The Lower Palaeozoic Geology of the Lickey Hills

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All illustrations by the author, except where otherwise indicated.

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Front Cover: Recumbent fold in Barnt Green Road Quarry
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Back Cover: Recumbent fold in Barnt Green Road Quarry
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Foreword

The Lickey Hills constitute a north-south ridge, straddling the border between Birmingham and Worcestershire. In geological terms, they are an inlier of Ordovician rocks, surrounded by younger formations. Quarrying of the local Lickey Quartzite for road stone ceased in 1935. Since then, the disused quarries have become partially infilled and overgrown, or have disappeared completely beneath residential developments.

Since 2008 a group of volunteers belonging to the Herefordshire and Worcestershire Earth Heritage Trust have worked to maintain the remaining exposures, most of which lie within the Lickey Hills Country Park. With the support of the Country Park Rangers, these 'Lickey Hills Geo-Champions' seek not only to preserve these sites, but also to deepen our understanding of this fragment of Lower Palaeozoic rock. To this end, they have unearthed new evidence which gives fascinating insights into the evolution of this remarkable formation

This booklet draws together information from many sources in an attempt to assemble our current knowledge of the associated formations in one publication. It is only being offered as in pdf format, as it is intended to be an active document that will be updated as new information becomes available.

Alan Richardson 2023

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Contents

The Lickey Inlier

The Lickey inlier is a block of Lower Palaeozoic rocks bounded by faults that bring it up against younger Upper Palaeozoic and Mesozoic formations. Recent conservation work by the Lickey Hills Geo-Champions has revealed new evidence about the structural evolution of the area and the relationship between the Ordovician Lickey Quartzite and the overlying Silurian Rubery Sandstone. The Lickey Quartzite varies in composition between a mature quartz arenite, and an immature lithic arenite; in places it is interbedded with soft clay-rich fine sands and fine micaceous shaley siltstones. In thin section, the quartz grains are seen to have sutured contacts. The presence of clay-rich horizons precludes a metamorphic origin for this mosaic texture: deep burial below 1km would be sufficient to account for its development. The composition of the clay minerals may offer more evidence of the burial history. At the southern end of the hills, in the Barnt Green area, older rocks of volcanic origin are poorly exposed.

Before the advent of radiometric dating techniques, the Lickey Quartzite formation (LQF) was thought to be Cambrian in age. While an absolute age has not been determined for the Lickey Quartzite, the Barnt Green Volcanic Formation, thought to underlie the LQF, has been dated to 485.4 - 477.7 Ma, suggesting an age of 485.4 – 443.8 Ma for the quartzite. [Source – BGS Geology Viewer 2023]

The rocks are described as having been deformed into a north-south trending anticline. Thrust faulting, associated with California-type strike-slip tectonics during the Shelveian deformation event, may be responsible for localised recumbent folding. The rocks are well-jointed and cut by many faults.

Unconformities have been identified between the LQF and the overlying Silurian Rubery Sandstone, and the Carboniferous Halesowen Formation. An unconformity of unknown age has recently been described on the crest of the Lickey Ridge.

BGS Redditch Memoir

The BGS Redditch Memoir gives the following account of the formations present in the Lickey inlier.

 Sourced from pages 4, 5 and 7 from BGS Publication: "Redditch. Memoir for Sheet E183: Old, R.A. 1991" Source: https://shop.bgs.ac.uk/Shop/Product/BSP_EM183

Barnt Green Volcanic Formation 485-478 Ma*

Water-laid crystal and crystal-lithic tuffs, together with tuffaceous sandstones, siltstones and mudstones, known collectively as [the] Barnt Green Volcanic Formation, occur in a small, fault-bounded inlier extending southwards from Kendal End [003 747]. Apart from the outcrops at Kendal End, the formation is less well exposed now than when first surveyed in the [19th] century, and little can be added to the field description of Gibson and Watts (1898) and Lapworth (1899).

The beds are steeply dipping and generally strike north-west – south-east, roughly parallel to the major bounding faults of the Lickey Inlier; there is no consistent direction of dip, however, and many exposures are so weathered, shattered and veined that the bedding is difficult to distinguish in them. At Kendal End farm, excavations have exposed beds dipping steeply to the east-south-east. The section shows about 25m of coarse, dark green tuffs and tuffaceous sandstones, including 0.5m of thin bedded, dark purple-grey burrowed siltstones and mudstones intruded by a 30cm microdiorite sill.

Examination of thin sections largely confirms the descriptions given by W W Watts (Gibson and Watts, 1898); the significant differences are included below.

In the tuffs, the component mineral grains and rock fragments are predominantly angular, although plagioclase and quartz may form, respectively, euhedral and corroded phenocrysts; they have clearly not been transported after ejection from the volcano. Plagioclase is nearly always the dominant feldspar, contrary to Watts' observation. The 'orthophyre tuffs' recorded by Watts appear to equate with the crystal-lithic tuffs except that they also contain numerous rock fragments' including non-porphyritic andesite and altered porphyritic acid or intermediate lavas, some as pumice.

The matrix of all these pyroclastic rocks consists predominantly of cryptocrystalline silica.

Sections of the laminated siltstone from Kendal End show an abundance of moderately well-sorted, angular quartz grains and mica flakes; plagioclase is present only in minor quantities. The few rounded quartz grains are probably derived phenocrysts, rather than water-worn fragments. Other grains include opaque minerals and carbonates, the latter possibly replacing plagioclase. The cement is a mixture of silica and opaque mineral, the latter sometimes abundant though largely absent from burrow fills. Most of the tuffs and siltstones show extensive secondary veining by calcite or quartz.

The Microdiorite intrusions are leucocratic, fine-grained and generally non-porphyritic. They consist predominantly of plagioclase (oligoclase/andesine) in sheaf-like aggregates, commonly with a weak preferred orientation. Chlorite occurs interstitially and is presumable a secondary replacement of the rarely preserved hornblende. Opaque mineral is abundant in association with chlorite, and carbonate is common in veins and patches. One thin section shows a few slightly larger feldspar phenocrysts and more interstitial chlorite, giving an ophitic texture.

The 'brecciated porphyritic basalt' recorded by Gibson and Watts (1898) was not located during the present survey, and there are no hand specimens or thin sections matching this description among the local collections of the British Geological Survey.

Lickey Quartzite 485-444Ma*

The Lickey Quartzite crops out in the north-north-west trending inlier of the Lickey Hills, in the north-west of the district between Kendal End [001 746] and Holly Hill [991 784]. It is a hard, brittle, jointed and very shattered rock, forming several low, steep-sided hills that are covered with a wash of quartzite chips and which support sparse vegetation. The inlier seems to be fault bounded on all sides, except at Rubery where the Lickey Quartzite is overlain unconformably by the Rubery Sandstone or the Halesowen Formation. Elsewhere, its stratigraphical relationships are unclear and no confident estimate of its thickness can be given.

Tuffaceous material occurs most commonly in what are probably the oldest beds exposed, and there may be an upwards passage from the Barnt Green Volcanics (Lapworth 1899). The structure of the Lickey Hills is complex locally, and with very variable dips, but in general an anticline trends parallel to the bounding faults of the inlier and plunges gently to the north-north-west. The steepest dips and overfolding occur mainly along the edges of the inlier and may relate to later movements along the bounding faults.

The petrography of the Lickey Quartzite has been studied by Watts (*in* Lapworth, 1899) and by Strong (1983). Strong's results are summarised in Table 1. The heavy minerals, notably glauconite, occurring in the Lickey Quartzite are listed by Fleet (1925, p.100).

There is no clear relationship between the degree of sorting or the maturity of the sediments and their stratigraphic position in the Lickey Quartzite. The sorting, grain shape and sedimentary structures of the rock suggest deposition in a high-energy marine environment. Primary grain boundaries are still discernible and pressure welding is uncommon, suggesting early silica cementation. The presence of secondary chlorite, sericite and rare authigenic epidote indicates very low grade regional metamorphism.

Strata low in the sequence, exposed in a quarry [001 753] ***[Barnt Green Road Quarry]*** opposite Reservoir Road, Cofton Hill, comprise pale grey, brown and purple, flaggy, immature to submature quartzites in beds up to 0.6m thick, interbedded with purple sand and micaceous shales. The colour of the quartzite is caused by finely-disseminated, feldspathic, tuffaceous debris, and the shales are largely composed of the same material. This quarry exposes a synclinal overfold, with the beds folded about a near-horizontal axial plane (Plate 2) (Boulton, 1928, diagram p.256).

Ascending the sequence, the Lickey Quartzite becomes paler and incorporates less tuffaceous material. In the largest quarry, in Rednal Gorge [998 759], massive beds of dark purplish quartzite, each up to 1m thick, are separated by yellowish green and deep purple, sandy clay partings. At the disused Leach Green Quarry [995 769] and at the Bristol Road south cutting [992 774], the

Lickey Quartzite varies from a from fine-grained and white, to coarse, grey and pebbly, and is in massive beds up to about 1m thick, which were lithified and jointed before the transgression of the Llandovery sea, because sands of Llandovery age have infiltrated down cracks. The formation here is cut by a very weathered dyke which is truncated by, and thus older than Llandovery strata.

Table 1 Petrography of the Lickey Quartzite

	Composition	Sorting	Specimen	Locality
IMMATURE Lithic arenites	Q/F/RF/MP/C Q/F/RF/C	P p-ms	E58477 E58478 E2939	Cofton Hackett Cofton Hackett Rubery
ARKOSIC Mainly Arkoses 10-25% F	Q/F	p-ms	E58474 E58475 E58482	Reservoir Road Reservoir Road Lickey
SUBMATURE Feldspathic quartzites 10% F Quartzites	Q/F Q/C	p-ms p-ms	E58476 E58476 [sic] E2938 E11573 E58480 E58485	Cofton Hackett Lickey Keepers Lodge Rubery Hill Lickey Rubery Hill
MATURE Mature Quartzites	Q	ws	E58479 E58483 E58484	Kendal End Lickey Leach Green

Q – quartz, F – feldspar, RF – rock fragments, MP – chloritic mud pellets, C – cherts, p – poorly sorted, ms – moderately sorted, ws – well sorted

Table 1 - Petrography of the Lickey Quartzite reproduced with Permission of the British Geological Survey Source: Redditch. Memoir for Sheet E183: Old, R.A. 1991 https://shop.bgs.ac.uk/Shop/Product/BSP_EM183

Rubery Sandstone 444 – 433Ma*

The Rubery Sandstone overlies the Lickey Quartzite unconformably, and crops out at Rubery Hill Hospital [993 778] and Rubery [993 773]; the presence of a third inlier at Rosleigh Road [999 767], recorded by the previous survey has not been confirmed. Exposures in a quarry [9927 7727] south of Bristol Road show massive, coarse-grained, decalcified sandstone, varying from pale grey and compact to open-textured, with reddish and purple stains. Some of the constituent grains are well-rounded and probably aeolian in origin. The basal bed contains clasts of Lickey Quartzite up to 15cm across, and locally fills hollows in the irregular surface of the underlying quartzite. Sand-filled 'neptunean dykes' up to 20cm across extend down into fissures in the quartzite. The beds were deposited in a sea transgressing a rugged, arid shoreline. They probably buried the Lickey Quartzite ridge completely, but Rubery Sandstone fragments occurring in the basal conglomerate of the Halesowen Formation in Leach Green Lane [9939 7720] (Boulton, 1928) afford the only evidence of Silurian strata west of the ridge.

The full sequence at Rubery was exposed when Bristol Road was widened (Wills et al., 1925). It is 31.7m thick, the upper part including white, red and purple shales interbedded with fine and coarse sandstones. North of the mapped outcrops, the Rubery Sandstone continues at shallow depth beneath rocks of the Halesowen Formation. It was previously exposed, resting on Lickey Quartzite, at Hollyhill Quarry [c. 9910 7838] (Eastwood et al., 1925, p.13) and fragments of red sandstone, which are probably Rubery Sandstone, have been recorded at Kendal End (Lapworth, 1899). Heavy minerals occurring in the Rubery Sandstone are listed by Fleet (1925, p.104).

Rubery Shale 439 – 433 Ma*

The Rubery Shale succeeds the Rubery Sandstone conformably in inliers at Rubery and Rubery Hill Hospital, where it is overlain unconformably by the Halesowen Formation. Wills et al., (1925) describe the lowest 23m of strata along Bristol Road, as buff, grey, blue and purple, non-calcareous shales (with 'fucoids' at the base), interbedded with thin beds of fine-grained, decalcified, fossiliferous white and purple limestone. Late excavations are described by Wills and Laurie (1938). Strata higher in the sequence, formerly regarded as of Wenlock age (Eastwood et al., 1925), but now recognised as of late Llandovery age (Ziegler et al., 1968, p.764) are visible in Callow Brook [9929 7762]. They are pale grey, buff and purple shales with beds of hard, fine-grained, pale grey, crystalline limestone up to 15cm thick.

*dates from the BGS *Geology of Britain Viewer.* (May 2019)

Kendal End Quarry SP 001747

In the Kendal End Quarry the quartzite is well-bedded, with minor laminations of clay-rich sediment. The bedding dips north east at about 44°. The western end of the exposure is cut by a southwest dipping fault with striations on the fault surface. At the northeast end, two faults are evident in the form of brecciated zones trending WNW - ESE. Three joint sets can be clearly identified.

Figure 1. A panoramic view of Kendal End Quarry. The bedding is seen dipping steeply from left to right. One fault is evident on the left.

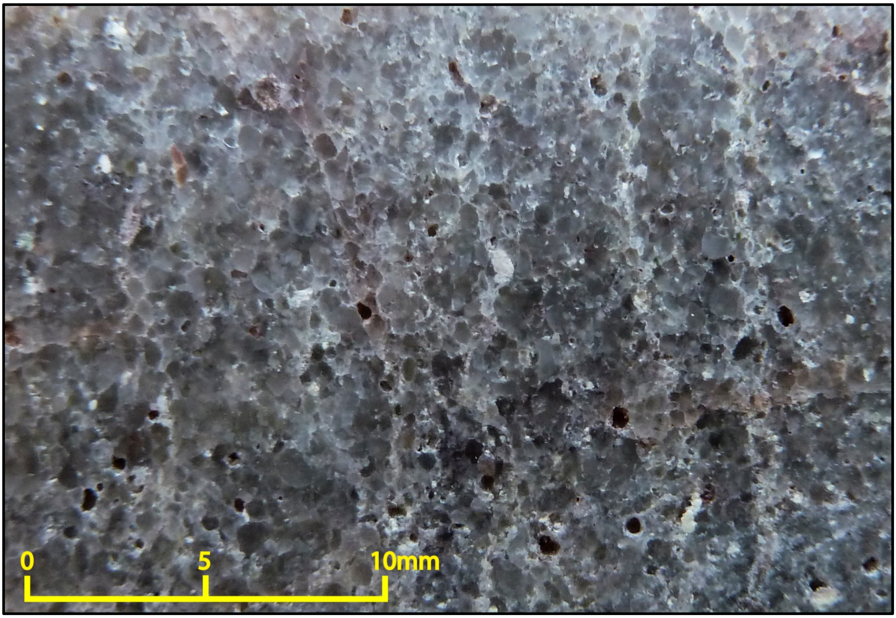


Figure 2. A polished surface of the quartzite in Kendal End Quarry. It is well-sorted quartz arenite. A few cavities are evidence of feldspar having been weathered out.

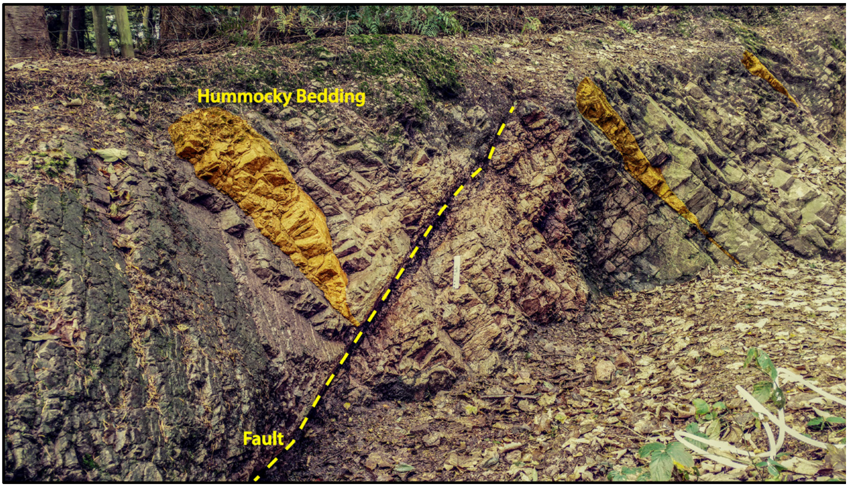


Figure 3. The fault at the west end of Kendal End Quarry. The highlighting picks out the hummocky bedding seen in places.

The sediment is well-sorted, and has a restricted mineralogy: both of these properties are consistent with deposition in a coastal environment. Within the LQF, hummocky bedding has only been observed in this quarry. It is considered to be evidence of water of sufficient depth that only storm waves were capable of agitating the sediment.

In addition to the two near-vertical faults at the northeast end of the quarry, there are breccias that may be fault-related or fissure infills. Further work is needed to establish their origin. Adjacent to these features, a poorly consolidated breccia, immediately below the soil layer, may be a post-glacial channel infill.

On the footpath below the quarry small boulders of quartzite breccia silcrete have been found, suggesting the possibility that Cofton Hill may be capped by the same silcrete seen on Bilberry and Rednal Hills. This is discussed in more detail in later sections.

Barnt Green Road Quarry SP 001753

Figure 4. The Barnt Green Road Quarry following a major restoration in 2010: the main face exhibits a recumbent fold, cut by at least one fault in addition to the one shown in Figs. 5 and 6.

Barnt Green Road Quarry (BGRQ) lies next to the Barnt Green Road on the eastern flank of the Lickey Ridge. The rocks here are believed to represent the lowest exposed sequence in the Lickey Quartzite Formation. They are less mature and have more interbedded clay-rich fine sands and purplish micaceous horizons than rocks higher in the formation.

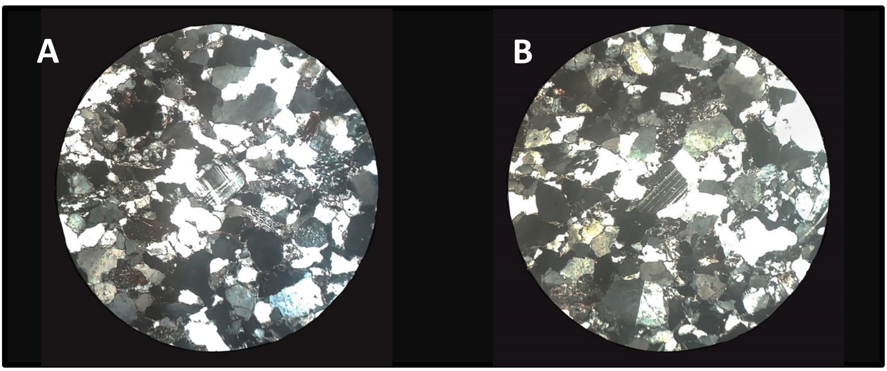


Figure 5. XPL Thin section of the BGRQ quartzite: field of view 1.5mm. In addition to orthoclase feldspar, microcline (View A) and plagioclase (View B) are present.

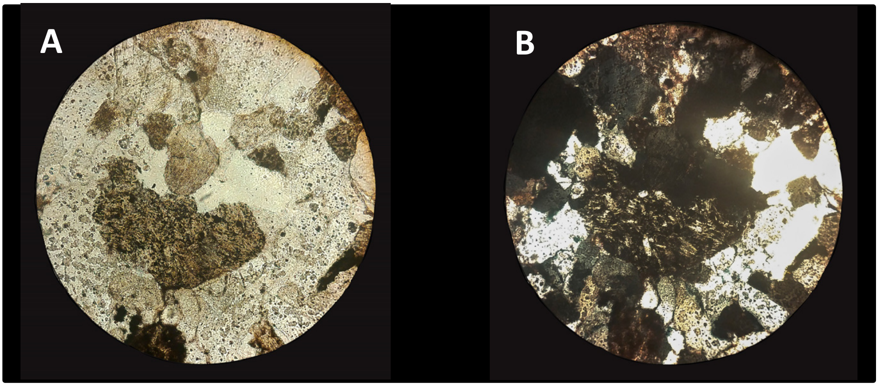


Figure 6. Thin section of BGRQ quartzite, PPL and XPL: field of view 0.75mm. A lithic grain of fine-grained igneous rock containing plagioclase feldspar laths.

What appear to be thin layers of soft clays between the thick quartzite beds are actually clay-rich fine sands. When freshly exposed they are typically green in colour, but rapidly oxidise to red on exposure to oxygen and water. The quartzite here is a sub-arkose: its red colouration appears to be due to haematite, seen as opaque grains in thin section. Grains of orthoclase, microcline and plagioclase can be seen, as well as lithic grains of volcanic rock. The evidence is consistent with the clays being bentonites, possibly recording eruptions associated with the later stages of the Barnt Green Volcanics that are believed to underlie the LQF.

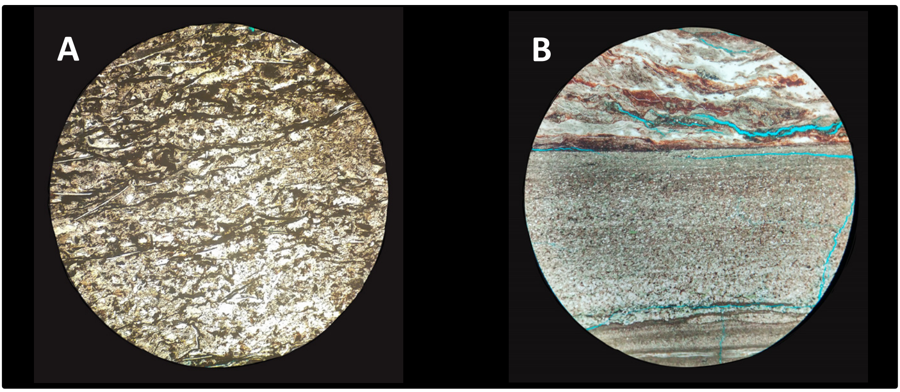


Figure 7. PPL thin sections: field of view 4mm. View A – In places the texture of the rock appears to be the result of shearing. View B – Graded bedding in silt, which becomes increasingly mica-rich upwards, and is then overlain by a clay-rich layer.

Figure 8. Composite wraparound panorama of the Barnt Green Quarry Direction of view at 1 is approximately south west; at 2 it is south east. The recumbent fold is most clearly visible at 1; the complex fracture system is exposed at 2. Views 1 & 2 are enlarged in Figs 10 & 11 below.

Figure 9. View 1. On the main face of the quarry, the recumbent fold is exposed. Careful examination of the hinge area reveals overlaps between the upper and lower limbs where intense fracturing has allowed differential movement.

The recumbent fold seen in the main face of the quarry is the result of flexural slip facilitated by the clay-rich laminations. In the hinge zone the thinner beds of quartzite have suffered extensive brecciation, and in places it is difficult to trace individual beds from one limb to the other.

In the south-east corner of the quarry, the folded rocks appear to have been thrust to the south along multiple planes, which correspond to the clay-rich laminations in the lower limb of the fold. On the left of this face the thrust cuts across the bedding of the upper limb, and becomes a steeply-dipping oblique reverse fault. Stereographic analysis of the planes of movement suggests a movement axis of 179°.

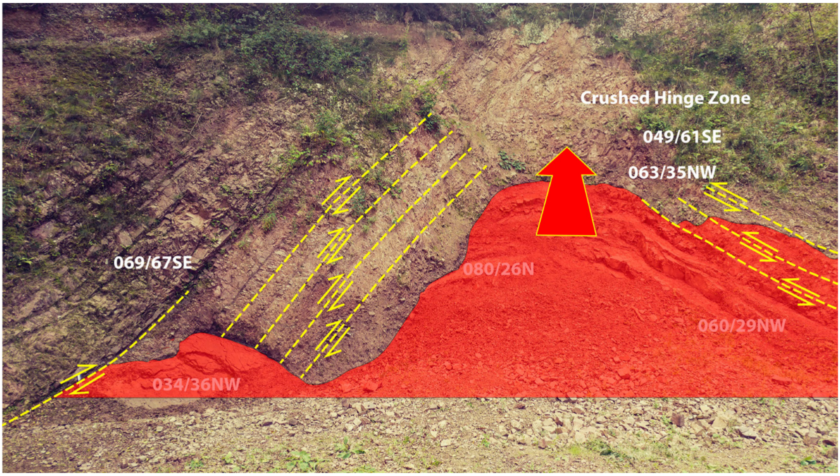


Figure 10. View 2. On the south east face of the quarry, a complex thrust exploits the weakness of the clay-rich layers to produce multiple planes of movement. To the left of the photograph, the thrust cuts through the upper limb of the fold, and becomes a steeply dipping oblique reverse fault, following bedding.

The BGS *Geology Viewer* records the age of the Lickey Quartzite as "approximately 444 to 485 million years ago in the Ordovician Period", but if analysis of the interbedded clays identifies any bentonites, this date may be further refined by analysis of zircons. Textural evidence suggests burial in excess of 1000m, followed by thrust faulting generating localised recumbent folding with a WSW–ENE trending axis. Subsequent uplift exposed the Lickey formation to erosion before deposition of the Upper Llandovery Rubery Sandstone (See Rubery Cutting on p.22).

Rose Hill Quarries SO 998759

The east-west trending Lickey Gorge transects the Lickey inlier. At its base, The Rose Hill Quarries cut through a west-dipping thrust.

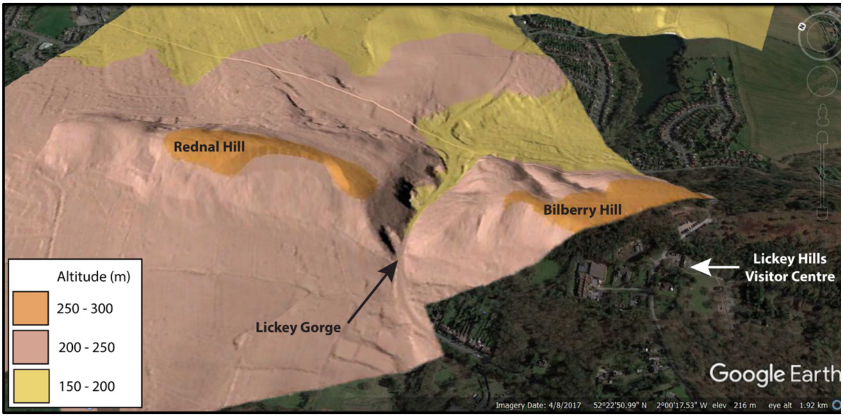


Figure 11. Partial LIDAR coverage has been draped over an oblique Google Earth image of the north Lickey Ridge (with x3 vertical exaggeration). The Rose Hill quarries can be seen on the north side of the Lickey Gorge ('Rednal Gorge' in some publications).

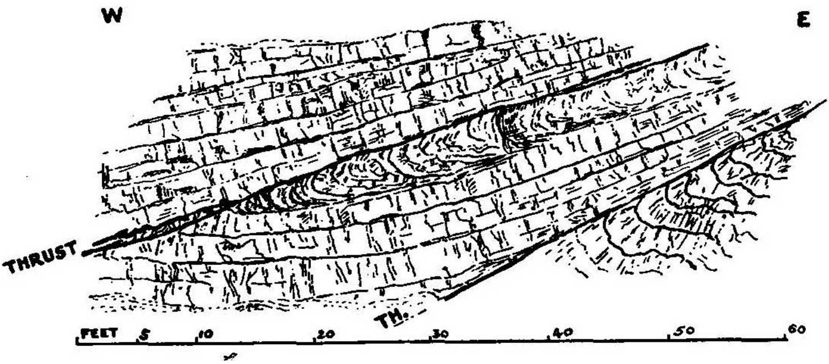


Figure 12. Sketch showing two thrust planes in quartzite at base of quarry, north side of Rednal Gorge. (Boulton)

In *The Geology of the Lickey Hills*, Prof. W.S. Boulton made the following observation, "Other evidence of overthrusts in the Quartzite can be seen near the base of the large quarry on the north side of Rednal Gorge and about 900 yards south of Eachway Lane. Two adjacent thrusts converging eastwards are here exposed, the upper inclined to the west at 18^o and the lower at 25^o. Eastward they end rather abruptly against a vertical shatter belt in the quartzite."

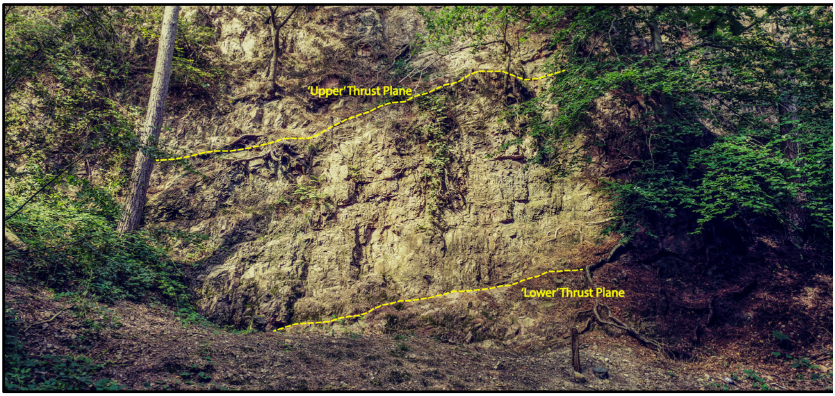


Figure 13. The main face of the largest of the Rose Hill Quarries, showing two possible thrusts. The 'Upper' Thrust is difficult to confirm because of its inaccessibility. The 'Lower' one is more certain, and further work may identify it as the higher of the thrusts in Boulton's sketch.

Boulton describes the two thrusts as being "near the base of the large quarry": it is possible that they lie deeply buried under accumulations of quarry spoil. However, examination of the main face in the largest of the quarries has identified structures that superficially appear consistent with Boulton's field sketch, but seem to lack the drag folding he recorded.

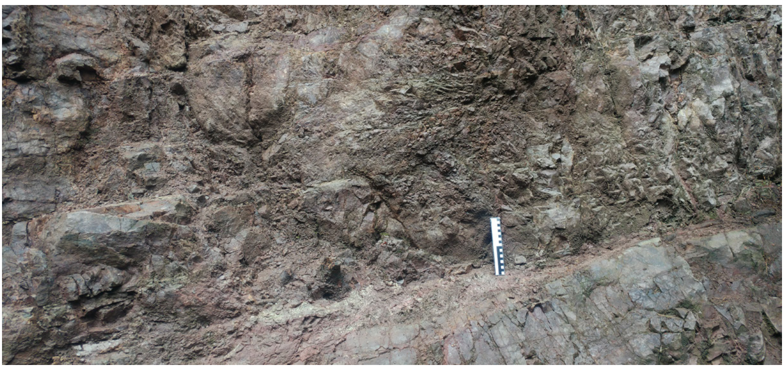


Figure 14. Close-up of the 'Lower' Thrust from Fig 8. The photo scale is sitting on the plane of movement.

Figure 15. In the face of the lowest tier of the main quarry the thrust can be studied in relative safety, away from the towering main face. This picture shows the extent of brecciation, with imbrication confirming the sense of movement.

Other locations for the thrusts have been explored. Excavation of one potential site was undertaken in 2019, in the smaller west quarry, but the results were somewhat mixed in terms of providing the anticipated evidence. With the vegetation and debris removed, the movement plane turned out to be significantly steeper than the 18^{o} recorded by Boulton. With respect to the drag folding, it had been hoped that more definitive

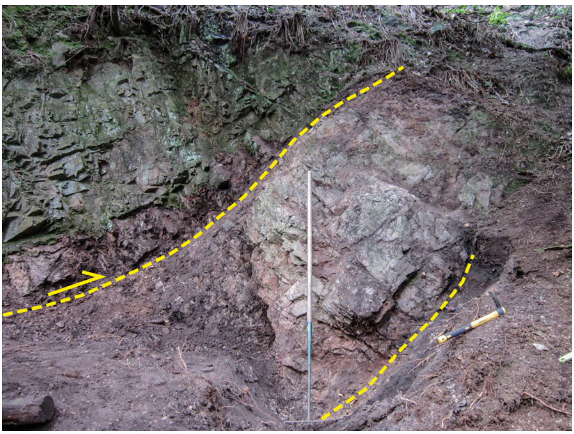


Figure 16. Two sub-parallel planes of movement in the western bay of the Rose Hill Quarries. The faults are seen as zones of breccia with a clay matrix.

evidence would be found in the form of a deformed clay layer – however, the new excavations did not unearth any such structure.

The clearance work revealed a second fault plane at a lower level. It is characterised by a fault breccia, consisting of fragments of Lickey Quartzite in a matrix of soft clay. It proved impossible to expose more of this structure, owing to the proximity of a substantial root, the removal of which would have destabilised the Scots Pine to which it belonged.

It seems unlikely that these movement planes are the thrusts recorded by Boulton: further work on the main face may reveal features that correspond to those on his field sketch. It may be that the thrusts he recorded are now covered by the thick accumulation of rock debris that currently fills the base of the quarry.

Eachway Lane Quarry SO 995765

In his 1898 'Sketch of the Geology of the Birmingham District', Lapworth observes, "No fossils, except worm-burrows, have yet been detected in this Lickey Quartzite…". As is often the case with published works of this age, no indication is given as to the location of these trace fossils. However, they have recently been rediscovered. A single bedding surface in Eachway Lane Quarry preserves the paired burrow openings of Diplocraterion. The sands of the Ordovician tidal flat would have been scoured by tidal flow, bioturbation and wave agitation; soft bodied organisms would have fallen prey to predators and scavengers, and any skeletal remains or shells would have been quickly disarticulated and fragmented in the high-energy environment. For these trace fossils to be preserved, an unusual event must have inundated the sea bed with sediment, without disrupting the burrows. This life assemblage is overlain by an uncemented clay-rich fine sand, which may turn out to be a volcaniclastic deposit, responsible for killing the infaunal occupants of these burrows and preventing their destruction during subsequent reworking of the sediment.

Figure 17. The Eachway Lane exposure after a clean up in 2019. The handle of the small mattock rests on the bedding plane that preserves the trace fossils.

Figure 18. Paired burrow openings on a single bedding plane in the Eachway Lane Quarry.

Warren Lane Quarry SO 998747

The Warren Lane Quarry exposes the western limb of the 'Lickey Anticline', with bedding dipping to the southwest at around 50^o. Bedding planes occasionally exhibit isolated asymmetric ripples, and there are thin beds of clay. Above the remains of the outer wall of the First World War ammunition store, at the western extremity of the quarry, a concordant unit of reddish pebbly sandstone interrupts the otherwise monotonous well-sorted quartzite. The single layer is exposed on the two adjacent faces above the ammunition store. The faces are at 90^o to one another so that the unit is cut through creating two isolated exposures.

Figure 19. On the north face of the quarry, bedding dips steeply to the west above the back wall of the ammunition store in Warren Lane Quarry. The area of fissure infill shown in Fig. 20 is indicated by the white rectangle.

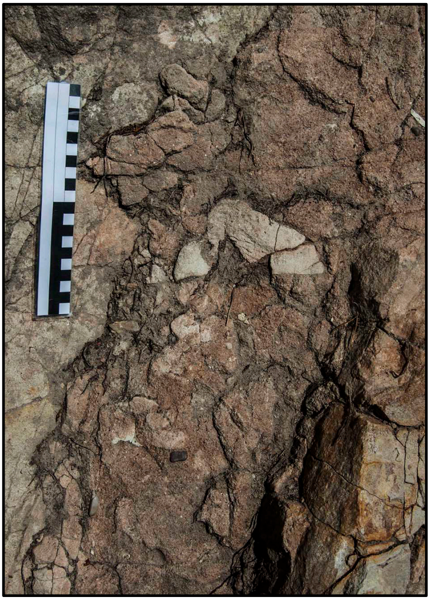


Figure 20. The photo scale is lying on a smooth surface of Lickey Quartzite, which is seen again in the bottom right of the image. Sandwiched between is a layer of reddish, more poorly cemented sandstone, which contains the occasional well-rounded quartz pebble. Of greater significance are the pale angular fragments of quartzite within this layer.

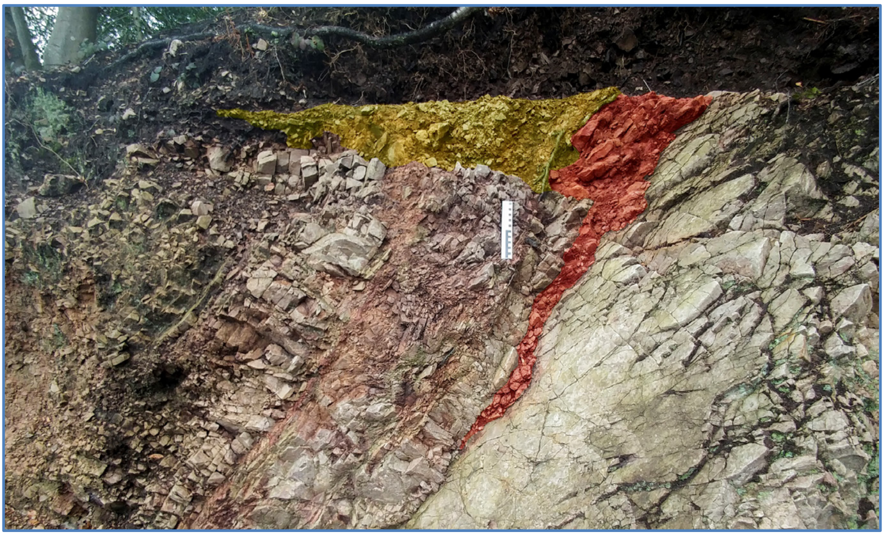


Figure 21. The material filling the tapering fissure has been coloured red. It contains rounded pebbles and angular fragments of Lickey quartzite in a sandy matrix which has an abundance of well-rounded, frosted grains. To the left of the fissure, faulting has folded and shattered the rock.

On the smaller western face, the unit tapers downwards before pinching out completely (Fig. 21). On the northern face, the unit is seen to contain angular fragments of the grey Lickey Quartzite (Fig. 20).

Fig 22. A sample of the fissure infill, composed largely of well-rounded, frosted grains, with a significant matrix of finer grains.

In thin section (Fig 16), the grain size, sorting and clast compositions of the quartzite and the matrix of the pebbly sandstone are similar. However, the Lickey Quartzite exhibits closely sutured clast boundaries, suggesting a depth of burial in excess of 1000m. This mosaic texture is absent from the pebbly sandstone, suggesting it has not experienced the same depth of burial.

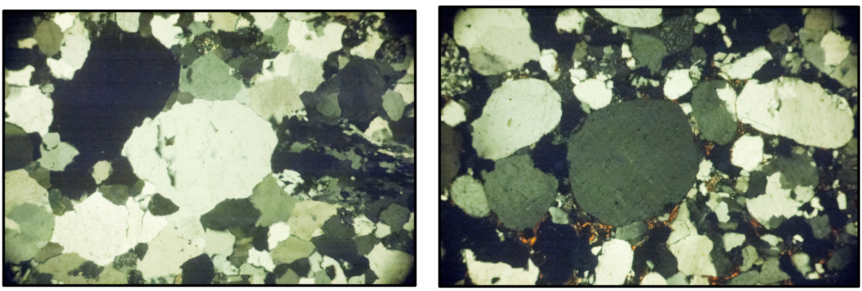


Figure 23. Thin section photomicrographs of the two lithologies in cross-polarised light. On the left, the Lickey Quartzite exhibits tightly sutured grain boundaries, while the fissure infill on the right does not.

Despite the pebbly sandstone unit appearing concordant with the Lickey Quartzite, the included angular fragments of the latter, and a sharp, irregular contact perpendicular to bedding in places, show that its formation post-dates the quartzite's lithification, and the lack of sutured grain boundaries demonstrate a different burial history. It can therefore be interpreted as a fissure infill. (The term 'Neptunian dyke' seems inappropriate for a concordant structure which would more appropriately be described as a 'Neptunian sill'.) The fact that the fissure opened along a steeply dipping bedding plane indicates that the folding of the quartzite into the Lickey Anticline had already occurred before the extensional episode responsible for its opening.

There are other small, isolated occurrences of the pebbly sandstone, and in places there are northeast-southwest trending zones of fault breccia

Figure 24. Cruziana – the feeding trace of a trilobite, exposed on the main face of the quarry.

In January 2021, a falling slab revealed the feeding trace of a trilobite near the base of the main quarry face. Subsequent oxidation of the exposed surface has discoloured the rock, obscuring the fossil.

Rubery Cutting SO992774

Figure 25. The Rubery road cutting at the A38 – Leach Green Lane Junction. At the corner of the exposure, the unconformity is approximately half way up the exposed rocks.

The road cutting at the A38 westbound off-ramp at Rubery exposes the unconformity between the Ordovician Lickey Quartzite Formation, and the overlying Upper Llandovery (Silurian) Rubery Sandstone 444–433 Ma. The latter is a reddish, mature, well-sorted sandstone that includes well-rounded quartz grains, interpreted as being of aeolian origin. It also contains the occasional well-rounded pebble, in similar abundance to the pebbly sandstone in the Warren Lane Quarry. Near the base of the Rubery Sandstone, angular fragments of Lickey quartzite are common.

Despite evidence of different burial histories for the two units, and the very irregular nature of the erosion surface that separates them, the formations appear very nearly concordant at the point where the road cutting turns to meet the face of the disused Leach Green Quarry. However, strike and dip readings recorded on a field slip by Edwin Sherstone show the Rubery Sandstone to be dipping at around 30^{o} to the north east, while the LQF (in the now inaccessible Leach Green Quarry) dips at around 20^{o} to the west.

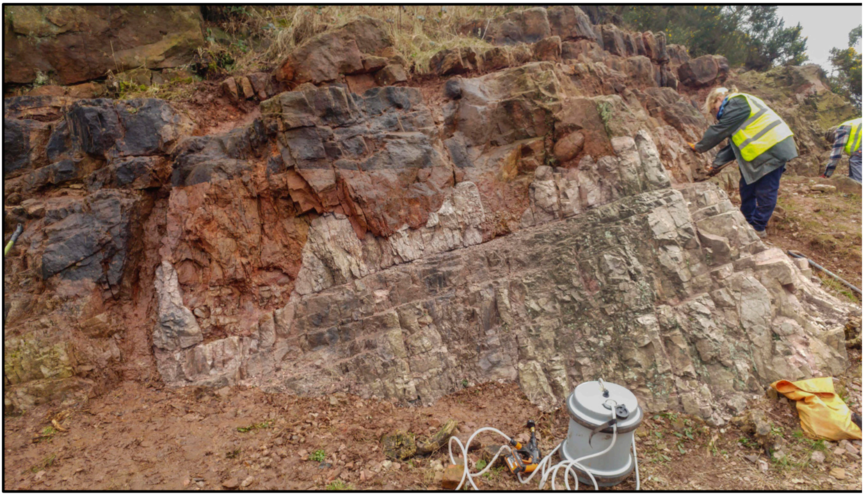


Figure 26. The unconformity after weeding and pressure washing. The picture has been enhanced to show the distinction between the two formations. The strike-slip fault is on the left.

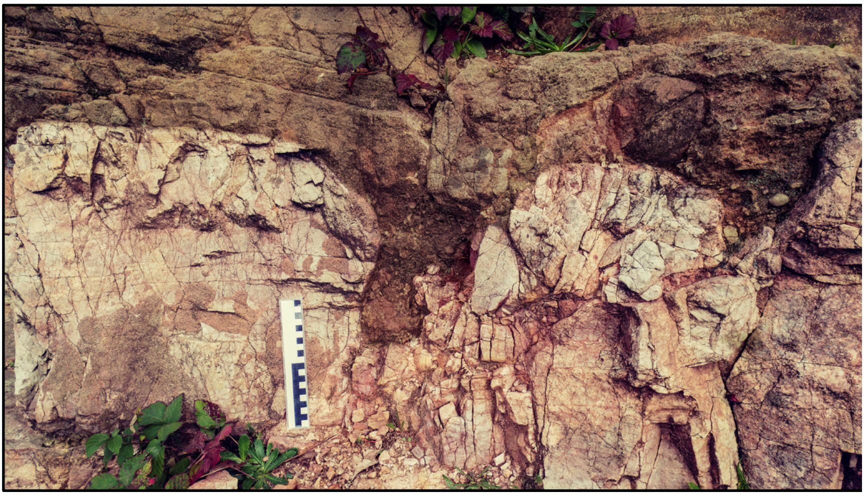


Figure 27. A close-up view of a section of the unconformity. The picture has been photo-enhanced to emphasise the contrast between the Ordovician Lickey Quartzite, and the overlying Silurian Rubery Sandstone.

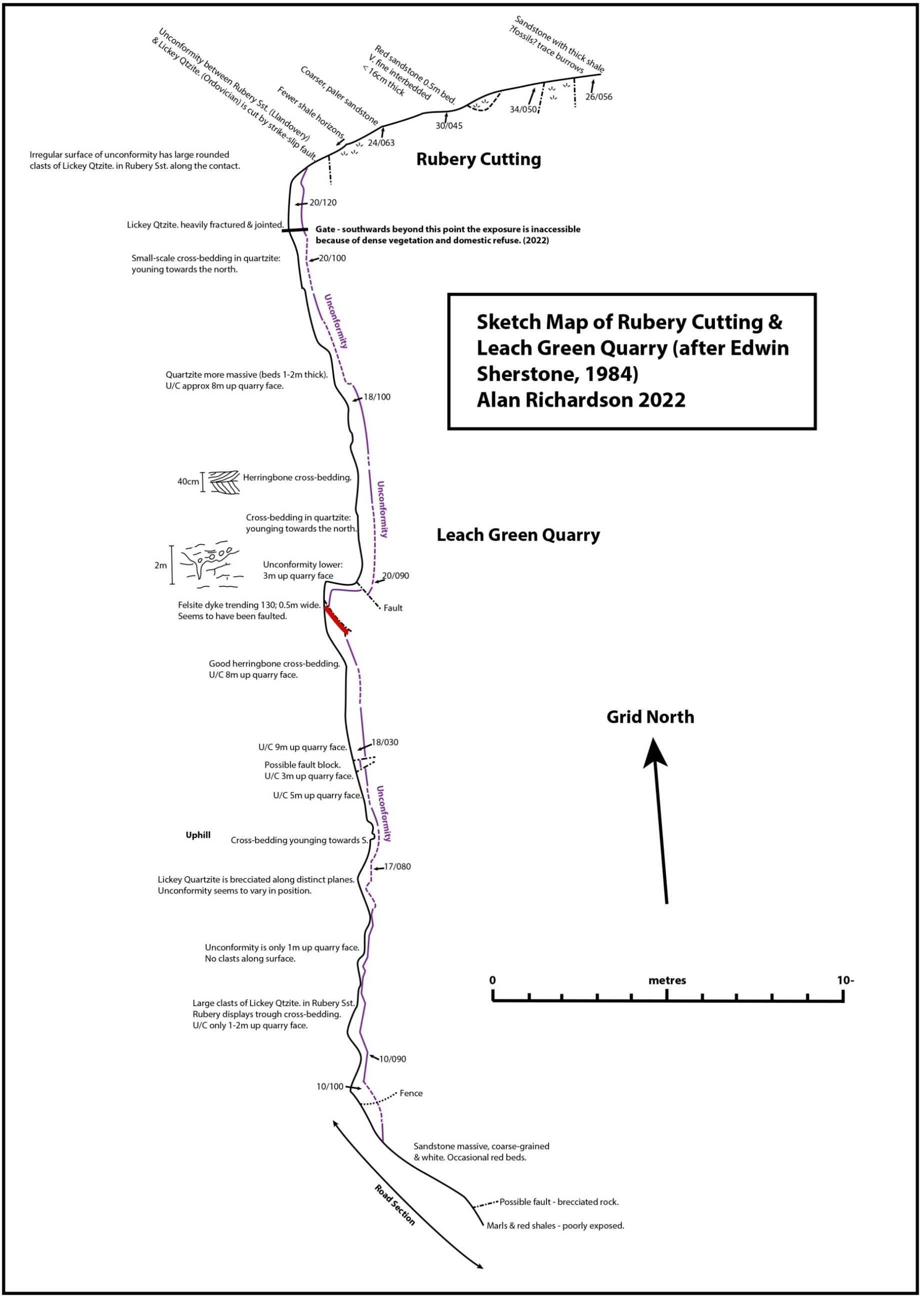
The gently-dipping rocks of both units are cut by a near-vertical infilled fissure. The matrix of the fissure infill is consistent with it being derived from the Rubery Sand. Angular fragments of grey Lickey Quartzite can be seen below the level of the unconformity. At higher levels in the fissure, there are broken fragments of the Rubery Sandstone, suggesting that opening of the fissure occurred after the lithification of the Rubery. While some authors have described this feature as a 'Neptunian dyke', sub-horizontal striations on the faces of the fissure provide evidence of strike-slip faulting, with the infill being a fault breccia.

Figure 28. The infilled fault fissure cutting through both the Rubery Sandstone and the Lickey Quartzite. Striations can be seen on the face above the photo scale

The old quarry face runs southwards from the road junction between Leach Green Lane and the A38. It lies behind a row of houses and a high steel fence and is now heavily overgrown, so access is currently prevented. In his pamphlet, *A Guide to the Rocks and Scenery of the Lickey Hills Area*, W. G. Hardie offers the following account:

> **Rubery Sandstone (Lower Silurian)**
> The northern outcrop in the private grounds of Rubery Hall Hospital is practically unexposed. The southern outcrop [Figs. 17 and 18], however, is very well exposed and is unique in being the most easterly exposure of Silurian rocks in England (and therefore well worth preserving). Exposures of the latter start in Bristol Road South [A38] (cutting adjacent to shops, south side of road), and then continue southwards along the top of the rock face of Lickey Quartzite (old quarry) behind the houses in Leach Green Lane, before finally reaching pavement level in the lane.
>
> The contact of the sandstone and quartzite is fully exposed from Bristol Road South southwards. Since the contact surface separates rocks of Lower Silurian age from those of Lower Cambrian age, this means that it represents a gap in time of the order of 100 million years. Rocks of Ordovician age are missing (they were never deposited in the Midlands) besides those belonging to the Middle and Upper Cambrian. [The age of the Rubery sandstone can be confirmed by fossils, and it remains in the Llandovery, however, the Lickey Quartzite is now regarded as being of Lower Ordovician age.] Such a gap in the sedimentary succession is known as an **unconformity**. In the present case the Rubery Sandstone can be said to rest unconformably on the Lickey Quartzite (Fig. 1).
>
> Almost a full succession of beds can be seen in the road cutting, where the beds are inclined gently to the east at much the same angle as the underlying quartzite. The basal beds are massive (thick) and consist of coarse-grained, loosely-compacted red sandstone. These are followed to the east by thinner beds of sandstone together with occasional thin seams of pale grey or red shale. The succession finishes with very poorly-exposed red shale.

Sketch Map of Rubery Cutting & Leach Green Quarry



Some beds contain marine fossils, mainly moulds of shells (the latter long-since dissolved away), but these are not particularly easy to find. An extensive collection was made when the cutting was excavated (Wills, L.J. and others, 1925).

From the main road southwards the sandstone immediately above the unconformity contains occasional concentrations of rounded water-worn pebbles and boulders of quartzite. These were obviously[!] derived from the Lickey Quartzite and indicate that the latter was already strongly compacted by Silurian times.

Immediately south of the old quarry where the sandstone begins to descend to pavement level it has lost most of its red colour. This bleached rock can only be distinguished with difficulty from the small thicknesses of underlying quartzite. Further south still, just short of the termination of the outcrop, a vertical fault separates massive basal beds (north side) from thinly-bedded sandstone and shale belonging to higher up in the succession. It is estimated that the latter have been downthrown approximately 13 metres.

Igneous dyke. Half way along the old quarry where the rock face is displaced forward a little, a narrow vertical dyke (sheet) of igneous rock cuts the quartzite but terminates at the sandstone. The age of this intrusion must therefore ante-date the latter, and is regarded as being of Ordovician age, a time when there was much volcanic activity in North Wales. The rock itself is very decomposed and soft, and varies from purple-brown to very pale yellow.

Origin. The Rubery Sandstone was deposited as sand on the floor of an early Silurian sea that covered the Midlands. Circulating ground waters then deposited small amounts of quartz in the pore spaces between the sand grains. The red colouration is believed to have been a much later addition, and due to red iron oxide (hematite) leached out of younger red beds, e.g. Bunter Pebble Beds, that once covered the sandstone.

Bilberry Hill SO99807568

On the east side of the footpath that runs along the crest of Bilberry Hill lies a small cluster of exposures. Until recently, the only rock exposed here was quite unlike the lithologies seen in any of the Lickey Hills quarries: a silica-cemented breccia. In the past there was some debate over its origin: although it must lie close to the supposed hinge of the Lickey Anticline (if indeed there is an anticline at all), it seemed unlikely that it had a structural origin. The intense folding seen in the Barnt Green Road Quarry has not generated this scale of brecciation, and its distribution does not conform to the clearly delineated pattern of a fault. It was therefore suggested that it is of sedimentary origin, and lies unconformably on the Lickey Quartzite Formation.

Recent clearance work (2019) has exposed a clear but irregular junction between the overlying breccia and Lickey quartzite below. It is clearly an erosion surface, and represents an unconformity between the Ordovician Lickey Quartzite and what may be the base of the Silurian Rubery formation above, but is more likely to correspond to the Triassic breccia described by Wills & Shotton (1938), in a trench excavation in Tessal Lane, Longbridge. The larger clasts (some in excess of 30cm) are angular and have suffered minimal movement. Smaller (<4cm) fragments include a proportion that display a significant degree of rounding, and in places a sandy matrix includes some well-rounded, frosted grains of aeolian origin, similar to those in the Rubery Sandstone, and the Warren Lane fissure infill. The breccia in the Tessal Lane trench was described by Wills & Shotton as being, "entirely composed of angular blocks and smaller fragments of the Lickey Quartzite. This breccia very closely matches the Basal Triassic Quartzite Breccia recorded in boreholes in Birmingham by Professor Boulton (1933) which had never previously been seen at the surface. The blocks varied up to about a foot in diameter, were completely unrounded, and there was little, if any, sand or clay between them. The breccia was seen to rest unconformably with a rather high dip on chocolate-coloured Keele Clay [U. Carb.]. It passed upwards into soft red Bunter [L. Trias.] sand-rock with thin seams of breccia, and this into soft Bunter sand-rock."

Whether the unconformity on Bilberry Hill is of Silurian or Triassic age, it lies at a significantly elevated position when compared to occurrences elsewhere. While this difference could be the result of later faulting, it may reflect topographical relief at the time of deposition.

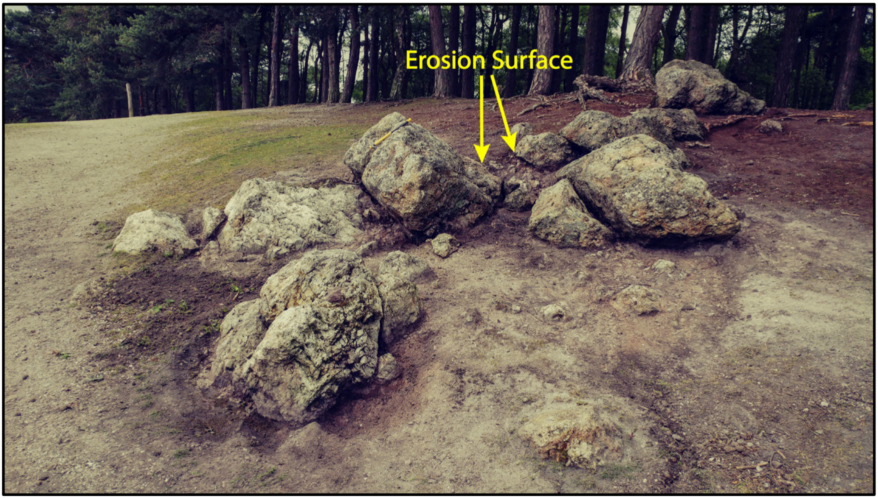


Figure 29. The exposure at the summit of Bilberry Hill looking north, showing the location of the unconformity.

Figure 30. The same exposure looking eastwards. The breccia has been darkened to distinguish it from the quartzite. Note that above the mattock's head the quartzite does not appear jointed, while below the head, it is extensively fractured.

Figure 31. Standing in the gap in the exposure shown in Fig. 29, but looking west, the unconformity is seen even more clearly.

Figure 31. When the breccia is darkened digitally, the nature of the unconformity becomes very clear. Note that in the quartzite immediately below the breccia the joints have been cemented, but below the level of the photo scale the joints are still open, and erosion of these lower layers has produced an undercut in the exposure. The area shown in Fig. 30 is just visible in the background at the right hand edge of the picture.

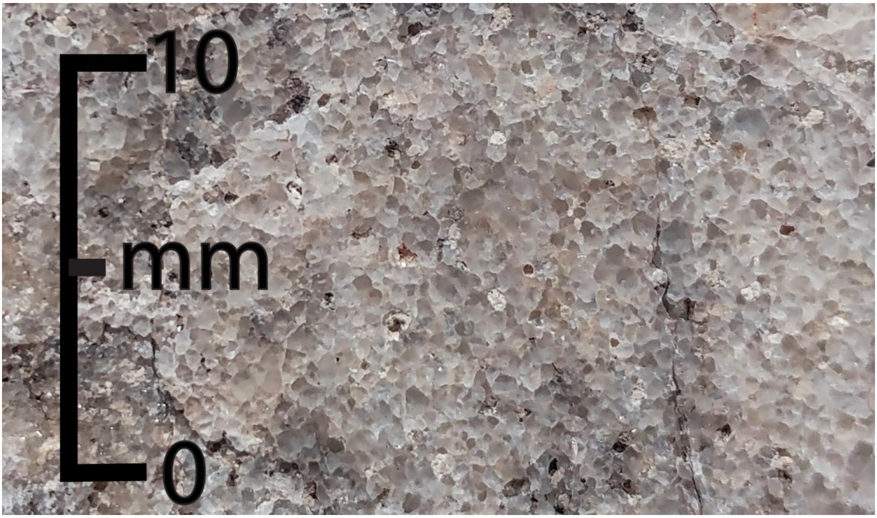


Figure 32. A polished surface of the Lickey quartzite on Bilberry Hill. It is very well sorted. A few feldspar grains are apparent, as well as cavities where feldspars have been weathered out.

Figure 33. The maximum clast size is in excess of 30cm, and these large clasts are very angular. Irregular patches are finer grained, and the smaller clasts of quartzite, as in this photograph, tend to show a higher degree of rounding, and are supported by a sandy matrix that includes some well-rounded, frosted aeolian grains.

Boulders of the same breccia can also be seen next to the bridleway, directly below this exposure on the west side of the hill, and also just above the point at which the ridge crest footpath on Rednal Hill meets Eachway Lane. The latter is yet to be evaluated, and may turn out to be outcrop.

Rednal Hill SO996765

The same sequence of rocks that was recorded on Bilberry Hill has now been identified on Rednal Hill, albeit in a much more discrete exposure.

Figure 34. The rucksack on the path marks the location of the Rednal Hill breccia outcrop.

Like the exposure on Bilberry Hill, the breccia and the uppermost Lickey quartzite are both well-cemented and very resistant. However, below this level, the quartzite is heavily jointed, and blocks can easily be pulled out. This has provided the basis for proposing that the very tough layer of breccia and uppermost quartzite is a silcrete.

Figure 35. The excavated exposure on Rednal Hill. The yellow dotted line shows the position of the unconformity. Breccia lies above, with re-cemented quartzite between the breccia and the heavily-jointed quartzite below.

Near the base of the north end of Rednal Hill, where the footpath descends towards Eachway Lane, a prominent 'boulder' of breccia projects out of the surrounding soil. Excavation around this prominence has exposed another occurrence of the unconformity, with silcrete-reinforced quartzite beneath the breccia. Below this re-cemented layer, the quartzite is heavily jointed. Further work is required to establish whether this is a loose boulder or outcrop. If it turns out to be the latter, it would show that the unconformity and silcrete developed across a topography of considerable relief, as the unconformity here is steeply inclined and at a much lower level than the same feature seen at the summit of the hill. This raises the prospect of the Lickey Ridge having been a topographical feature at the time the silcrete formed – possibly as far back as the Triassic or even the Silurian. It is yet to be seen whether the same unconformity is preserved on Rubery Hill to the north: a possible outcrop of breccia has been identified.

Figure 36. The prominence of breccia next to the footpath on Rednal Hill, close to Eachway Lane.

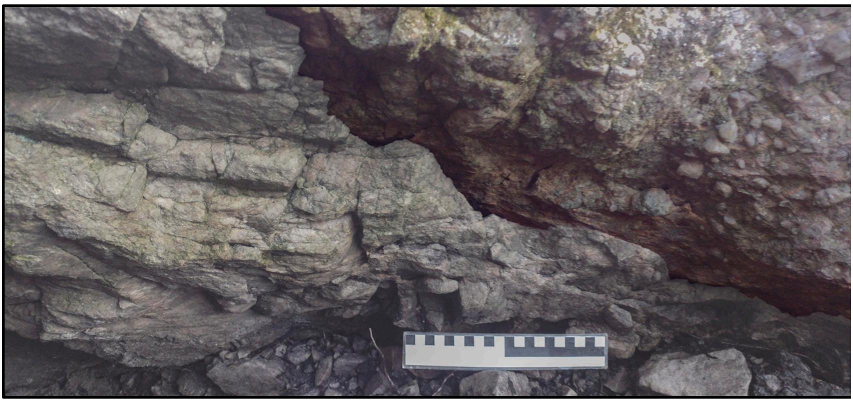


Figure 37. The breccia is clearly seen lying above the re-cemented quartzite, below which the quartzite is closely jointed, and easily eroded, producing a considerable undercut.

In the early 1920s, road widening and trench digging offered opportunities to document rocks that were subsequently reburied, and are no longer accessible. However, detailed observations were recorded by Professor W. S. Boulton, and published in a section of *The Geology of the Lickey Hills* entitled, *The Geology of the Northern part of the Lickey Hills, near Birmingham*. His account is reproduced below.

The complex structure of the Lickey Hills, 7 miles south of Birmingham, has attracted the attention of geologists since the early part of last century, and interpretations of some details of their geology have been almost as numerous as the observers. The hills form part of the district recently remapped on the 6-inch scale by the Geological Survey.[1] Extensive road widening and trench cutting for sewers carried out in the area in 1923-4 has revealed new and important information, which has already been published in part.[2]

During 1925 a deep trench was dug from the main Bristol Road at Rubery, southward along Leach Green Lane, past Leach Heath, and then westward down the cross-road called Eachway Lane. A close watch was kept on the excavation from day to day for some months, and the facts recorded. As the trench traverses a critical part of the Lickeys and the facts observed seem to have an important bearing on the structure of the district, they are set forth below, and embodied in the geological map; and in the light of other observations referred to above and recently published, the general structure and history of the northern part of the Lickey range is here briefly discussed.

SUMMARY DESCRIPTION OF TRENCH SECTION.

Starting from Bristol Road and passing southwards along Leach. Green Lane, the trench and manholes, from 10 to 12 feet deep, exposed quartzite rubble embedded in red, yellow, and lilac-blue clay for a distance of 190 yards. In part of the section (150 to 162 yards from Bristol Road) the rock fragments were almost entirely Llandovery Sandstone. For the next 155 yards the trench cut solid well bedded quartzite, with a coarse granular texture and abundant feldspar fragments. Near the cottage in the triangle of roads at the top of Whetty Lane the quartzite is overlain unconformably by the Rubery (Llandovery) Sandstone, dipping south at 20°, the dip of the underlying quartzite being 10° to the south-east. The sandstone is much stained with hematite and manganese, and contains large round pebbles of quartzite near the base, resting upon an irregular surface of bedded quartzite. At a point 60 yards further to the south-east and opposite a cottage, the Coal Measure clays rest unconformably on the Llandovery Sandstone. The clay exposed to a depth of 10 feet is purplish-red and sandy, blotched with yellow and bluish patches, and dips at about 20° off the Sandstone, lumps and fragments of the latter lying in the base of the clay. The Llandovery Sandstone rises to within 3 feet of the surface 18 yards south-east of the cottage, and large angular lumps of it make up the base of the clay, but the sandstone floor gradually deepens again until the whole of the trench was occupied by gently dipping yellow, buff and red clay.

For the next 200 yards the trench with its manholes, to a depth of 12 feet, passed through yellow and red-purplish Coal Measure clays, containing fragments of quartzite and sandstone, and dipping a' small angles.

At a point 15 yards south of the Library the Quartzite rises to the surface again, in a little easterly spur 11 yards wide, the bed dipping east at about 30°. Red, purplish, and bluish-green sandy clay, with much quartzite rubble in the base, dips steeply off the bedded quartzite on both sides of the knoll, and then gradually flattens out, occupying the trench southward for the next 165 yards, when it abuts against the Bunter Sandstone. A few yards north of this junction the Coal Measure clay is bluish-grey with black coaly matter. The junction of the Coal Measures and Bunter crosses the road obliquely and is clean cut, black stained, and steeply dipping to the south-east.

From this point to the junction of Leach Green Lane and Eachway Lane, a distance of 185 yards, the Bunter Sandstone was exposed to a depth of about 12 feet, covered by an irregular mantle of Drift, consisting of coarse gravel and large blocks of quartzite below and red sandy clay above. The total thickness of the Drift varies from about 12 feet near the Coal Measure junction to about 2 feet near Eachway Lane. In places the gravelly Drift occurs in pockets of the Bunter, in one of which a platy felsite boulder, 3 feet by 2 feet, occurred.

In two manholes at the junction of Leach Green Lane and Eachway Lane, the pebbly Bunter Sandstone with a thin cover of pocket gravelly Drift was exposed, and in the lower few feet of the manholes purple red clay of Coal Measure type, with abundant fragments of Llandovery Sandstone, was visible under the Bunter. Turning westward down Eachway Lane, which cuts across the general axis of the Lickey Ridge, an interesting exposure was laid bare in the deep trench, at a point about 25 yards from the junction with Leach Green Lane. Typical Bunter Sandstone, which could be followed to this point from the road junction, was exposed to a depth of 14 feet, and is brought abruptly against red Coal Measure clay. The junction is clean cut and darkly stained and dips steeply to the west. The clay is about 2 feet thick at outcrop, but thickened rapidly to about 7 feet at a depth of 10 feet in the trench, and is overlain by solid but broken quartzite, the junction of quartzite and clay being even and clean cut, with a dip westward at about 45°. Thus the beds have been overturned, and the quartzite is apparently thrust eastward over the Coal Measures, squeezing and almost cutting them out, while the latter are overturned on the Bunter Sandstone. The Quartzite which here dips north at 25°, continues to outcrop westward for about 34 yards, when purple, sandy Coal Measure clay containing angular fragments of quartzite, rests upon an irregular inclined surface of it. The Quartzite is brought up to the surface again 10 yards further west by i small fault with an easterly downthrow. The bedded quartzite, capped by quartzite rubble, then continues for 15 yards, when it is succeeded again by the same Coal Measure clay, dipping off the quartzite, and Coal Measures occupied the whole of the deep trench to the last manhole 34 yards to the west.

The new evidence obtained from the trench just described, together with that from other trenches and excavations in the area, of which summaries have been previously published (ibid.), now permits of a more exact determination of the outcrops and inter-relations of the rocks than was formerly possible. The formations may be taken in stratigraphical order :-

1. LICKEY (CAMBRIAN) QUARTZITE.
Excavations for the new extension of Rubery Asylum showed that the Quartzite occurs under a thin cover of Coal Measure clay in the ground due north of the School at Rubery, and on both sides of the main Asylum drive from Bristol Road. Thus, 90 yards north of the School, and again 65 yards still further north, two small knolls of Quartzite rise through the Coal Measure clay mantle. Consequently the main outcrop of Rubery Sandstone which occurs on the eastern flank of the Quartzite south of Bristol Road does not continue northward as shown on the new Survey 6 in. map, but is cut off just north of the road, its normal strike position being occupied by Quartzite,. almost entirely covered by a thin mantle of Halesowen Clay. The general easterly shift in outcrop of Quartzite, Rubery (Llandovery) Sandstone and Rubery Shales in the foundations and grounds of the Asylum seems best accounted for by a north-east and south-west fault with a south-east downthrow.

2. RUBERY (LLANDOVERY) SANDSTONE.
Much of the outcrop of this Sandstone round Leach Heath as shown on the recently published 6-inch map of the Geological Survey must now be replaced by overlying Halesowen Beds ; while as stated above, the supposed outcrop of Rubery Sandstone between Bristol Road and Rubery Asylum must give place to the same Halesowen clays resting upon the Quartzite. It is evident from the map that the Rubery Sandstone, where it rests upon the Quartzite at Leach Heath is rolling over southward, and the large quantity of sandstone debris in the base of the Halesowen clay on the west flank of the Quartzite suggests that the Rubery Sandstone may occur in situ on this west side and partake of the general anticlinal structure of the Quartzite ridge. The most southerly exposure of the Sandstone iinder the Coal Measure cover seen in the trench was near the house about 198 yards north-east of the top of Whetty Lane. South of this point, the only known outcrop of Llandovery Sandstone is a knoll about 165 yards north-west of Rednal House surrounded by Bunter Pebble Beds, and beyond the margin of the map.

Wherever the Rubery Sandstone has been seen, its relation to the Quartzite is the same as in the well-known exposures at Rubery, where the unconformable junction with the Quartzite is irregular and marked by many water-worn quartzite pebbles and boulders near its base.

3. COAL MEASURES.

One of the outstanding facts revealed by the new evidence is the much greater spread of Coal Measure clay over the Quartzite and Llandovery than was formerly supposed. At Leach Heath and in Eachway Lane the Coal Measures invade hollows and gullies in the older rocks, while at Rubery the clays breach the Quartzite ridge along the line of Callow Brook, and then spread out north and east as a thin ragged mantle over the older rocks, joining up with the large spread of Halesowen Beds to the east of Rubery Hill and between Callow Brook and the River Rea. It is likely that the Coal Measures of Leach Heath extend unbroken in an easterly direction under the Bunter and join up with the Coal Measures proved in the Bristol Road trench.

Wherever the base of the Halesowen Beds is visible there are abundant rock fragments, usually small angular chips, but sometimes large angular blocks of either Quartzite or Llandovery Sandstone according to its underlying formation. At two places between Bristol Road and Rubery Asylum a coal seam was met with, doubtless the same seam as that exposed to the north-west of the Asylum.

As we pass southward to Leach Green and beyond to Eachway Lane, no satisfactory junction marking the oncoming of Keele Beds could be seen. On the whole, red, purple, yellow, and blue are the predominant colours hereabouts, with occasional coaly smuts, and sometimes a lilac-blue clay makes its appearance. The clays between Leach Heath and Eachway Lane are probably near the top of the Halesowen Beds. The Halesowen clays which fringe the western side of the Quartzite pass up gradually into the Keele Beds as we pass south of Eachway Lane, possibly due to the fact that submergence of the Cambrian and Silurian rocks in Coal Measure time took place gradually and progressively from north to south. On the other hand, a differential tilt in post-Coal Measure time, with relative elevation and subsequent greater denudation in the northern part of the range would also account for the facts. If the latter is the true interpretation, the Halesowen Beds should occur under the red Keele clays which flank the Quartzite on the south-west side of Rednal Hill and Bilberry Hill.

The Coal Measure clay, containing a Spirorbis Limestone, discovered in 1924 in a trench during the widening of Bristol Road between the Birmingham Fault and the Rubery Shales is of interest in connection with the Coal Measures now known to extend over Leach Heath and also between Bristol Road and Rubery Asylum. These red and buff mottled clays with Spirorbis Limestone were provisionally placed in the Keele, partly because of the red colour of much of the clay and also because the contained Spirorbis Limestone is similar to other Spirorbis Limestones found in the Keele Beds along the southern fringe of the South Staffordshire Coalfield. The clays found in the road trench are about 170 yards from the blue and grey Halesowen Clays, with a thin coal exposed in Callow Brook to the north, but it is difficult to measure the stratigraphical interval between the two exposures because the beds hereabouts are disturbed and rolling. In recording this exposure in 1925 the writer assumed a possible small east-west fault between Bristol Road and Callow Brook, separating the Halesowen Beds to the north from the clays with Spirorbis Limestone in the road. The difficulty is to fix, the horizon of this Spirorbis Limestone. It is very unlikely from its position that it is the same limestone which occurs in bright red clay, 120 feet above the 30 feet sandstone (Hunnington) on the south of Hollymoor Asylum. Again, it has generally been assumed that the Illey Brook Limestone in the Upper Halesowen Beds is distinguishable from the blue-grey limestones in the Keele by its dirty white or putty colour. Recently, however, Dr. L. J. Wills has obtained specimens of the Illey Brook Spirorbis Limestone in situ in a trench-cutting on the Halesowen- Romsley Road, 150 yards south of Oatenfields Farm, which are blue-grey in colour, and the rock is not unlike the Spirorbis Limestone from the road trench at Rubery.

Up to the present it has not been found possible to correlate the Halesowen Beds of Rubery with those of the type area south of Halesowen. It is probable that the red and yellow mottled clays associated with the Spirorbis Limestone in the Bristol Road trench lie above the blue and grey clays with thin coal exposed in Callow Brook, less than 200 yards to the north, and that the former lie near the top of the Halesowen Beds, if not actually in the basal beds of the Keele.

The sub-Bunter outcrop of the Spirorbis Limestone probably runs east of the Birmingham Fault and a little south of Colmers Farm. It should also outcrop along the northern fringe of Balaam's Wood, which is a little to the north of the map, but so far it has not been seen there.

There is as yet insufficient evidence to show whether more than one coal seam is present in the Halesowen Beds in the Rubery area. A seam 2 feet thick is said to have been worked at one time at or near the village of Rubery. The Coal which the writer saw exposed in the trench between Callow Brook and the Asylum was about 1 foot thick, and is probably the same as that exposed on the north-west side of the Asylum, which is about the same thickness. The Coal exposed in Callow Brook is about 6 inches thick.

With the evidence now available, one is tempted to assign a stratigraphical position for the blue and grey clays with the Rubery Coal seam or seams, as equivalent to that of the Wassel Grove Coal series of the Hayley Green district north of Hagley Wood. The Limestone in the Bristol Road trench might then correspond to the Limestone, of which fragments have been found in Turnpike Coppice, to the north-east of Hagley Wood and just north of the Hagley- Birmingham Road. The Survey doubt whether this latter is the same as the Illey Brook Limestone, which they are inclined to assign to a somewhat lower position, and associated with the Wassel Grove Coal. But if the correlation now suggested be correct, it would mean that the Spirorbis Limestone in Bristol Road is high up in the Halesowen Beds, and either equivalent to that of Illey Brook or not far above it.

4. BUNTER SANDSTONE.

Observations made during the widening of Bristol Road between Longbridge and Rubery proved that Bunter Pebble Beds occupy the ground round Colmers Farm and the Leys. This is shown as Enville Beds (Calcareous Conglomerate Group) on the new Geological Survey 6 in. map. Moreover, the writer has failed to find any evidence of this Calcareous Conglomerate Group north-east of the railway, where it is shown by the Survey, faulted to the north-west against Keele Beds. There are bright red clays visible in places, especially near the base of the Bunter close to the railway, so that the evidence such as it is points to Keele Beds and not to the Calcareous Conglomerate Group as outcropping here, and underlying the Bunter to the eastward.

THE BIRMINGHAM FAULT.
As previously recorded the Birmingham Fault, bringing down Bunter on the east against red and blue Coal Measure clay on the west, crosses the Longbridge-Rubery Road 108 yards west of the School House near Colmers Farm.

A notable fact now established is that this fault does not continue southward across the Lickey Hills as shown on the Survey 1-inch map (1897), and as is drawn on the new 6-in. Survey map. Every foot of the longitudinal trench section from Rubery to Eachway Lane was carefully examined during the whole time the excavations were in progress, and naturally the Leach Heath section, where the fault is drawn as crossing on the new 6 inch Survey map, was specially noted, but no break in the Quartzite, Llandovery Sandstone, or Coal Measures could be detected. In the low ground at Leach Heath the Rubery Sandstone, with a thin cover of Coal Measures, is resting on the Quartzite in a narrow, east-west unfaulted syncline. The throw of the fault where it crosses Bristol Road must be small, and it apparently dies out before the Lickey Ridge is reached.

It is now possible to correlate the new data referred to above with observations made nearly a hundred years ago, and about which there has been some doubt in recent years. In 1829 James Yates recorded the fact that "at Colmers Farm[1]. . . a bed of pure limestone is worked about 2 feet in thickness and 8 feet from the surface of the ground. A red stiff marl lies over it, and beneath it is a similar marl variegated with blue".[2]

There can be little doubt that the limestone referred to by Yates is the same as the Spirorbis Limestone recently exposed in the road trench (p. 260), but all trace of the old workings he mentions has long since vanished. Yates further states that "at a short distance to the east of this limestone, and at the base of a hill called Leach Heath, a shaft has been sunk to a depth of 125 yards". It is probable that the site of this old shaft is about 150 yards to the north of the School and near the present Filter Beds. The thickness of the Coal Measures and Silurian referred to in his description is not given, and therefore the base of the Halesowen Beds in the section is uncertain; but the Silurian rocks are said to extend to a depth, of " above 100 yards from the surface ", and further on he says that the quartz rock (presumably Llandovery Sandstone) was met within the shaft at a depth of more than 100 yards from the surface. The position of this shaft is indicated in the section, as is also the well and boring at the Longbridge Pumping Station, in which Silurian Shales ("Blue Binds") occur from a depth of 357 to 496 feel; (the bottom of the boring). Above this are red and blue marl with coal fragments and "pebbles", which no doubt belong to the Halesowen Beds, while above them are about 300 feet of Bunter and overlying Drift. The section shows that the Keele Beds which emerge from the base of the Bunter and outcrop a little to the north, are overstepped by the Bunter about 130 yards west of the Longbridge Pumping Station, while the Halesowen Beds are similarly overstepped about 200 yards to the east of it. Thus, while the Coal Measures on the eastern flank of the Lickey Hills are probably absent under the Bunter south-east of the road which runs from Longbridge to Eednal, they extend, possibly for a considerable distance, under the Bunter north of the Bristol Eoad between Longbridge and Colmers Farm.

South-east of the Longbridge-Rednal road Silurian rocks probably occupy much or all of the sub-Bunter ground up to the Silurian outcrop at Kendal End. Still further south-east of this one might expect the sub-Triassic floor to reveal Cambrian and pre-Cambrian rocks, of which the outcrop of the Lickey Hills is but a small fraction.

OVERFOLDING AND THRUSTS.

The evidence of overfolding of the Quartzite, Coal Measures, and Bunter near the top of Eachway Lane is of some interest, and may be related to other evidence of thrust-faults and crush-belts to be seen to the north and south of Eachway Lane.

At the north-east corner of an old quarry in the Quartzite, 370 yards north-north-west of the top of Eachway Lane, two roughly parallel faults with a north-west bearing and about 50 feet apart, can be seen, and are marked on the Survey new 6-inch map. The Quartzite dips 70° to the south-west between the faults, while the dip on the north-east of the faults is to the north-east at about 25° and on the south-west of the faults it is 15° to the north-east. This can be explained by a south-westerly thrust which is nearly in line with the overturned and thrust junction of Quartzite and Coal Measures in Eachway Lane, and extending north-north-west nearly parallel to Leach Green Lane.

Crush-belts, varying in width from a few feet to several yards, are met with at intervals in the Quartzite of Leach Green Quarries. They all have a general north-west, south-east bearing with, a high dip to the south-west.

Reference may also be made to the thrust-fault which strikes north 30° west, near the base of the Rubery Shales seen in the road widening and trenches in the Bristol Road, Rubery.[1]

Other evidence of overthrusts in the Quartzite can be seen near the base of the large quarry on the north side of Rednal Gorge and about 900 yards south of Eachway Lane. Two adjacent thrusts converging eastwards are here exposed, the upper inclined to the west at 18° and the lower at 25°. Eastward they end rather abruptly against a vertical shatter belt in the quartzite. Similar thrusting from the west is visible in the quarry on the south side of the gorge, but the beds are there more shattered. The finest example of overfolding in the Lickey Hills is that which is exposed in the large quarry further south, on the east side of Bilberry Hill near the road from Rednal to Barnt Green. This exposure has been known for many years. The beds in the upper 20 feet of the quarryface are sharply bent over from south-east to north-west into small, recumbent, sigmoidal folds. The plane of separation between the overfolded beds and their downward continuation, where they dip abruptly in the opposite direction, is undulating and nearly horizontal. At the south end of the quarry the overturned beds are faulted down to the south-east. The structure is obviously due to intense compressive stress, and it seems necessary to postulate either a thrust from the south-east, or a more deepseated thrust from the north-west, with a lag in the higher beds when a thick cover of rocks existed at the time of the thrusting movement.

Whenever the thrust movements just referred to had their origin, the overfolding and thrusting revealed in the trench sections in Eachway Lane indicate a post-Triassic date for some, at least, of it. Intense compressive movements of post-Permo-Carboniferous age have been seldom recorded in the Midlands, so that this instance is of interest. It probably reflects a marginal phase of the great Alpine movement of Western Europe, but whether of late Mesozoic or of Tertiary date is not certain.

The writer has thought that the effect of similar thrusting from the west may have been responsible for the remarkable structure in the vicinity of that portion of the Russell's Hall fault which lies south of Dixon's Green, south-east of Dudley, in the South Staffordshire Coalfield and some 7 miles north of the Lickey Hills. This fault-belt with the adjacent Dudley-Rowley Ridge to the east of it, can be regarded as a structural continuation of the Lickey Hills. The sudden change in throw of the Russell's Hall Fault from southwest to north-east, and the curious deep trough in which the Thick Coal has been found, tucked in, as it were, under the Rowley Dolerite Hills, is very suggestive of an intense squeeze from the west.

May it not be that this deep-seated squeeze in post-Permian time was responsible for the intrusion of the Rowley-Dolerite laccolite into the Etruria Marls, as well as similar and smaller intrusions in this Coalfield; and the striking narrow trough immediately north of Yewtree Colliery[1] may be a subsidence which followed in the wake of the squeeze out of the basic magma into the laccolite.

Finally, it is interesting to note the great antiquity of the Lickey Ridge as an outstanding buttress against which lapped successive Palaeozoic seas, and along which marginal basal sediments were deposited. On the south-east flank of the Quartzite, in the large quarry with the overthrust, a coarse gritty and conglomeratic type of quartzite can be seen, full of rounded fragments of the underlying Uriconian volcanics. The Llandovery Sandstone, as we have seen, exhibits an unusually fine conglomerate base with rolled quartzite pebbles and boulders fringing the irregularly eroded quartzite cliffs. The Halesowen Beds of the Coal Measures also show signs of a marginal fringe. But in this last case, the waters in Upper Coal Measure time quietly submerged the older rocks with an absence of turbulent wave action and erosion. For wherever the base of the Coal Measures is seen, and it has been closely examined at many places, the basal clays contain abundant large and small, but quite sharp-edged and angular lumps of quartzite and sandstone, the aerially-denuded debris of the land of the period, which was quietly submerged or which fell into the shallow water of the time.

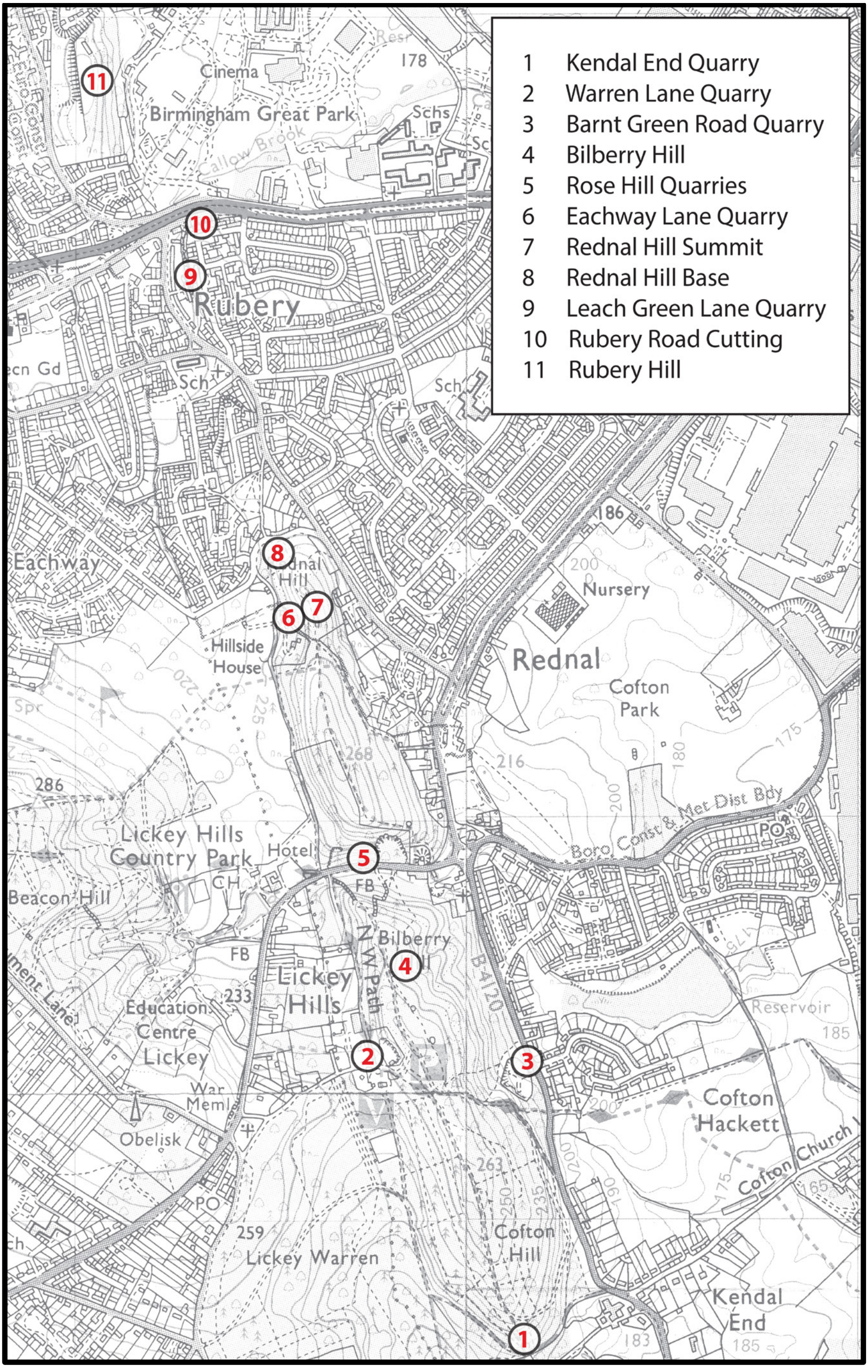
The Cambro-Silurian ridge assumed an anticlinal structure and formed part of a land surface which was deeply denuded during Devonian and early Carboniferous time. It was partly submerged in Halesowen time, but was probably completely covered by the Keele Beds, and possibly by an overlying Calcareous Conglomerate Group. Then followed prolonged denudation and elevatory movements during the arid period when the Clent Breccias were accumulated, composed chiefly of Cambrian, Silurian, and pre-Cambrian rocks of the Lickey core and other ancient ridges now buried from sight. After that came the desert sands and shingle beds of the Bunter, whose basal rocks, with their occasional angular blocks and fragments of quartzite and Llandovery Sandstone, fringe the Lickey Hills on the east and south, and testify that the quartzite core of the ridge had again been laid bare by Triassic time.

No rocks newer than the Bunter, except the Glacial deposits, are now present in the immediate neighbourhood of the north end of the Ridge to record subsequent events, but these Bunter Beds, have suffered faulting and other disturbances, and on the eastern flank of the Ridge have been thrown into gentle synclines and anticlines with a pitch to the south-east.

I wish to thank Mr. W. H. Laurie, of the Geological Department of the University of Birmingham, for re-drawing the map and sections which illustrate the paper.

1 " The Geology of the Southern Part of the South Staffordshire Coalfield " : *Mem. Geol. Surv.,* 1927, pp. 160-3.

Lickey Hills Locations



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The Lickey Hills inlier is a unique island of Lower Palaeozoic rocks on the Birmingham-Worcestershire border. The complexity of its structure, and its often obscure relationships with younger rocks, provide a wealth of opportunities for geological investigation.