Notes on U3A Geology group field trip to the S Malverns 14th June 2017

led by Dr. David Bullard

Dave shared his expertise and detailed knowledge of the Malvern Hills. Having researched the area for his PhD in the 1970s, he has paid numerous return visits, extending and consolidating his understanding of these ancient rocks and the history of their formation. Eight locations were visited, in the order described here. (This was not quite as planned since the second location in the plan was actually visited last.)

These notes provide a brief summary of what we learned about the places visited on the day and their implications for the geology of the area. Dave has kindly reviewed them and corrected them where necessary, for which I am most grateful. They hopefully bring together the major geological points, but fail to capture all of the nuances of Dave's very informative tour, or the humour and infectious enthusiasm with which he entertained us on the day.

LOCATION 1: Slashers Quarry (SO 759371)

Slashers Quarry and Hollybush Quarry were both exploited for their hard, Pre-Cambrian Malverns Complex stone. They are located on the southern slopes of Midsummer Hill on the flanks of a deep valley that cuts into the hill on a N-S axis, with Slashers Quarry to the West and Hollybush Quarry to the East. The valley coincides with at least a pair of faults dipping steeply to the east.

The line of the fault coincides with the E face of Slashers quarry. Here the quarrying has exposed rocks on the hanging wall of the fault that consist mostly of Hollybush Sandstone of Cambrian age topped by some Silurian limestone. This face is now completely overgrown, though water emerging along the east side of the quarry is indicative of a fault line. Wild clematis growing on the face and Harts Tongue fern near the entrance to the quarry on this side are both indicative of limestone, presumably fallen from high on the rock face.

The entire quarry is now very overgrown so it is only possible to view the higher rock faces from a distance and examine any loose rocks on the floor of the quarry. Research conducted in the 1970's, when the quarry was still being worked, showed that the rock exposed on the West and North faces is predominantly metamorphosed gabbro with intrusions of granite and dolerite, consistent with formation within a volcanic arc. Ages of these rocks range from 680 to 610 Ma. These rocks formed when ocean crust was subducted under the continental crust of Gondwana in late Precambrian time, when this tectonic part of the world lay in the southern hemisphere about 25 degrees south of the equator and was drifting very slowly southwards. The uplift of these lower crustal rocks occurred firstly about 400Ma and secondly in the Variscan Orogeny about 300Ma.

Between the two large quarries is a smaller quarry referred by Dave as Middle Hollybush Quarry. This quarry is very overgrown now, and used to expose a valuable section of an unconformable contact between the Cambrian Malvern Quartzite and the underlying Malvernian complex of rocks mostly diorites. Aspirations by EHT to clear the face have so far been thwarted because of the presence of a large overhanging tree which would cost £1000 to remove.

Dave briefly summarised the conclusions from the 1970's work and subsequent dating studies in 2000, providing a very useful context for understanding the rest of the tour.

Examination and analysis of Malverns Complex rocks and rock formations has revealed that there were at least six phases of folding and faulting, as well as at least three phases of igneous activity, distinguished by the rocks' chemistry and by the numerous and widespread cross-cutting formations. Much of the mass of Malverns Complex rocks was formed initially when massive intrusions of a basic mafic magma rose through country rock at around 15-18km deep on the margins of Gondwana. Initial magma temperatures were around 1000 degrees, and as the magma slowly cooled to around 650 degrees, zircons were able to recrystallize and record the age date of 680my. A subsequent medium grade (lower temperature) regional metamorphic event at 450-500 degrees C, combined with super-heated steam, modified the gabbro minerals (pyroxenes such as augite, plagioclase feldspars and some olivine) to black hornblendes, white hydro-muscovite and green chlorites and epidote. Age dating of the hornblendes, recrystallising within this temperature range, yields a date of ~650Ma for this event, using Argon isotopes 40 and 39. This was probably linked to a phase of dolerite intrusion. A later lower grade metamorphic event resulted in veins of felsitic aplites and pegmatites, predominantly quartz and feldspar with some muscovite mica. The crystallisation of muscovite mica has indicated a cooling temperature of ~410 degrees C and dating gives an age of ~610Ma. There is some evidence from the work of Piper (1982) that there are actually 4 phases of dolerite intrusion, the youngest being from the lower Cambrian.

A rock picked up in the quarry illustrated these major events, since it consisted mainly of the metamorphosed gabbro typical of the bulk of Malverns Complex rock, while one face appeared to expose a felsitic intrusion, with its pink mineral content, thought likely to be calcium-rich oligoclase rather than orthoclase.

Three distinct sets of dolerite and intermediate intrusions have also been identified, D1, D2 and D3, which differ from each other in both chemistry and age. No radioactive dates have been obtained, but cross-cutting relationships gives evidence of relative ages. The oldest, D1 intrusions (seen later at Ragged Stone Hill West) are modified to meta-dolerite (or amphibolite). The D2 intrusions (seen at Dingle Quarry W Malvern) are more coarse-grained micro-diorite and have undergone only slight metamorphism. The latest (D3) intrusions (e.g. exposure at Ivy Scar Rocks) are 'fresh' unmodified, fine-grained dolerite with no signs of metamorphism, suggesting they post-date the Cadomian orogeny. They could possibly be contemporaneous with later Precambrian rocks such as the Warren House formation in the Malverns and Longmyndian in Shropshire, but could be as late as the Ordovician.

Dolerite intrusions are present in Slashers Quarry but now concealed by vegetation.

Zircon dates for Malverns Complex rocks in the northern hills were obtained most recently by Murphy et al and published in 2000, using modern techniques that can yield multiple dates at

different layers within the same crystal. The results indicate an oldest zircon date of 1600Ma, with peaks at 1100 and c750Ma, as well as the most recent dates of ~680Ma. This suggests that country rock into which the Malverns Complex rocks intruded could be as old as nearly 2Ga. A small number of possible exposures of such rocks within the Malvern Hills have been found, including metamorphosed limestone and sandstone but none has been dated.

A final point of interest: one of the hills north of the Worcester Beacon has very few exposures, but their soils reveal unusually high levels of Chromium and Nickel. However despite Dave's best efforts, no gold or silver has been detected in the Malverns.

LOCATION 2: House in the Hill, N slopes of Ragged Stone HIll East (SO 762368)

The owners kindly welcomed us to view the rock face behind their home and the building itself. The rock face has a fault running across it. Rock above and below the fault is Hollybush Sandstone. The fault line is low angle in the plane of the rock face but is thought to dip down into the rock face, making it dip to the East, roughly parallel with other Variscan faults along the Malverns lineament.

The house owner had excavated the ground in the immediate area and extracted a wide variety of Malverns complex rocks, which have been used for the building itself. The variety of rocks suggests they come from solifluction deposits: the result of glaciation in the last ice age (Anglian stage). Some stones show the steely blue surfaces where haematite has weathered from the rock within joints, others show pink felsitic veins, pale green of epidote and (as shown in centre of photo) the stripey, gneissose appearance of igneous rocks subject to the high temperatures and pressures within stress faults.

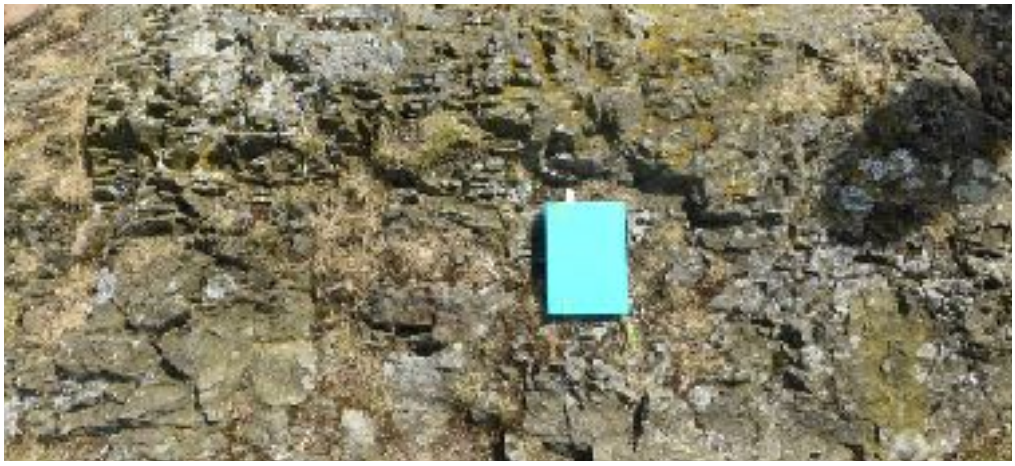
LOCATION 3: Eastern Ragged Hill summit (SO 761365)

This hill commands a fine view of the surrounding area, including much of the line of the Malvern hills and the Cotswolds escarpment which may form the opposing side of the Triassic Worcester Graben. The Forest of Dean and May Hill are clearly visible to the South West and South respectively, with May Hill lying along the line of the Malvern Lineament.

Exposures on the hill include some of the wide variety of rocks which make up the Malverns Complex, but also some lighter coloured meta-sedimentary rocks: a quartzite conglomerate containing rounded quartzite pebbles up to ~12mm across in a matrix of well cemented sand grains, making a very tough rock. This suggests that formation of the sediment pre-dated the Cadomian metamorphic events and is formed of clasts that at that time had already undergone extensive weathering and reworking. It is thought that this sandstone may represent the country rock through which the Cadomian volcanos erupted, in which case it is a piece of the old Gondwanan continent and possibly the oldest rock exposed in England and Wales. No radioactive dating has been attempted to date, but it would be extremely interesting to establish a date for this rock.

LOCATION 4: Western Ragged Stone Hill summit (SO 759365)

Views from here are even more extensive than from the Eastern summit and include the hills of Herefordshire as well as more distant Welsh mountains and Shropshire hills. The sedimentary rocks of Herefordshire, deposited from Cambrian to Devonian times, were folded by the same forces that thrust the pre-Cambrian Malvernian Rocks up from great depths in the Variscan orogeny of the late Carboniferous. Subsequent erosion, especially by Quaternary ice, has removed the tops of the anticlines so that the remaining landscape exposes successions of rocks of different ages, dipping mostly to East and West, with the relatively hard Silurian limestones standing out as small hills and escarpments.



A Dolerite intrusion near the summit is thought to belong to the oldest, D1 set of intrusions in the Malvern Hills. It shows the angular, rhomboidal jointing typical of such intrusions in the Malverns Complex rocks. Rocks either side of the intrusion are much less fractured. The A6 notebook in the photo indicates scale.

A short way down the S ridge, a small, pink felsitic intrusion can be seen within the much darker rocks. This is an unusual rock composed almost entirely of oligoclase, a sodium/calcium feldspar, with almost no quartz or other minerals present in the rock.

LOCATION 5: Path South of Ragged Stone Hill West summit (SO 760363)

Further down the ridge, within the woods, the rock type changes from Malvern Complex to Hollybush Sandstone at a contact that runs almost along the line of the path. The Sandstone can be distinguished by the bedding and by extensive jointing at right angles to the bedding. Fractures in Malverns Complex rocks are often not straight and occur at much more irregular angles.

LOCATION 6a: Whiteleaved Oak Quarry, top level

The quarry exposes a contact between the near vertical beds of the Cambrian Hollybush sandstone/conglomerate and the underlying Malvern Complex rocks at bottom right of the picture.

There is disagreement whether this is a fault or an unconformity. The fact that the contact is not straight and there is no indication of stresses where the line bends suggest this is an unconformity, where an uneven, eroded rock surface has been covered with marine sediment during the Cambrian. Grain sizes within the Hollybush sandstone range from fine sand to gravel.

LOCATION 6b: Whiteleaved Oak Quarry, lower level (SO 761361)

At this level in the quarry, intense shearing of the rocks is exposed. The high pressures of the shear zones combined with temperatures above 400 degrees C resulted in recrystallisation of the original rocks (probably Malvernian igneous rocks) to phyllo-silicates around 650Ma.

The shearing is complex, with cross cutting of near-vertical and near-horizontal shear zones and faults. Granite intrusions crossing both these lines are also found and were formed later at around 610Ma.

Rock taken from the quarry was used for road building – probably mostly in the Eastnor estate as the quarry ceased operation in the 1940's. Rocks from other quarries in the Malverns, operating until the 1970's were used to build the M5. Most of this rock was for hardcore, but phyllites were reserved for dressing layers as they provide exceptional grip and anti-skid properties.

On route to the next location, near-vertical beds of Hollybush Sandstone outcrop on the track itself, having the same N-S orientation as observed in the top level of the White-leaved Oak Quarry and in the path above.

LOCATION 7: Field edges west of Ragged Stone Hill (SO 758361)

At the bottom of the western slope of Ragged Stone hill, the Hollybush Sandstone gives way to Cambrian White-leaved Oak Shales and then the more recent Bronsil Shales (Tremadocian) at the base of the Ordovician. The clay content results in more fertile soil.

Brachiopods were found in both a piece of Hollybush Sandstone that had fallen down the hill (see photo) and also in the shales.

A small hill in the middle of the field suggests harder rocks along the line of the sedimentary beds. On investigation these revealed an outcrop of igneous rock, having the orange colour associated with weathered Basalt. It follows the bedding plane of the country rock and is hence a sill. It is presumed to be Llanvirn (Ordovician) age, contemporaneous with the major volcanic activity in Wales and the Lake District, but it has not been dated.

LOCATION 8: Hollybush road cutting (SO 757368)

This cleared area exposes Hollybush Sandstone with a band of igneous intrusive rock at least 10m wide running through it along the bedding planes. This is thought to be Ordovician in age, though it has not been dated and probably includes two sills of different chemistry, one of basalt/dolerite, the other of andesite.

Lastly, I would like to thank Dave for treating us to such an enjoyable, entertaining and informative day out.

Kay Hughes
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