A Geological History of The Malvern Hills

Dr. Dave Bullard

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On the BGS Worcester map, most of the Malvern Hills is coloured a uniform deep purple, but of course we all know the rocks found in that area are far from uniform! As a Malvern-based geology group, unpicking the complexity of Malvern Hills rocks is surely a topic of intense interest: an interest shared whole-heartedly by our speaker for the day, Dr Dave Bullard.

His detailed study of the Malverns Complex rocks began when far more rock was exposed than we can see today: this, and his continued interest in the area probably gives him an unparalled knowledge and understanding of 'our' hills. It was therefore a great privilege to be able to welcome him to Malvern to talk to us.

These notes summarise what I took as key geological messages from Dave's talk, but they fail to capture all the detail, or the rich variety of anecdotes with which he entertained us on the day. The presentation slides used with the talk are available separately, so I have not included them with these notes. I am most grateful to Dave for his permission to use this material and also for taking the time to correct and comment on my initial draft, though of course any mistakes or inaccuracies are mine alone.

Introduction

Dave started by introducing himself and describing his long association with the Malvern Hills. Having enjoyed his first visit to the area as a teenager, Dave became very familiar with the Malvern Hills when, after graduating in geology at Nottingham University in 1970, he embarked on a PhD funded by Rio Tinto Zinc (RTZ) to research "The Rocks and Soils of the Malvern Hills". Throughout his career as a teacher, Dave has retained a strong interest in the area: paying numerous visits, writing a short book on the geology of the Malverns in 1986, and continuing to track ongoing research. Now he has retired he is taking the opportunity to revisit old field notes and amalgamate his accumulated knowledge into an enhanced understanding of the Malvern Hills rocks.

Much of what Dave presented has never been published, so it was a great privilege to have it explained to us.

In his talk, Dave surveyed the most relevant literature on which his research was built, recounted some of his fieldwork experiences, and provided a systematic breakdown of the rocks to be found on the Hills, while recounting the processes that are thought to have led to their formation. Dave concluded by advocating a set of practical measures that could both enhance our understanding of Malvern Hills geology and make this more accessible to a wider public.

Research history

Geologists have been interested in the Malvern Hills since before William Smith's time. As early as 1811, Leonard Homer produced detailed descriptions of rocks and their locations, some of which can be identified with confidence to this day. John Phillips surveyed and attempted to map the area in 1848 and acknowledges his sister (Miss Phillips) as having discovered the unconformity on the Western slopes which bears her name. Further work by Harvey Holl in 1865 was very influential, while the publications of Charles Callaway in 1889 and 1893 turned previous work on its head, recognising that all the rocks were igneous in origin but had since been changed by metamorphism. The maps and cross sections of

Theodore Groom, although impressively detailed, were not so helpful when working in the field, as they did not seem to match the rock formations found.

In the early to mid twentieth century, Arthur Bramall studied the hills extensively, but sadly almost all of his specimens and papers were lost during the Second World War. Among his few remaining papers, is a report of finding gold in the red granite of one of the quarries to the west of the hills. This was the trigger that promoted the interest of RTZ, but Dave was unable to reproduce the work there or anywhere else on the hills, so, fortunately for the Malvern Hills Conservators, RTZ lost interest in them.

Francis Blyth of Imperial College also worked extensively in the Malverns in the middle of the twentieth century and developed a great knowledge and love for the area, which he shared with Dave during his PhD viva. Neil Butcher's paper of 1962 was particularly important as it was the first to describe the structure of the hills as a monocline, with the folding of the Silurian rocks to the West, while Michael Brooks provided useful data that helped interpret the Malverns Complex rocks. Richard Thorpe's excellent work emerged as Dave was conducting his own research and provided valuable input. Some of the work was very localised and detailed, while other papers placed the local geology in the broader context of plate techtonics and paleogeography.

Dave's own PhD thesis, completed in 1975, presented the results of analysing many hundreds of rock and soil samples, documented the rock formations in all of the quarries in the Northern part of the Malvern Hills, some of which are no longer accessible, and presented a 25" geological map of the entire area. Most of this work has never been published.

Following his thesis in 1975, Dave was asked to publish his work, but has largely been unable to find the time to do so, apart from the small but very informative book he published in 1989 with funding from the Nature Conservancy Council. He has however continued to take an interest in the area and has tracked the various pieces of research work that has since been published. Notably, John Piper, a geophysicist, published in 1982 his investigations of the magnetic properties of the dolerite dykes, helping to pinpoint the age and location of their formation. Tucker and Pharoah, in 1991, used Uranium/Lead dating to obtain a whole rock isochron date of 677Ma for the igneous plutons. Strachan et al in 1996, 2000 and 2007 published work identifying successive periods of metamorphic activity by analysing the minerals present in the rocks. For example, while muscovite forms at around 400 degrees C, formation of epidote requires higher temperatures. The presence of epidote therefore suggests an earlier period of intensely high temperatures.

All of this later work has been used by Dave to put together his current view of Malverns Complex geology.

Composite view of Malverns geology

In putting together a coherent overview of "the Malverns Complex" rocks, Dave has made use of the most recent dating results, which complement his own results from the 1970's, based largely on the traditional principles of stratigraphy and on analysis and examination of thin sections from numerous rock samples. With this information he has defined several categories of rocks according to the time periods in which they were formed. These can be correlated with current knowledge of English paleogeography derived from broader national and international research work, in particular, the creation of Avalonia as a volcanic arc on the margins of Gondwana in the Southern hemisphere during the latest Precambrian (Neoproterozoic), its subsequent separation and long migration North across the Iapetus Ocean to dock with Laurentia during the Paleozoic, and its marginal involvement in the Variscan orogeny at the end of the Carboniferous period. The erosion of the most elevated rocks, notably in the Anglian ice age, resulted in the hills we enjoy today.

The categories of rocks chosen by Dave are:

1. Rocks thought to have formed at the margin of Gondwana prior to Iapetus ocean subduction (>680Ma). Only about 5% of rocks currently exposed fall into this category.

2. Rocks formed during an intense period of volcanic arc intrusion, accounting for about 80% of rocks exposed today (680-670 Ma).

3. Igneous activity during the next 260 million years as Iapetus closure continued and the Rheic Ocean to the south opened then closed again. (660-400Ma) These represent approximately 10-15% of rocks currently exposed.

Rocks thought to pre-date Proterozoic volcanism (>700Ma)

Some rocks within the Malverns Complex have been interpreted as meta-sedimentary rocks, formed prior to the creation of the volcanic arc and subject to high levels of metamorphism. These are all found in the more southerly parts of the Malvern Hills, which have been less intensively studied than the northern hills.

Four types of meta-sedimentary rock have been found: quartzite, garnet-bearing gneiss, marble and amphibolite.

A small part of the summit of Ragged Stone Hill is composed of a quartzite conglomerate. This is thought to have been the country rock through which the adjacent igneous rocks intruded. There has been no attempt at radiological dating.

Many banded rocks with the appearance of gneisses are found in the Malvern hills, but some gneisses found in Gullet Quarry, east of the unconformity, and also on Swinyard hill contain garnets. Their mineral composition suggests that they are ‘true’ (meta-sedimentary) gneisses, originally formed as muddy sediments on the ocean floor, and that high pressure metamorphism has enabled garnet formation. They must pre-date the igneous rocks formed by the volcanic arc activity that intruded through them, but no accurate date for them has yet been obtained.

Malvern Marble is a metamorphosed algal limestone found in Pyx Ty quarry above Malvern Wells and elsewhere to the East and South. Again, no radiological dating results are available.

Intrusive igneous rocks formed during a period of major volcanic activity (680-670Ma)

The rocks formed in this period are intrusive igneous rocks typical of volcanic arcs at subduction zones and account for 80% of exposed Malverns Complex rocks.

The majority (60-65%) of rocks in the Malverns Complex are of dioritic composition[1], including some that are coarse-grained, some fine-grained and some that include a mix of crystal sizes. Tonalite[2] also occurs and can be seen at Pyx (or Tank) quarry.

Much of the Worcestershire Beacon and Sugar Loaf hills consist of a white granite formed during the earlier part of this period. Examples of ultrabasic hornblendites can also be found, such as at Lower Tollgate quarry.

Dolerite dykes that formed later in this period cut across the granite and diorite plutons. They have in turn been cross-cut by subsequent intrusions and have been affected by high grade metamorphism. They have a brecciated appearance.

The Late red binary[3] granite also appears as intrusions cutting across earlier plutons and dykes, as seen at Slashers quarry.

Later igneous activity (660-400Ma)

A small but significant proportion (~10-15%) of rocks in the Malverns Complex are thought to have formed as intermittent intrusions over a long period of time.

The earliest of these is thought to be the pseudotachylite[4] found by Richard Thorpe in the foliated rocks on the south side of the Wyche cutting. An approximate date of 660-650Ma is derived from the phase of shearing in which it occurs.

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[1] Intermediate between felsic (acidic) rocks like granite and mafic (basic) rocks like gabbro and basalt.

[2] Tonalite has a higher quartz content than diorite but its feldspar is predominantly plagioclase.

[3] Binary granites contain both biotite and muscovite mica.

[4] a glassy rock associated with frictional melting

Large dykes of microdiorite are thought to have intruded later, around 630-620Ma and are found all along the Eastern side of the hills and on the summit of the Worcestershire beacon. They are referred to as D2 dykes to distinguish them from the earliest 'D1' dykes described as severely metamorphosed dolerite.

Cutting through the D2 dykes is a series of large pegmatite veins, quartz-rich in composition and of three types: some are pure quartz, some quartz with albite and some are quartz with microcline. All are thought to be approximately 620-610Ma old.

A further series of dykes, the D3 dykes have a different chemistry from the D2 and D1 dykes. They consist of quartz dolerites and basalts and although they are undated it is thought they may have been formed in the same time period as the basalt of the Warren House Formation: 570-530Ma.

A fourth series of dykes, D4, is thought to have formed much later in the early to mid Ordovician. These 'basalt ribs' are found within the Malvern Complex rocks and match the Bronsil Castle intrusions located at the Southern end of the Hills, where they intrude across the Cambrian to Precambrian boundary. If this date is correct, the intrusions occurred at around the time that Avalonia rifted from Gondwana, though there is no evidence currently that links the rocks to that event.

Finally, a trachyte vent, found by Richard Thorpe in Earnslaw Quarry is of particular interest. It displays a flow of very fine-grained volcanic material, rich in potassium feldspar, in which granite xenoliths are trapped and in which the direction of flow can be clearly identified. This is thought to have formed around 400Ma, at the time of the Acadian orogeny when the Rheic Ocean had started to subduct beneath Avalonia from the South.

The Earnslaw Quarry in which the trachyte vent appears is typical of the Malverns quarries in exposing a wide range of rock types with cross-cutting faults and intrusions. The trachyte vent occurs close to a major fault line: rocks to the West are granite, while those to the East are diorite. Diverse faults and intrusions occur within both plutons, as well as some copper mineralisation.

Phases of mineralisation

A series of mineralisation phases has also been identified, each characterised by a particular mineral.

Epidote is thought to have penetrated the rocks at an early date, around 650Ma, while muscovite and quartz are thought to have followed somewhat later in the Precambrian at 610 and 600Ma respectively. Haematite is found extensively in the fissures of the Malverns Complex rocks and is thought to date from around the time of the Warren House formation.

Calcite veins are thought to have appeared around 400Ma, at the time of the Acadian orogeny, along with Sepiolite first identified at the Lower Tollgate Quarry. Later during the deformation of the Variscan orogeny, (~300Ma) Dolomite and Steatite are thought to have crystallised along joints, while the deposits of Barytes along the Eastern edges of the hills are thought to relate to the rifting that formed the Worcester Graben in the Triassic period and are found along joint and fault planes.

Identification of metallic minerals, especially gold and silver was a key objective of Dave's research, but no economically viable sources were discovered. In particular, he was unable to replicate Bramall's reports of gold in the red granite. His systematic method involved taking and analysing soil samples at 50m intervals right across the hills, but only very small concentrations were found. Analysis for gold used a novel 'wet' technique to detect exceptionally low concentrations of the metal.

Some Gold was found associated with dolerites and microdiorites probably with the iron pyrites found there, while some silver was associated with late mineral veins containing chalcopyrite and also the late trachyte pipe in Earnslaw Quarry.

Copper was found with lead and zinc in the col between Sugarloaf and Worcestershire Beacon, which was almost certainly a mineralised fault plane like the one in Pyx granite quarry. Copper by itself was found in the area around Earnslaw Quarry and the summit of

North Hill, where it is associated with dioritic rocks. Some lead was found in the area around the Gold Mine near Wyche Cutting, while in the area around the summit of Summer Hill (west of North Hill) there were relatively high levels of chromium in the soil, but at 1% it was still not worthy of further investigation.

Structures in the Malverns complex rocks

The Malverns complex rocks contain innumerable instances of faulting of all kinds: low and high angle thrust faults, lateral, strike-slip (or tear) faults, most of which are sinistral, as well as high angle normal faults resulting from extensional forces. Faulting has occurred intermittently throughout the period from 670-300Ma and in many cases faults have been repeatedly reactivated. Slashers quarry provides a clear example, where a fault has moved (at least) twice, the first affecting just the earlier granite intrusion, while a subsequent movement also affected a later basalt intrusion.

At least five periods of compressional folding and shearing can be identified. The first four are all within the Neoproterozoic period of volcanic activity, and were the subject of investigation by Strachan in the 1990’s. The final episode relates to the Variscan deformation that thrust the Malvern rocks up from deep within the earth’s crust.

The first of the episodes of Neoproterozoic folding occurred while the major plutons were still hot and almost fluid, around 675Ma. In a later phase, the deformation was less ductile and is seen to cut across the first phase, for example in the crags SE of the path to St Ann’s Well. In a later episode around 645Ma the folding is crenulated, while an episode of open folding, evident in the rocks of Gullet Quarry occurred around 610Ma.

Deformation in the Variscan orogeny results in monoclinal folding of Paleozoic (mostly Silurian) sedimentary beds as a result of thrusting of more competent Malvernian rocks. This was described graphically by Butcher in 1961 and evidence can be found at several points along the Western side of the Malvern Hills. At the Herefordshire Beacon, the Malvernian rocks are thrust right over the Paleozoic rocks, the Warren House formation is thrust over the Malvernian rocks, and in each case, thrusting is seen to have distorted the original precambrian foliation in the Malvernian rocks. At Swinyard Hill contact with the Paleozoic rocks is almost vertical, as can clearly be seen at the unconformity exposed on the Western side of Gullet Quarry. At White-leaved Oak Quarry, the contact is sloping more gently towards the west, but the old surface of the eroded Malvernian rocks is similarly irregular and filled with pebbles of various sizes. At Midsummer hill, the angle of slope is gentle but several normal and reverse faults have left an interesting sequence of rocks across the Midsummer and Hollybush hills. At Hollybush quarry the unconformity between Malvern Complex rocks and the Malvern quartzite was clearly exposed in 1986 but has since become totally overgrown and a mature tree high on the slope has made clearance an expensive operation.

Normal and reverse faults are also in evidence on the Northern hills, where slickensides can be found along the line of the reverse fault between North Hill and Summer Hill. At Broomhill Quarry in West Malvern, a small outlier of Wyche Beds was exposed between steeply dipping Normal and Reverse faults to West and East respectively. Again this has become overgrown, but could be cleared.

Extensive major faults within the Malvern Complex rocks may also help to explain an anomaly found with the first rail tunnel, abandoned in the early 20th century. While digging of the tunnel from one side of the hills was relatively easy, digging from the other side proved so difficult that the project became almost unviable. This difference could be explained by the different nature of the rocks above and below a low angle thrust plane, the rocks below the thrust being more massive and much harder than the foliated rocks seen above the thrust and on the summit of Wych Hill above the tunnel.

The major faults delineating blocks of granite and diorite show up particularly clearly when the results from soil samples are plotted on a map. This gives a rough but interesting indication of the underlying geology.

Numerous smaller faults are in evidence at Dingle Quarry, which also shows several rock types representative of the Malverns Complex as well as numerous intrusions. Having easy public access, it would be a good candidate for educational use if it were cleared.

To conclude his composite view of Malverns geology, Dave then briefly summarised the geological history of the Malverns within a global tectonic context.

Further photos of Malverns rocks from the 1970's and 80's were a particular treat: of Gullet quarry when it was active, of the immediate aftermath when it became the local swimming pool and of students clearing geological sites - all before modern Health and Safety laws had been introduced.

Way ahead

Dave concluded his talk by suggesting some ways in which our understanding and appreciation of the Malvernian rocks could be enhanced. I include his list here.

1. An in-depth study of the dolerite/microdiorite/basalt intrusions - age dating them matching them to other nearby locations, which expose Precambrian rocks.
2. A detailed mapping exercise of the Eastern Raggedstone Hill to find extent of metasediments and their age, particularly the conglomerate west of the summit.
3. A detailed study of the late quartz pegmatites: 3 types a) quartz albite, b) quartz microcline and c) quartz by itself. Are they all the same age?
4. A detailed study of Wyche and Jubilee Hills to see if there are, as he suspects, 3 phases of early compression leading to 3 different sets of foliations in the rocks.
5. Some regular site clearing/cleaning to maintain the value of these very special sites e.g. Earnslaw, County, Lower Tollgate, Dingle and Pyx Granite Quarries.

Conclusions

Dave's own conclusion was to provide this admirably concise summary:

"The Malvernian rocks offer a 'small in area, but large in data', picture of the late Precambrian of the Welsh Borderland. The rocks are mostly Igneous in origin, and have subsequently been intensively affected by several phases of both compression and tension in the crust, as well as at least 2 phases of pre-Cambrian metamorphism and much late mineralisation. Many rock boundaries are fault or shear zones."

End piece

Finally, I would like to thank Dave for his most interesting and entertaining talk. It is clear that what Dave has shown us to date is just a fraction of the information he holds about the Malvern Hills. We are therefore most fortunate that he has promised to return later in the year and possibly to work with us in the future to help unpick more of this fascinating story.

Kay Hughes
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