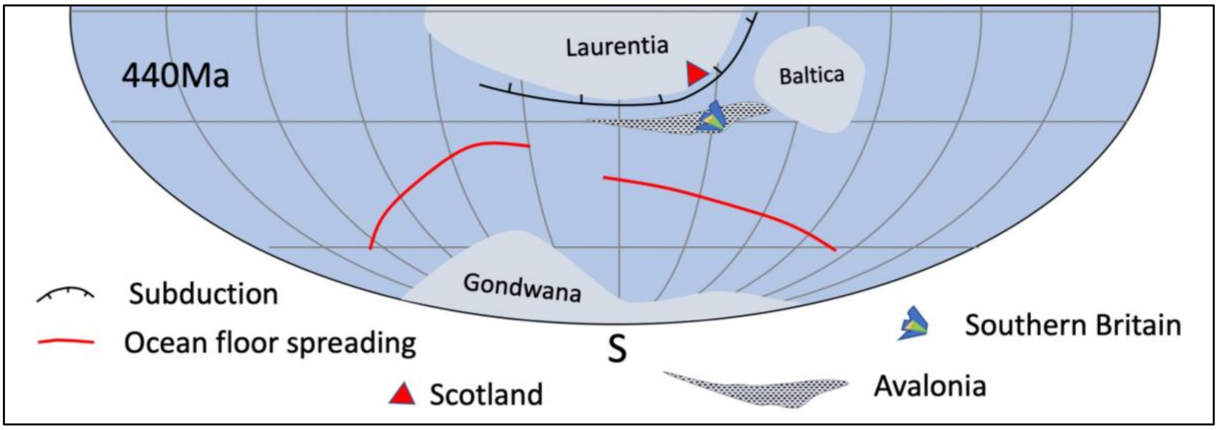
As Avalonia was heading towards subtropical waters, the world was in the grip of an Ice Age that brought icebergs to its submerged continental shelf. Water was locked up in thick ice sheets over Gondwana, left behind around the south pole, and global sea levels fell. Parts of the English midlands became land and erosion on the Avalonian landscape created sediments which appear as sandstones in the earliest Silurian rocks.

At the same time, subduction of the Iapetus ocean under Avalonia had ceased and dykes intruded into the Ordovician deposits of both counties. A likely reason for this is the break-off of the subducting slab, opening a gap for hot mantle melt to rise through the crust. Collision with the large continent of Baltica to the east was happening at much the same time. It is not certain which of these was the primary cause of the Shelvian event, when folding and faulting uplifted Ordovician rocks in the Lickey Hills in North Worcestershire as well as those in Shelve in Shropshire, and may have disturbed some old faults in the Welsh borderlands. The extent of the damage is uncertain, as it was to be masked by later distortion.

A low-lying, ocean-bound island in sub-tropical seas

Herefordshire was submerged for most of the Silurian Period and displays a complete record of the rocks formed at that time. Early to mid-Silurian deposits are also found in northwest Worcestershire which must also have been submerged, but the Worcester Basin might have been uplifted and above sea level for at least some of this time.

The earliest Silurian rocks were sandstones, but as sea levels rose again and the supply of sediment diminished, the clear, shallow, subtropical seas teemed with life. Hard shells and skeletons made of calcium carbonate settled on the sea floor to form fossils and became cemented together to create thick, hard limestone. In deeper waters, life-forms were less abundant and fine siltstones built up very slowly from miniscule particles washed into the ocean together with some fossils. As sea levels fluctuated, so the rocks alternated between limestone and siltstone.



Docking with Laurentia: a land-locked, arid, tropical flood plain

Baltica and Avalonia continued moving together towards Laurentia. Sediment received from the larger continent muddied the waters and the fossiliferous Upper Ludlow Siltstones were formed. When collision with Laurentia finally happened, most of the impact was borne by Scandinavia to the east and Newfoundland to the west, so that although accretion of the soft sediments of the Laurentian shelf created the Southern Uplands of Scotland, the only effect on Southern Britain was to raise much of it above sea level.

At this time, a very gently shelving sandy coastline spread across the Welsh borderlands, with sand supplied by the rivers of Laurentia. This produced the Downton Castle Sandstone. As the sea retreated further the uplifted sea bed became a vast alluvial plain. Surrounded by land, in a tropical climate, with arid, oxidising conditions, iron in the sediment turned red. For about twenty million years, rivers wound their way across the plain, bringing sediment from distant mountains. Sand was deposited in the ever-shifting river beds and tropical storms brought flash floods that spread mud over the plains. This was the scene for the Old Red Sandstone that underlies most of Herefordshire today and is reflected in rocks of this time across the vast continent of Laurasia (Laurentia and Baltica combined), which has been called the Old Red Continent.

All this changed in mid Devonian times with the Acadian Orogeny. The cause is uncertain, but tectonic forces from the south thrust against the old solid rocks of the Midland Platform and caused intense folding, faulting and uplift in the thick, softer deposits to the north, creating the mountains of North Wales and the Lake District. The English midlands and the south of Wales were certainly uplifted at this time as sedimentation across Herefordshire was interrupted during the mid-Devonian. Movement along some old fault lines may also have occurred, but there is no clear evidence for this. By late Devonian, the land had subsided again: erosion from the newly built mountains in the north was bringing coarse sediment, creating the sandstones and conglomerates found in the south of the county. Land plants and animals around the globe had emerged from the seas and were thriving, but there is almost no sign of this in the Old Red Sandstones, formed in semi-desert conditions.

Shallow seas return, with a hot, wet, equatorial climate

Much of Britain was flooded in Carboniferous times by a shallow sea that encroached from the North: the Euramerican seaway. Higher land across the Midlands was above water but deposits remain in the north of Worcestershire (the Wyre Forest and south Birmingham) the south of Herefordshire and a vestigial piece in the middle near Martley. Exactly how much of the area was submerged in the early Carboniferous is unknown. At least in south Herefordshire, abundant marine life thrived once again, capturing carbonates from the sea for their hard parts so that fossil-rich limestone built up on the sea floor. Further south, the Rheic Ocean was closing. Several micro-continents like Avalonia were caught in a collision between the major continents of Gondwana and Laurasia. By the mid Carboniferous, the Variscan Orogeny that distorted and uplifted much of southern Europe was starting to affect the most southerly parts of Britain.

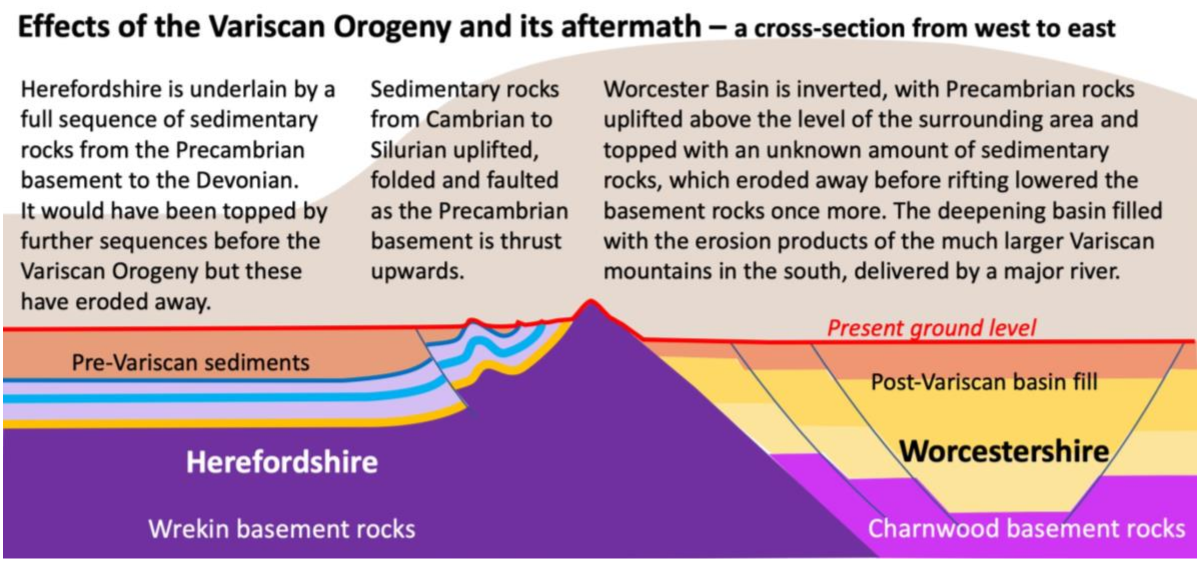
Britain was now close to the equator, and by the middle of the Carboniferous Period, deltaic sandstones were forming. Rain forests grew in low-lying swampy areas and after many millions of years of burial, their remains turned to coal.

Uplift of the Malvern Hills

The most dramatic event to affect the two counties since Precambrian times happened almost certainly in the late Carboniferous in the final stages of the Variscan Orogeny. Forces from the southwest caused the ancient basement to buckle along the suture between the Wrekin and Charnwood terranes. The Worcester Basin was inverted, creating a small range of mountains. In this process, the eastern edge of the Wrekin terrane was folded and thrust upwards, bending and compressing the overlying sedimentary rocks into great folds and faults. At the Herefordshire Beacon the Precambrian rocks were thrust over and overturned the Silurian sediments and the Precambrian rocks of the adjacent Charnwood terrane were thrust over those of the Wrekin.

When, in Precambrian times, the Malvern Hills plutons had been buried around 20km deep or more in the crust, the effect of the Cadomian Orogeny on the Malvern Hills rocks had been to bend and distort the rock with ductile shearing. In contrast, at the time of the Variscan event the same rocks were covered with no more than a few kilometres depth of sedimentary rock and the effect was to shatter the rocks with fractures and faults. The rocks are extensively cracked and major faults divide the line of hills into a series of blocks, with distinct differences between blocks. Judging by the degree of corresponding faulting on the overlying rocks, the movement on these transverse faults in Variscan times was not very great. It is likely that the fault lines represent weaknesses created in Precambrian times, and movement along these lines in earlier times might have been much greater.

The Silurian rocks west of the Malvern Hills and elsewhere along the Malvern lineament were intensively folded and faulted, so that the bedding is often vertical or overturned. After the tops of the folds had eroded away, the rock sequences were clearly exposed as alternating bands of hard limestone and softer siltstones creating ridges and valleys respectively.



A rift valley forming in a tropical desert environment

In the wake of the Variscan upheaval came erosion. Shattered fragments of Malvernian rock slithered down the slopes in a slurry of mud to form the Clent Breccia in north Worcestershire and the Haffield Breccia southwest of the Malvern Hills. Magnetite crystallised in this rock, and its compass tells us that Britain was approaching the northern tropical belt at this time.

The Variscan Orogeny had marked the collision of major continents, eventually creating the single supercontinent of Pangea. Britain was in the centre of this supercontinent, in climatic conditions similar to those of the Sahara today, and with a massive mountain belt to the south of it. In the hot dry climate, winds would have slowly eroded exposed rocks and turned them to sand, so that by early in the Permian Period, the uplifted rocks from the Worcester basin had been worn down to expose the Precambrian Basement rocks of the Charnwood terrane. These were then covered in the sand dunes of the early Permian Bridgnorth Sandstone Formation, which are now found deep in the Kempsey borehole, lying directly on Precambrian rocks, and at the surface on the margins of the Worcester Basin lying on the newly deposited Haffield and Clent Breccias.

At the same time, worldwide tectonics were starting to affect the region again. The entire continent of Pangea was rotating and starting to break apart once more. Rifting between Greenland and Scandinavia propagated southwards so that the sides of the Worcester Basin were pulled apart and the old rocks started to subside again. Rifting continued intermittently throughout the Triassic period, but as fast as the floor dropped, the basin became filled with sediment. Rotation of Pangea had brought Britain further north and the global climate was changing. Seasonal rainfall over the eroding Variscan chain created fast flowing rivers laden with sediment. One of these started to flow from France through the Worcester Basin and northwards into the Cheshire basin, leaving deep sediments of the Sherwood Sandstone Group and Mercia Mudstones.

Initially the river brought coarse sandstones with rounded pebbles of quartz and some volcanic clasts; later fluvial deposits were formed of very red wind-blown sand. Near the Western edge of the Worcester Basin the deposits largely comprise Malverns Complex and Silurian stones and include fan deposits brought down the steep valley sides. In the mid-Triassic, extensive sandstones gave way to alluvial plain deposits, with sandstones confined to the ever-shifting river beds and mud spread over the flood plain. Salt deposits are also found near Droitwich, formed in a desert environment.

Britain was now in the subtropics of the northern hemisphere.

The sea returns as Pangaea is pulled apart and the Atlantic Ocean opens up.

By the late Triassic, the supercontinent of Pangaea was starting to break up. The sea was encroaching over lower lying parts of Europe and mudstones and later limestones started to form in the warm shallow sea. The Penarth Group in eastern parts of Worcestershire were formed at this time. They may have extended over all of the two counties, but any such deposits have been completely eroded away. Early Jurassic marls and limestones can be found further east in Worcestershire, formed as shallow marine conditions largely prevailed.

Throughout the sixty million years of the Cretaceous period, most of Britain was under water and almost certainly received a cover of Cretaceous chalk, but none of this remains in the two counties or in regions immediately north and west of here.

Landscapes are formed, many different rocks are exposed

Around the end of the Cretaceous Period, uplift and volcanism centred to the west of the Faeroe Islands triggered the opening of the northmost Atlantic Ocean between Britain and Greenland. The effects were widespread, with volcanism in Scotland and uplift across all but the south east of England. From this time until the start of the Quaternary Period and the great Ice Age only 2.5 million years ago the story of Herefordshire and Worcestershire was dominated by erosion, so almost nothing remains to tell us of its history, although the shape of the landscape gives some clues to the drainage patterns of the time.

Repercussions of the Alpine Orogeny were felt in southern Britain from this time until the present day, but Herefordshire and Worcestershire have not been affected apart from perhaps some minor movement on pre-existing faults.

During all this time Britain's northward journey continued, bringing it close to its present position in the cool temperate, west coast climate of the northern hemisphere. But things were about to get much colder.

The Ice Age and its aftermath

For the last two and half million years, glaciers have come and gone over northern Europe, but none were as extensive as those of the Anglian glaciation of half a million years ago, which obliterated most of the evidence of previous glacial stages except in regions beyond its reach. Finds from the south east of England show that people had reached Britain 800 thousand years ago, and they could have ventured as far as Herefordshire and Worcestershire, but that is speculation.

Anglian glaciers swept across Herefordshire from the west and through Worcestershire from the north, bulldozing the landscape as they advanced and leaving copious deposits as they retreated. The occasional clue to previous drainage patterns is all that remains. A second glaciation, the Devensian, advanced only part way across Herefordshire and did not reach Worcestershire at all.

A rich variety of glacial and periglacial deposits and landforms can be found across both counties, from massive erratic boulders, brought from Wales and northern England to fine-grained lake deposits; from entire landscapes of hummocky moraine littered with ice age ponds, to tundra polygons and landslips on the hillsides. River terraces of widely differing ages give clues to changing river patterns and contain the remains of mammoths, hippos and rhinos, as well as insects and pollens that reveal much about how the environment changed over time.

The landscapes even reveal geology in action today, with areas of blown sand, recent landslips and outcrops of tufa forming before our eyes.

A wealth of Earth Heritage to be valued and protected.

There can be very few places in the world where so much of the past is revealed in so small an area. The richness of our rocks and landscapes should be celebrated and enjoyed. What is robust should be exploited to the full though recreation, education and research, and where appropriate for mineral extraction, but we need to recognise what is fragile, and manage its protection with care to preserve what is valuable for future generations.

Acknowledgements, references and further reading

This account owes a great deal to the masterful "Geological History of Britain and Ireland", 2nd Edition by Nigel Woodcock and Rob Strachan, published by Wiley-Blackwell, 2012. It documents the series of major geological events described here and provided the basis of most of the diagrams.

The maps of the British Geological Survey (BGS) and the associated memoirs covering the two counties were essential sources of information in matching the wider British and world events to local rocks and were the source for drafting the simplified west-east cross section. These can be viewed online on the BGS Maps Portal and BGS Memoirs pages of the BGS website.

For details of Herefordshire's geology, "Herefordshire's Rocks and Scenery: a geology of the county", edited by John Payne, published by Logaston Press 2017 is an excellent source and a very worthwhile read.

There is no equivalent for Worcestershire, but for its Quaternary Geology, "Lost Landscapes: the story of the ice age in Worcestershire" is an excellent booklet. For a detailed breakdown of likely events affecting the Worcester Basin, "The complex tectonic evolution of the Malvern region: crustal accretion followed by multiple extensional and compressional reactivation" by Tim Pharaoh, in "Proceedings of the Open University Geological Society", Vol 5, 2019 is an interesting read. It can be found on our website, thanks to the kind permission of the OUGS and the author.

The booklets provided for the H&WEHT Champions sites as well as the various geological Trail Guides available via the Trust provide a wealth of more detailed information about the rocks and landscapes of the two counties. Information about specific rock formations and a wide range of geological sites can be found by following the links on the Trust's Local Geology web page, but please note that for many of these locations there is no public access and the site may have become overgrown or unsafe.

Last but not least, I would like to thank Ian Fairchild, John Payne, Moira Jenkins and Brian Hughes for providing very useful comments on draft versions.

Kay Hughes
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