THE STRUCTURE OF THE SILURIAN ROCKS OF THE MALVERN AND ABBERLEY HILLS, WORCESTERSHIRE.

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C O N T E N T S.

VOLUME I.

INTRODUCTION.

This thesis is an account of the structure of the Silurian rocks lying to the west of the Malvern and Abberley Hills, but it has been impossible to confine interests to the Silurian rocks alone, since many of the answers to the structures lie within the neighbouring formations. Therefore, this thesis also concerns itself, in a lesser degree, with other associated problems.

The area described lies between Great Witley in the north and Hereford Beacon in the south, a distance of $16\frac{3}{4}$ miles, and occupies the Ordnance Survey 6 inch maps:

Worcestershire	Sheet	XX. S.E.		Worcestershire	Sheet	XXXII S.W.	
"	"	"	XXVII N.E.	"	"	"	XXXIX N.E.
"	"	"	XXVII S.E.	"	"	"	XXXIX S.E.
"	"	"	XXXII N.E.	"	"	"	XLVI N.E.
"	"	"	XXXII S.E.	"	"	"	XLVI S.E.

The thesis is in three parts. Part I is the text, Part II includes sketch maps, sections, diagrams and photographs illustrating Part I and the last part contains geological maps on the scale 6 inches to 1 mile. Part I is written in two sections, the first deals with the stratigraphy of the area and the second, the main part of the thesis, is concerned with the structure and the structural history of this district.

Abbreviations and symbols used on the maps and sections are those found in the "Standard Legend, Geological Department" of The Shell Petroleum Company Limited.

Acknowledgements.

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HISTORY OF PREVIOUS RESEARCH.

Murchison's great works, "The Silurian System" published in 1839 and "Siluria" published in 1854 represent the first work dealing with the structural interpretation of this area. In them Murchison describes briefly the main outcrops of limestone with their fossil content, draws various sections and plans of the folded Silurian rocks and describes numerous exposures and workings which have since become overgrown.

The first investigation by the Geological Survey was carried out by John Phillips and published in 1848 as a Geological Survey memoir. Phillips produced many measured sections of the limestones and again recorded many outcrops which have since become inaccessible or overgrown. He recognised the main geological structure and his interpretations have not been seriously contradicted to this day. As a result of Phillips' work a series of 1 inch maps were published in 1855 placing the main outcrops with fair accuracy, but showing a greatly simplified picture of the tectonics of the Silurian formation.

In 1860 the Great Western Railway constructed a tunnel through the Malvern and Ledbury Hills. This excavation was surveyed by Symonds and Lambert and they published their observations in the following year.

Between 1861 and the end of the last century several other workers made reference to the district in published work. The chief of these was H.B. Hull who dated the age of the metamorphism of the Malvernian and associated these rocks with part of a much larger mass, peaks of which are seen at Malvern, Cowleigh Park and Martley. Other minor publications of this period were produced by Symonds, Callaway, Arber and King.

Fifty years after Phillips' mapping, Professor T.T. Groom mapped the entire Malvern-Abberley range of hills and published an account of their geology in the Quarterly Journal of the Geological Society for the years 1899, 1900, 1901 and 1902. His opinions are illustrated by several sections in which a complex series of faults and thrusts are invoked to explain the structure, this complexity is particularly noticeable north of Martley. Groom was the first to recognise "Malvernoid" folding of Coal Measure age by noting the analogous relationship of the two patches of Coal Measures of Woodbury Hill and Kingswood Common. Groom also established the "Malvern Fault" theory which has not been disputed until recently. In a subsequent publication of 1910, Groom produced an extensive faunal list of the Silurian rocks of the Malvern-Abberley range, including one of fauna apparently confined to their major lithological divisions.

Arber (1913) and Cantrill (1917) in their work on the "Wyre Forest and Mamble Coalfield" made passing references to the Woodbury Hill district.

W.W. King read a paper to the Worcesterhsire Field Club in 1923 on the Permo-Carboniferous unconformities of Worcestershire. In this he described the Coal Measures of Kingswood and Woodbury Hill and concluded that their lithological similarity showed them to be of the same age. By assuming the Haffield Breccia to be Permian, he showed that the greater part of the Upper Coal Measures was unrepresented in this area.

In 1925 another tunnel was made through the Malvern Hills very close to the old one. The Geological Survey again surveyed the excavations and their observations were published in a Summary of Progress of the Geological Survey for that year. Mention is made in another Summary for the year 1936 of work carried out in the district north of Berrow Hill by Hollingworth. The New Series geological map (Droitwich Sheet) for which Hollingworth's work was carried out, has not yet been published. A map showing "head" or hill-wash deposits to the north of Penny Hill, Martley, together with a brief description of them by Hollingworth is found in the Geological Magazine for 1940.

Since the last war interest has been renewed in the Malvern and Abberley Hills with the result that papers have occurred quite regularly in geological literature.

N.L. Falcon published a short paper (1947) in which he re-interprets Groom's data in the light of modern throught. By taking into account the possibility of superficial contortions of dip due to soil creep in the exposures of Coal Measures of Kingswood, he concluded that these beds were not involved in the Malvernoid folding. He also re-introduced Murchison's and Holl's idea of an unconformable Triassic system as opposed to Groom's faulted theory.

The following year A.H. Cook and H.I.S. Thirlaway contributed a paper on gravity observations made in the Welsh Borderlands. This work threw light on the problems of the Malvern boundary fault and showed the Palaeozoic surfaces to dip at 45° to the east under the Mesozoic cover.

Also in 1948 the Geological Survey published a handbook of British Regional Geology entitled "The Welsh Borderland" (second edition) by R.W. Pocock and T.H. Whitehead. This excellent work outlines the geology on a broad scale and includes a good bibliography.

In 1951, W. Mykura published a paper with a map and section of the Walsgrove Hill district in which he discusses evidence by which to date the Malvernoid folding to greater accuracy, and also reveals in his section new ideas in the interpretation of Woodbury Anticline.

Last year three papers were published which have contributed to the knowledge of this range of hills. The first was by F.G.H. Blyth who discusses the geology of the Hereford Beacon district and suggests probable directions and controlling forces that have created the Malverns. The second was a paper by A.H. Cook and others on the gravity observations of the area immediately to the north of Abberley and substantiates the existence of the Malvern boundary fault into that district. The last publication is by F. Raw who proposes an original theory on the structure and origin of the Malvern Hills involving overthrust nappes and two periods of movement along the boundary fault.

This summary of the history of previous research within the Malvern-Abberley chain is by no means complete. Numerous other workers have made small contributions, but the work of the principal investigators has been outlined above.

S T R A T I G R A P H Y.

PRE-CAMBRIAN.

Malvernian.

These rocks have been described by Rutley[1] and in general consist of a series of schists and gneisses in which hornblende, chlorite, white mica, felspar and quartz are the dominant minerals. Associated with these are red granitic rocks, dolerites and a few olivine dolerites. The dominant pink colour of the rock is due to the high content of pink felspar but on weathering the surfaces of the rocks become dark brown to black. The rock is tough and breaks with an uneven fracture and also has numerous joint planes with no common plane of orientation.

Age. About one hundred years ago an important school of thought believed that the crustalline rocks forming the core of the Malvern Hills were intrusive syenites, presumably of post Silurian age. Holl[2] suggested that they were actually pre-Cambrian metamorphics, but this view was contested by so eminent a geologist as Murchison[3]. Present day knowledge of British stratigraphy shows that the conditions necessary for the formation of such rocks has not existed in this area since Pre-Cambrian times. Moreover, Groom[4] points out that many of the pebbles in the Cambrian conglomerate have been derived from "a complex resembling the Malvernian, and others from a volcanic series like the Uriconian".

1. Rutley, F. Q.J.G.S. 1887. Vol.XLIII p.481.
2. Holl, H.B. Q.J.G.S. 1865 Vol. XXI p.72-102.
3. Murchison, R.I. 1867. "Siluria" p.14.
4. Groom, T.T. "The Malvern & Abberley Hills". Geology in the Field, 1910. p.701.

<u>Occurrences.</u> There are three localities where Malvernian type rocks occur:

1) The main Malvern chain from North Hill to Hereford Beacon where they form a narrow strip of high ground 4. miles long and between $\frac{1}{4}$ and $\frac{3}{4}$ miles wide.

2) Two small patches S.S.E. of "Rough Hill", Cowleigh Park (32/763477 and 32/762480).* The rock exposed here is of the usual type with what appears to be more hornblende than that found at North Hill. The most interesting feature of the rock is its mode of weathering. On the outer surface the rock weathers to a dark brown to red colour and the weathered material is very friable. About any inch below the surface the colour is similar, but there is a gloss on the brown surface characteristic of haematite.

3) 500 yards due north of Berrow Farm, Martley (32/745595) there is a small quarry showing a red granite type of rock similar to the Malvernian exposed further south. This small quarry has been described by many workers including Murchison[1], Phillips[2], Coles[3], Groom[4].

Warren House Series.

This series of rocks was recognised, but its boundaries were not mapped. They are found on the eastern side of Herefordshire Beacon and in the neighbouring part of Castlemorton Common.

1. Murchison, Sir. R. Silurian System 1839. p.420-421.
2. Phillips, J. Memoir Geol.Surv. Vol. II part II 1848. p.38.
3. Coles, Geol.Mag. 1898. p.304.
4. Groom, T.T. Geol.Mag. 1898. p.562.

* Grid references to the nearest 0.1 kilometre.

The rock is principally a fine grained volcanic rock and resembles the Uriconian group of Shropshire. Pebbles, which are very similar in nature to the Pre-Cambrian, are found at the base of the Cambrian in the Malvernian Quartzite.

CAMBRIAN.

The Cambrian system is represented by three types of rock in the Malvern Hills:

3) The White-leaved Oak Shales ("Black Shales").

2) The Hollybush Sandstone.

1) The Malvern Quartzite.

The only member of this series that outcropped within the area mapped was the basal member (1), the other Cambrian rocks are found further to the south.

The Malvern Quartzite is commonly a grey quartzite of rather fine grain with bands of conglomerate which contain pebbles of the older pre-Cambrian rocks. It is exposed only in shattered strips and thus estimates of its thickness are impossible, but from evidence in the Eastnor area T.T. Groom thought it might have been several hundred feet thick, although only 50 or 60 feet of the series can now be seen[1].

The quartzite was exposed in two places:

1) Martley Gravel Pit (32/745596)

This pit shows red syenites overlying a thickness of 3 feet of quartzite, characterised by well cemented and well rounded medium sized grains.

Groom and Coles agree that the quartzite is very unlike any of those found interbedded with the schists and gneisses of the

1. Groom, T.T. 1910 "Geology in the Field" p.701.
2. Groom, T.T. "Notes on the Martley Quartzite" Geol.Mag. 1898.
3. Coles, C. St.A. Geol.Mag. 1898. p.304.

Malvernian. According to them the quartzite is similar in all respects to the Lower Cambrian Quartzites of the Malvern and Lickey Hills with which it may safely be correlated.

2) Cowleigh Park, North Malvern (32/764476)

A strip of shattered quartzitic rock is exposed on the eastern side of the pre-Cambrian patches. Phillips regarded this strip of rock as altered "Caradoc" though he correctly termed it a "quartzite or quartz-rock". Groom[1] correlated this with similar rocks exposed further south which he had established were Cambrian in age.

Mention must be made of a well and boring sunk many years before Groom's mapping "... near the foot of the slope" (referring to North Hill)[2]. The observation made by Rev. G.E. Mackie were recorded in Groom's paper and includes a description of 6 feet of hard quartz breccia and 18 feet of black shales, both correlated with the Cambrian.

1. Groom, T.T. 1900. Q.J.G.S. Vol. LVI. p.160.
2. Groom, T.T. ibid. p.157.

THE LLANDOVERY SERIES.

This series contains three distinct lithological groups:

A. Woolhope Shales.

B. Wyche Beds.

C. Cowleigh Park Beds

B and C are often grouped and called the May Hill Sandstone.

In general, mapping of these groups was impossible except over small areas.

C. Cowleigh Park Beds.

These beds are coarse sandstones and grits, generally brown to purple, but sometimes green and grey in colour with subordinate conglomerates and shales. In the neighbourhood of Cowleigh Park there is a well defined thick band (estimated at 20-50 feet) of pink grit which runs north-south through Rough Hill and Cowleigh Park forming a well marked topographical feature. This pink grit forms a useful marker horizon. A hand specimen of this grit shows that it is hard and tough and breaks with a fairly even fracture. It appears pinkish in colour and examination under a lens shows this colour to be due to large numbers of minute felspar fragments disseminated through the rock. There are also small fragments of reddish rock probably pieces of Malvernian. Very little weathering was observed. Thin sections show the quartz grains to be angular and often strained and shattered. Many of the quartz grains are coated with limonite.

There are no exposures of the beds below this grit, but rock fragments of red shale and shaley sandstones and grits suggest a shale-sandstone sequence.

The pink grit is overlain by a thin series of purple and greenish sandstones and conglomerates. These conglomerates are fossiliferous and are known as "Miss Phillips's Conglomerate" and form a useful horizon in the series since they are traceable from Rough Hill to West Malvern. Groom[1] has analysed the pebbles from the conglomerate and shows that the assemblage found would most likely have been derived from the pre-Cambrian.

Thickness. The Cowleigh Park Beds are most probably incomplete at Rough Hill, but measurements from the map show it to be at least 500 feet thick. Phillips[2] thought it to be about 600 feet thick, but Groom gives 900 feet as more probable in this area. Groom adds that the Cowleigh Park Beds possibly only attain a thickness of 420 feet in the Eastnor district and attributes this decrease to at least some thinning of these beds southwards. It is estimated that the pink grit lies between 200-300 feet beneath the top of this series, which is in agreement with Groom's estimate.

Occurrences. Besides those already stated, the beds occur at:

1. Ankerdine Hill (32/736564)

Fragments of Cowleigh Park Beds can be found all over the hill, but only a few exposures can be found which may be considered to be in situ and they occur on Ankerdine Hill itself and in a number of cuttings on the eastern side of the

1. Groom, T.T. 1910. "Geology in the Field" p.706.
2. Phillips, J. op.cit. p.57.

Martley Road between the Sanatorium junction and St. Mary's Church.

ii. The Dingle, West Malvern. (32/765456)

Fragments of a purple speckled green conglomerate were found in the neighbourhood of the Archaean.

"Purple Caradoc" has been reported at Wind's Point, Herefordshire Beacon[1] and Wychcrest[2].

B. Wyche Beds.

These beds are much more uniform in character than the underlying Cowleigh Park Beds. In the weathered condition in which they are generally seen they consist of yellowish to pale brown-grey fine sandstones to siltstones which are frequently flaggy. The hand specimens show a hard closely jointed sandstone, surfaced with mica flakes. Individual grains of the rock cannot be distinguished, but acid shows it to contain a small amount of lime. The close jointing tends to split the rock up into small rhombohedrons rarely exceeding two inches across, thus making exposures hard to investigate. Some hand specimens show fine current bedding.

In thin section the rock can be described as a fine grained (silt size) siltstone containing quartz with a little felspar and muscovite mica. Included within this matrix can be found small fragments of a dark rock.

Towards the top of this division the rock becomes hard, more calcareous and micaceous. It is still finely jointed and shows a sedimentary rhythm of closely set (½ mm. apart) lightish bands against

1. Groom, T.T. Q.J.G.S. Vol.LVI. p.145-146.
2. ibid.

the dull grey background of the fine siltstone. These jointed calcareous siltstones are interbedded with yellow to orange-brown shales and sandy shales which on weathering create a sticky orange clay soil which characterises this part of the wyche beds.

The lithology suggests that more settled conditions of sedimentation existed by this time compared with the turbulent waters that deposited the coarse Cowleigh Park Beds.

Thickness. Phillips[1] and Groom[2] estimate the beds to have a thickness of about 500 feet. The present author estimates the total thickness of Wyche Beds and Woolhope Shale to be between 600 and 900 feet, but as the junction between the uppermost members of this Llandovery series is indistinct the thickness attributed to the Wyche Beds is uncertain. Symonds and Lambert[3] give a thickness of nearly 300 feet for the Shales, but elsewhere this figure appears too large and in the opinion of the present writer 50-100 feet and even less is more likely to be the true thickness.

Occurrences. This series is nowhere really well exposed, but a few of the outcrops investigated will be listed.

i. Hay Wood, Collins Green (32/737573)

Only fragments of Wyche Beds could be found, particularly in the northern part of the Wood where relatively thin bands of fossiliferous sandstone were found and rhythmic banded calcareous siltstone, the latter typical of the Upper Wyche Beds.

1. Phillips, J. op.cit. p.61.
2. Groom, T.T. 1910. "Geology in the Field" p.706.
3. Symonds and Lambert, 1861. Q.J.G.S. Vol. XVIII p.152.

ii. Storridge Anticline.

Scattered fragments are found in Ravenshill Wood and along the lanes of Alfrick, but the best exposures are to be found in the neighbourhood of Leigh Brook (32/749516). Old Storridge Common (32/748612) and Coneygore Coppice (32/744511). These show thin bedded, yellow to grey micaceous sandstones, all with very closely set joint planes.

Further to the south small sections of Wyche beds may be observed in stream sections of Birchwood Common (32/747500) and Doddenham Grove by the Worcester-Hereford Road. 10 foot sections in the latter show typical Wyche beds.

Still further south in the Malvern district exposures are even rarer and their presence is only shown by surface fragments and a belt of yellowish-grey clayey ground parallel to the pre-Cambrian rocks.

A. Woolhope Shales.

These correspond in position with the Tarannon Shales of other districts and have also been referred to as the Lower Wenlock Shales. They are of no great thickness and are rarely exposed but their presence may be inferred from small depressed features separating the Llandovery Sandstones from the Woolhope Limestones. They are green calcareous shales interstratified with a purple or lavender coloured variety, both with thin bands of nodular and flaggy impure limestones. They are best considered as passage beds between the overlying Woolhope Limestone and the older Wyche beds.

Occurrences.

The Woolhope Shales occur wherever the Woolhope Limestone and Wyche Beds are seen. The best exposures are:-

i. Knightwick Station (32/736551)

The railway cutting west of the station shows nearly vertical lavender coloured shales interbedded with thin bands of limestone. The shale is particularly abundant with the brachiopod *Fardinia*.

ii. Alfrick (32/743524

In the banks of the lanes between Alfrick and Alfrick Pound there are excellent exposures of the shales, which are generally olive green with thin limestone bands.

iii. Hill Farm, Storridge (32/756483).

Woolhope Shales are well exposed immediately to the west of Hill Farm. They are of similar type to those described in (ii).

Correlation.

The Llandovery series exposed in this district represents the Upper Llandovery of the type section in central mid Wales.

Paleontology.

All of the fauna collected, except for a *Lingula* belonged to the Wyche Beds and Woolhope Shales. The crinoid *Petalocrinus* which is found in the May Hill district has not been found.

Brachiopoda

Pentamerus cf. oblongus (Sow.)
Camarotoechia cf. borealis (Schlotheim).
Atrypa recticularis (Linn.)
Stricklandinia cf. lirarata
Fardinia sp.
Leptaena sp.
Chonetes sp.
Chonetoidea greyi (Dav.)
Lingula cf. attenuata (Sow.)
Bilobites biloba (Linn.)
Carlospira hemispherica (Sow.)
Parmorthis cf. elegantula.

Others

Petraea
Favosites
Tentaculites anglicus (Salt.)
Crinoid ossicles.

WOOLHOPE LIMESTONE.

This limestone series consists of impersistent bands of nodular and flaggy limestone interbedded with calcareous shales. A fresh unweathered surface of the limestone shows it to have a very fine texture and a blue-grey colour with a considerable amount of ferruginous staining along fractures which is characteristic of the Woolhope Limestone. Chemical tests show that a large amount of argillaceous material is present within the limestone. Joints are common and some of them are often lined by pink-coloured calcite. The shales are grey in colour and contain numerous fossil fragments.

Thickness.

The boundaries of the limestone are indistinct, as they gradually become more shaley upwards into the Wenlock Shale and appear to do the same downwards into the Woolhope Shale, thus in the majority of places estimates have to be made from the topographical feature which the limestone forms. At Alfrick, however, the limestone's thickness was measured from the exposures shown in the banks of the lane (32/739529) and was found to be about 70 feet. This seems to be thicker than that usually found, as 1½ miles to the south of this section, another measurement was made using a resitivity traverse and the thickness was calculated to be only about 50 feet. Both Phillips[1] and Groom[2] have recognised a much thicker development up to 150 feet, but the present writer has not found evidence of this. The thickness calculated from the map shows the limestone to be between 40 and 70 feet with 50 feet as a common figure.

1. op.cit. p.69. 2. op.cit. p.708.

Occurrences.

The Woolhope Limestone occurs along the whole western flank of Storridge and Malvern Anticlines and along the eastern flank in the north portion of Storridge Anticline. It is generally mapped as a steepening of the slope formed by the underlying Llandovery Series. The best exposures of the limestone are given below:

a. Alfrick District.

In the lanes between Alfrick and Alfrick Pound the limestone is well exposed and forms the eastern and western flanks of Storridge Anticline. Sections are seen 500 yards S.E. of Crew's Hill (32/739529) and by Mousehole Bridge (32/739516).

b. Malling Wood, Storridge Common (32/745497).

The stream through Mallins Wood shows a partial section through the upper part of the limestone series and demonstrates that the lime stone may be massive in some places forming beds up to 18 inches thick. These beds are not persistent over great distances and break up into thinner nodular bands.

c. Storridge (32/752486)

In this neighbourhood the limestone is exposed in the banks of the Worcester-Hereford Road and in the old quarries immediately to the north of this road.

d. West and North Malvern.

Phillips'[1] describes a section through the Llandovery and Woolhope series beneath the Worcestershire Beacon, but unfortunately this land has been built on and overgrown and only portions of it

1. Phillips, J. 1848. Mem.Geol.Survey p.73.

remain. The limestone is shown in a few old pits and a road cutting in West Malvern (32/762462).

e. Linden Manor Hotel (32/764426)

Numerous small pits show Woolhope Limestone and the underlying Woolhope Shales.

Palaeontology.

Brachiopoda

Leptaena rhomboidalis (Wilckens).
Bilobites biloba (Linnaeus).
Strophonella euglypha (Dalman.)
Pentamerus cf.geleatus
Chonetes striatellus (Dalman.)
Plectambonites cf. transversalis (Dalman.)
Atrypa cf. recticularis (Linnaeus).
Lingula cf. Dymondsi (Salter).

Anthozoa

Halysites cf. catenularis (Linnaeus).

Mollusca

Dawsonoceras annulatum (Sowerby).

WENLOCK SHALE.

The Wenlock Shale is a series of interbedded shales and a small number of thin bands of limestone and nodular shale.

The shale is almost entirely grey-green in colour, thin bedded and consistent throughout its vertical and horizontal extent. Approximate chemical and size analyses of the shale shows it to contain up to 20% of lime and 40% of silt grade material (0.01 - 0.1 mm. size particles), the remainder being made up of clay material.

The limestone bands are thin, impersistent, nodular, impure with argillaceous material, dark blue grey in colour on a fresh surface, fine grained and unfossiliferous. There is little evidence to show where limestone bands predominate. Murchison[1] claims they are greater in number at the top of the series, whilst Phillips[2] says they are concentrated at the bottom. What little evidence the writer has found, tends to show that limestone bands appear to be more frequent in the bottom of the formation.

Thickness.

No complete section through the Wenlock Shale exists, but estimates of thicknesses of the Shale from the mapped contacts it makes with the Wenlock and Woolhope Limestones show it to be:

575 feet at High Wood, Cowleigh Park (32/7547) SOUTH

575 feet at Whiteman's Hill, Storridge (32/7548)

640 feet at Halesend Wood, Storridge (32/7548)

765 feet at Longley Green (32/7350)

800 feet at Alfrick (32/7352)

820 feet at Crew's Hill, Alfrick (32/7353) NORTH

1. Murchison, 1839. The Silurian System.
2. Phillips, J. 1848. Mem.Geol.Survey p.76.

Further to the south the thickness is much less, e.g. immediately south of the Linden Manor Hotel, Colwall, the thickness is less than 300 feet, but this may be attributed to tectonic thinning or squeezing due to the close proximity of the Malvern Hills.

Considering the thicknesses above, it is immediately seen that the beds apparently thicken northwards at an average rate of 66 feet per mile. Incompetency may be responsible for this thickening but this seems unlikely since the intensity of the folding seems no greater in the south than in the north. For further consideration of this point see page 30 where the thickness variations of the Wenlock Limestone are considered.

Occurrences.

Exposures are few, but the shale's presence is inferred by the low lying ground between the Wenlock and Woolhope Limestones The best exposures of this series are listed below:

a. Martley District.

The Wenlock Shale forms a roughly triangular mass bounded on three sides by faults. It forms moderately flattish land except for the western side where it is part of the steep bank of the River Teme. Small tributaries of this river have incised deep valleys perpendicular to the Teme.

Some of the best exposures of Wenlock Shale are to be found in the road cuttings between Martley and Ham Bridge. Here the rocks are seen as a steeply dipping series of greenish-grey shales containing a few bands of calcareous nodules. Pink calcite veins are common and there is some iron staining. A prominent band of limestone nodules can be traced in Kingswood Common and Tee Bank Coppice. Much of the succession exposed in Kingswood Common had to be ignored since it has slumped down the banks of the River Teme and it is uncertain how much of it is actually in situo.

b. Tinkers Coppice District (32/742577).

A small area of Wenlock Shale is found in Tinkers Coppice. Three main outcrops can be seen, but plenty of fragments are also available.

i) A small exposure N.W. of the Limestone quarry in the banks of a track. This reveals buff and light green calcareous shales.

ii) N.E. of the Limestone quarry beside the road an old disused pit shows Wenlock Limestone dipping $40^{o}/073^{o}$. In the 10 feet of exposed rock the limestone grades downwards into a flaggy buff calcareous shale. A few feet from this pit is another small pit representing a lower horizon which contains uniform grey-green calcareous shales.

iii) This exposure shows irregularly N.W. dipping dark green calcareous shales with occasional bands of dark grey impure limestone 910 yards N. 5^{o} W. of Nipple Well.

c. Ravenshill Green (32/736547)

The presence of Wenlock Shale is inferred in this district by the fragments of shale found, the low lying ground and the underlying Woolhope Limestone.

d. Alfrick and Storridge.

Several exposures are to be seen along the eastern and western flanks of Storridge Anticline. The lower part of the series is exposed at the roadside by Mousehole Bridge where the dip is 20°/260°. Other good sections can be seen in the small stream that flows southwards into Leigh Brook at Mousehole Bridge. The stream section just mentioned shows persistent bands of white, grey and sometimes green and purple speckled clays. These clay bands vary in thickness from ½ to 3 inches and are irregularly spaced in the shale. Tests show these clays to have absorptive properties and are therefore associated with the bentonitic clay bands described later (see page 38). In the lanes leading from Alfrick Pound to Alfrick there are some excellent exposures of the shale showing it to be of the usual type.

Further to the south by Storridge Farm there are some strike sections of the shale in the lane cuttings. These exposures also contain the white clay bands mentioned above.

On the eastern flanks of Storridge Anticline, Wenlock Shales are exposed in the stream section immediately north of New Inn.

Exposures are rare further south from here, with only small exposures in stream and roadside cuttings. An excellent description of the Shale was made, however, when the new Malvern-Colwall railway tunnel was dug[1].

1. Robertson, T. 1926. Geol.Surv. Summary of Progress for 1925. p.162-173.

Palaeontology

Anthozoa

Cyathophyllum sp.
Favosites gotlandicus (Lam).
Heliolites sp.

Brachiopoda

Lingula sp.
Orbiculoidea sp.
Camarotoechia cf. borealis (Schlotheim).
Atrypa recticularis (Linnaeus)
Atrypa imbricata (Sowerby).
Leptaena rhomboidalis (Wilckens).
Strophonella euglypha (Dalman.) For variations in this species see Appendix.
Bilobites biloba (Linn.)
Eospirifer radiatus (Sowerby).
Parmorthis elegantula (Dalman.)
Gypidula sp.
Plectodonta transversalis (Dalman.)
Plectodonta sp.
Orthis antiquata (Sowerby)
Cyrtia exporrecta (Wahlenberg).
Chonetes lepisma (Sow.)
Craniops implicata (Sow.)
Sowerbyella cf. quinquecosta.
Skenidiodes sp.
Meristina sp.

Trilobita

Dalmanites vulgaris (Brunnich)
Proetid type.
Acidaspid sp.

Mollusca

Euomphalus sp.
Orthoceras sp.
Dawsonoceras cf. annulatum (Sowerby)

Various

Bryozoa
Serpulites sp.

WENLOCK LIMESTONE.

This formation consists of rubbley blue-grey limestone in the form of irregular beds and nodules with interbedded grey calcareous shales. In many cases what appears to be a massive limestone is found to be made up of tightly compressed nodules separated by thin and impersistent shale partings. Where fully developed, the limestone consists of two or more limestone stages alternating with shales, but in areas of intense folding, such as in the north by Martley, the shale bands become attenuated or perhaps squeezed out altogether. In these intensely folded districts the bedding planes are often encrusted with calcite, and generally show slickensiding.

Examination of the limestone shows it to be principally accretionary with a small percentage of its bulk made up of clastic deposits. These beds are composed of entire brachiopod shells, crinoid ossicles and other animal debris embedded in a lime mud. The fragments are unsorted and show no general orientation by water currents, also they are not heaped up into lenses or mounds to form bioherms. Separating these biochemical limestone bands are thin, but occasionally thick layers of finely bedded clastic material composed of shale, silt and sometimes sand and oolites. An alternation of calcium carbonate and silt has been recognised as a microscopic rhythm in some parts of the formation (see page 219). The limestone is very often dolomitic.

Opposite the northern end of the Malvern Hills, oolitic limestones are quite common. Examined in thin section the centres of the ooliths appeared to be composed of shell fragments and in some rare cases small crinoid ossicles. One specimen of this limestone contains ooliths up to ¼" in diameter and therefore would be classed as a pisolite.

In the neighbourhood of Mathon Park (32/762450) the formation appears to be considerably thinner than that found to the north and south. Immediately to the south of Mathon Park where the limestone is still thinner than normal, lenses of sand were found interbedded with the limestone. These beds are up to 2 feet thick and are considered as lenses since they cannot be traced from one exposure to the next among the excellently exposed strike quarries. The sand is soft, white to yellow, well sorted, medium grained, unfossiliferous and not very well cemented.

The Wenlock Limestone must represent a fairly shallow sea deposit influenced by sea currents and even perhaps seasonal variations (see page 221). The localised thinning and associated clastic deposit mentioned above, suggests more vigorous water movement indicative of perhaps a current channel or river estuary.

In Whitmans Hill Quarry (32/748483) small quantities of oil were found in limestone nodules. In this quarry the beds are almost horizontal with occasional "rolls." The particular "oil-bearing" limestone in question lies beneath about 15 feet of shale in the east face of the quarry. There is no oil visible until the limestone nodules are broken open and in some nodules as much as a thimble full of liquid oil could be found. In general, the oil coated cracks in the nodules and occasionally infilled cavities. A specimen of Favosites found in one of the nodules was partially infilled with a bitumen type material.

The presence of bands of persistent clay between 1 and 3 inches thick was noted at various horizons within the formation. These bands are usually white, although they are sometimes light green with purple mottling and weather yellow-brown. A.J. Butler[1] has shown that similar clays in the Walsall district are probably formed from fine volcanic ash.

Thickness.

No complete section through the Wenlock Limestone exists, but estimates of the thickness of the limestone from the mapped contacts it makes with the Wenlock and Ludlow Shale show it to be:

North.

120 feet at Penny Hill, Martley (32/752613)

250 feet south of Crew's Hill, Alfrick (32/733525)

255 feet north of Upper Tundridge, Longly Green (32/733513)

290 feet at Upper Mosewick, Longley Green (32/737506)

380 feet at Halesend Wood, Storridge (32/740495)

400 feet at Six Acre Wood, Whitman's Hill (32/750480)

500 feet at Bank Farm, West Malvern (32/755468)

540 feet at Croft Farm, West Malvern (32/757462)

350 feet at Upper House Farm, West Malvern (32/759459)

1. Butler, A.J. 1937. Geol.Mag. Vol. LXXIV.

300 feet at Mathon Park, West Malvern (32/761453)

400 feet at Park Wood, West Malvern (32/763443)

390 feet at The Quarry, Colwall (32/762433)

350 feet at Hanway Coppice, Evendine (32/862419)

480 feet at Hawkelts Coppice, Evendine (32/762410)

530 feet at Evendine Court, Evendine (32/761411)

South.

Further to the south the beds appear to be much thinner and are no doubt tectonically squeezed by the thrusting of the Hereford Beacon.

Examination of the figures given above shows that the limestone thickens southwards from 250 feet to a maximum of 540 feet at Croft Farm, which is a thickening of 74 feet per mile. South of this the formation rapidly thins by 190 feet in 350 feet and gradually thickens again to 530 feet at Evendine. The extraordinarily low thickness for Penny Hill in the north is possibly due to the elimination of much of the shale by intense tectonic forces.

This variation within the limestone must be considered with the variation of the Wenlock Shale described on page 23 . Summarising, the Wenlock Shale thins southwards at a rate of 66 feet per mile, whilst the Wenlock Limestone thickens in the same direction at a rate of 74 feet per mile.

Mapping and Occurrences.

In its normal condition the limestone formed a well defined ridge between valleys of the Wenlock and Ludlow Shales. Superimposed on the dip slope of the ridge were one or more other ridges representing other limestone developments within the formation. In general the ridges were well wooded and contained numerous old quarry workings. Occurrences are too numerous to describe as this limestone represents the best exposed formation in the district mapped.

Penny Hill Quarry, Martley is now being used and shows just over 100 feet of inverted limestone. A diagram of this Wenlock Limestone section is shown on page 226 and is typical of the numerous other old workings. Whitman's Hill Quarry is also working, but the sections through the limestone are limited in thickness since the beds dip at only about 10°.

Correlation.

Butler describes the Wenlock succession at Wren's Nest, Dudley, as having two main limestone bands separated by nodular beds with passage beds above and below the limestone bands with a total thickness of 197 feet for the formation. The recognition of two or more limestone horizons within this series of the Malvern district shows that it has a broad resemblance to that in North Worcestershire, but that of Malvern has a thicker development.

1. Butler, A.J. 1939. Q.J.G.S. Vol. XCV p.37.

Paleontology.

Anthozoa

Heliolites cf. megastoma (M'Coy)
Favosites cf. gotlandicus.(Linnaeus).
Halysites sp.
Syringopora sp.
Omphyma (?) sp.

Brachiopoda

Gypidula cf. galeata (Dalman.)
Athyris sp.
Camarotoechia sp.
Wilsonia wilsoni (Sowerby).
Leptaena rhomboidalis (Wilckens).
Strophonella euglypha (Dalman.)
Atrypa recticularis (Linnaeus).
Spirifer sp.

Trilobita

Dalmanites vulgaris (Brunnick).
Calymene sp.

Various

Stromatopora cf. typica
Monograptus sp.
Crinoid ossicles (very abundant).
Small branching and encrusting Bryozoa.
Bellerophon sp.

LOWER LUDLOW.

The Lower Ludlow consists, in the lower part, of thin bedded dark grey shales with nodules and bands of argillaceous limestone. The middle portion of dark grey shales and shaley nodules,and the upper beds become more flaggy with the gradual increase of silty material. The shales weather to a buff or light brown colour, very often parting around lumps in an "onion-skin" fashion. Very thin laminae of light grey silty clay often occur near the top. The calcium carbonate content of the shales varies almost rhythmically, soft grey shales and mudstones being found to alternate with calcareous, sometimes nodular mudstones. These zones of increased calcium carbonate content appeared to correspond with resitivity "highs" in the top of the Lower Ludlow exposed in Woodbury Quarry (see page 215).

Thickness.

Although the total thickness cannot be estimated very accurately it certainly exceeds the 500 feet characteristic of these beds in South Staffordshire, and probably approaches about 800 feet, the thickness of the Lower Ludlow stage in the type area.

Measurements calculated from field map:-

Penny Hill, Martley (32/752613)	650-850 feet.
Crew's Hill, Alfrick (32/733525)	800 feet. approx.
Upper Tundridge, Longley Green (32/733513)	700 feet.
Upper Mosewick, Longley Green (32/737506)	700 feet.
Halesend Wood, Storridge (32/740495)	700 feet.
Colwall (32/762420)	600 feet.

Evendine (32/762414) 700 feet.

It must be remembered that in all these localities the shale and neighbouring formations are intensely folded which would tend to attenuate the shaley formations. Thus, although 700 feet is a common figure in the list above, the true thickness is probably a little greater.

Occurrences.

Exposures are too plentiful to enumerate, but the chief occurrences are listed below:

1) Road section by Barrellhill Farm where 300 feet of shale are exposed (32/744641)

2) Woodbury Quarry showing the uppermost 160 feet of the shale (32/743636)

3) Lower Ludlow Shales are seen above the Wenlock Limestone in the quarry west of Wallhouse Plantation (32/750638)

4) 250 yards south of Fetterlocks Farm, 60 feet of mudstones are exposed in a stream cutting (32/752630)

5) South of Crew's Hill, Alfrick, the lanes show incomplete sections through the basal portions of the Lower Ludlow (32/732522).

6) Along a footpath leading off the Aymestry Limestone ridge by Upper Tundridge Farm there is an incomplete section through the upper part of the shale (32/731513).

7) Various small exposures in the roads and lanes of Longley Green.

8) There are some good sections through parts of the middle

beds by Old Vinesend, Cradley, but it is uncertain how much of this is faulted (32/743478).

9) Numerous small exposures occur in High Grove Wood, Rowburrow Wood and a stream by Mathon.

10) North of Evendine good exposures of the upper silty part of the shale are seen in the banks of a lane.

Palaeontology.

Brachiopoda

Chonetes sp.
Leptostrophia cf. filosa (Sowerby)
Strophonella euglypha (Dalman.)
Wilsonia wilsoni (Sowerby).
Leptaena rhomboidalis (Wilckens).
Orbiculoidea cf. rugata.
Orthis sp.
Atrypa recticularis (Linnaeus).
Gypidula galeata (Dalman.)
Dalmanella elegans.
Dalmanella sp.
Lingula cf. symondsii (Sowerby).
Craniops implicata.
Delthyris crispa (Hisinger).
Meristina tumida (Dalman.)

Trilobita

Dalmanites vulgaris (Brunnick).
Acidaspis sp.

Ostracoda

Beyrichia maccoyana

Mollusca

Orthoceras ibex (Sowerby)
Orthoceras filosum (Sowerby)
? Gomphoceras sp.
Murchisonia sp.
Euomphalus sp.
Platyschisma helicites (Sowerby)
Cardiola striata
? Goniophora
Poleumita globosa
Modioliform.

Bryozoa

Ceramopora sp.
Fenestella sp.
Other small encrusting forms.

Anthozoa

Cyathophyllum cf. pseudoceratites.

Others

Tentaculites
Monograptus cf. Leintwardinensis
Crinoid ossicles.
? Cornulites.

Very often certain species are so predominant that they exclude all other fauna. Careful study of the Lower Ludlow exposure in Woodbury Quarry shows that the following form bands:

Cyathophyllum

Gypidual

Leptostrophia

Wilsonia

Other species show a predominance over a wide zone, but include other forms, Strophonella euglypha is a type like this.

AYMESTRY LIMESTONE.

This formation consists of a series of limestones inter-bedded with calcareous shales. The beds forming the lowest 10 feet consist of blue-grey calcareous, muddy, flaggy siltstones weathering first to an olive-green colour and finally to a brown. As the beds are traced upwards the grain size of the detrital fraction diminishes and the calcium carbonate content increases. They become blue-grey argillaceous limestones which readily weather to an olive green colour. Polished surfaces show the limestone to be almost devoid of lamination and structural features. Calcareous organic fragments are scattered indiscriminately throughout the matrix. In the higher horizons pyrites is common and small flakes of biotite are developed on bedding planes. Nodular concretions are common and in the highest beds these tend to be segregated into slabs.

Observations in the Woodbury district show that at the base of the Aymestry Limestone and 20 feet above it, two persistent clay bands occur. Elsewhere clay bands are present, but their position with respect to the limeston's base is uncertain. These clays consist of light green and orange mottled plastic clays attaining thicknesses of 2 feet. Thin plates of pink calcite are sometimes formed within the clay. Other clays, only much thinner, are to be seen below the Aymestry Limestone in the uppermost Lower Ludlow series.

These clays have at times been described as bentonites, which they resemble and their occurrence has been used as evidence for intermittent activity of a distant volcanic centre during Salopian times[1]. Similar clays have been found in every other Silurian formation except the Llandovery and Upper Ludlow Series.

Tests carried out on a sample of clay from Woodbury Quarry showed it to have strong absorptive properties. A recent X-ray analysis of a similar clay from a quarry in the Aymestry Limestone from Shavers End, Abberley Hill, immediately to the north of the area here described, proved the clay to belong to the illite group of clay minerals.

Thickness.

The exact limits of the Aymestry Limestone were difficult to decide since the limestone grades from a shale to an argillaceous limestone at its base, to a calcareous shale and siltstone above. As might be expected the limestone formed marked changes in topographical slope as the quantity of shale increased, and these were taken as the limeston's boundaries. Measurements made in Woodbury Quarry show the limestone to be about 75 feet, but further south at Halesend Quarry (32/738487) the limestone, although still between 60-75 feet as defined by the change in topographical slope, appears to have fewer limestone bands and is, in general, less calcareous than its counterpart at Woodbury. Phillips[2] in his memoir ascribes the Aymestry Limestone group as having 75 feet at Halesend Quarry, but only 22 feet of this is thought to be true "Aymestry Rock".

In the Ledbury district Phillips recognises a thickness of 100 feet at Dog Hill Turnpike[3] whilst Piper[4] considers it might be

1. Butler, A.J. 1937. Geol.Mag. Vol. LXXIV.
2. Phillips, J. 1848. Mem.Geol.Surv. p, 94 & 98.
3. op.cit. p.97.
4. Pipr, G.H. 1893. Trans.Woolhope Club.

as much as 236 feet in this district.

Descriptions of Aymestry Limestone quarry sections are given with those of the Upper Ludlow series in the preceeding chapter, p.45

Occurrences.

The Aymestry Limestone is seen along the whole length of Woodbury, Storridge and Malvern Anticlines. It forms a prominent ridge along the western margin of all these structures and provided an excellent mapable feature. An additional series of outcrops are produced by the faulted limb of Woodbury Anticline to form the Aymestry "eastcrop". Repetition of the Limestone is also found in the Mathon district.

The main outcrops from which information concerning the Aymestry Limestone was gained are outlined below:-

1) Walsgrove Quarry where the beds are practically vertical and show the uppermost portion of the limestone and two well developed clay bands.

2) Barrellhill Farm Quarry (32/742640) shows beds belonging to the top of the Aymestry Limestone and the overlying Dayia Shales.

3) Woodbury Quarry (32/743636) shows a complete section of the inverted limestone.

4) Hillend, Martley (32/747609) 20 feet of vertical limestone.

5) Easthope Farm Quarry (32/744648), 30 feet of the basal portion of the limestone and upper part of the Lower Ludlow Shales, which are credited to be part of an overthrust mass.

6) 400 yards S.E. of the Talbot Hotel on the Worcester-Bromyard road (32/737557), there is a quarry showing inverted Aymestry and Upper Ludlow.

7) Hangman's Bank Coppice, Knightwick (32/733544) shows a 30 foot section through the upper part of the limestone which at this point is extremely contorted and variable in dip.

8) Longley Green (32/732504) district has two disused quarries, one of which, on the main road, shows an almost complete section through the limestone.

9) Halesend Quarry (32/738488). This is described in the next chapter.

10) 730 yards N.E. of Cradley Church there is an old quarry (32/740476) showing 60-80 feet of Aymestry Limestone and uppermost Lower Ludlow. At least three white bentonitic clay bands could be identified.

11) Hill Wood, Cradley (32/741467) has a stream section with a 20 foot section through the limestone.

12) The stream section beside the road leading from West Malvern to Mathon shows an incomplete section through the Upper Ludlow, Aymestry and Lower Ludlow (32/749454).

13) To the east of the exposure just described is an operating quarry in the lower part of the Aymestry Limestone (32/752456).

14) A small disused quarry at Evendine (32/756413) shows sections in the limestone.

15) Chance's Pit contains numerous small quarries along the strike of the upper parts of the limestone (32/750402).

Correlation.

The principal difference between this limestone and that found in the type area is the absence of Conchidium knighti which appears in the Ludlow district within the limestone in such great numbers. Groom[1], however, in his faunal list did record the presence of this fossil, but up to present it has not been found in this district by the writer.

Consideration of the variation of thickness of the Aymestry Limestone with other districts would not be very profitable since the author's limits are quite arbitrary and not based on fauna. Even so, the Limestone of Ludlow and Wenlock has a comparable thickness of 100 feet which is in agreement with those of this district. A marked difference, however, is seen between this area and South Staffordshire where the limestone only attains a thickness of 25 feet, and May Hill, Gloucestershire, where the limestone is practically non-existent.

The evidence of variations of thickness within the area described shows it to thin slightly southwards and rapidly thickens westwards. This data taken in conjunction with that outlined for neighbouring districts suggests that the isopachyte lines for the limestone would trend approximately N.N.E.- S.S.W.

1. Groom, T.T. 1910 "Geology in the Field" p.712.

Paleontology.

Anthozoa

Cyathophyllum cf. pseudoceratites.
Favosites sp.
Petraia sp.

Brachiopoda

Lingula sp.
Orbiculoidea rugata (Sowerby)
Dalmanella lunata (Sowerby)
Atrypa recticularis (Linnaeus)
Strophonella euglypha (Hisinger).
Leptaena rhomboidalis (Wilckens)
Wilsonia wilsoni (Sowerby)
Dayia navicula (Sowerby).
Camarotoechia nucula (Sowerby)
Gypidula galeata (Dalman.)

Trilobita

Dalmanites vulgaris

Ostracoda

Beyrichia sp.

Mollusca

Orthonota sp.
Pterinea sp.
Murchisonia cf. lloydi (Sowerby)
Euomphalus sp.
Orthoceras sp.
Poleumita globosa.

Others.

Small Bryozoan and Crinoid ossicles.

In general the fauna of the Aymestry Limestone resembles that of the Lower Ludlow except that a few species have ceased to exist, the chief of which are Delthyris crispa and Leptostrophia cf. filosa. Other species concentrate themselves into bands or zones, such forms are:

1) _Gypidual galeata_ 20 feet above the base of the Aymestry Limestone. This form is much larger than those found banded in the Lower Ludlow Shales.

2) _Cyathophyllum cf. pseudoceratites_ 30-40 feet above the base of the Aymestry Limestone. This species forms a prominent 2 foot coral band at 30 feet. This part of the succession most likely corresponds with the most calcareous part of the whole limestone.

UPPER LUDLOW GROUP.

Within this group are included all the beds between the top of the Aymestry Limestone and the Ludlow Bone Bed. This includes the Dayia or Mocktree Shales. It is realised that this is contrary to work carried out by the Geological Survey[1], but it was found convenient for mapping.

The change upwards from Aymestry Limestone to the Dayia shales is principally a decrease of calcareous matter, with an increase of argillaceous material. The beds change from the bedded blue limestone of the Aymestry to the nodular and flaggy blue limestone with shale partings of the Dayia beds. With the gradual decrease of lime the beds become pale blue, massive bedded mudstones, weathering olive green. Near the top the beds are silty and arenaceous, olive green in colour with purple mottled micaceous flagstones. In these flagstones, lamination occurs at certain horizons, being particularly prominent near the bone ned, where orange yellow sandy laminae are seen to grade upwards into dark olive green argillaceous layers, giving the whole a varved appearance. The group is sufficiently calcareous in all but the highest 35 feet to be quarried as a road metal. In the lower 100 feet or so, no distinctly calcareous horizons are present, but in the higher beds the more calcareous bands, easily seen in weathered exposures, occur at intervals. These minor limey bands are usually 4" to 6" thick and may reach 4 feet in places, but become thinner and more numerous in beds immediately

1. Pocock, R.W. & Whitehead, T.H. 1948. Brit.Reg.Geol. "The Welsh Borderland" p.60.

underlying the bone bed. Nodules are rare, unlike the lower members of the Ludlow.

Thickness.

Measurements in Woodbury Quarry were taken between the change in slope produced by the top of the Aymestry Limestone and the equivalent of the Ludlow Bone Bed. This showed a thickness of 175 feet, about 50 feet of this might be attributed to be Dayia Shales, although this would only be an approximation. Similar calculations at Halesend Quarry showed the Upper Ludlow Group to be just over 150 feet.

Occurrences.

Upper Ludlow beds always occur flanking the high Aymestry Limestone ridges and thus may be found along the western limbs of Woodbury, Storridge and Malvern Anticlines. Large exposures only occur in old quarries and it is from these that most of the information concerning this group was obtained.

1) Walsgrove Quarry (32/745660) shows a large bedding plane along the N.W. side of the quarry with abundant Camarotoechia nucula and Dayia navicula.

2) Woodbury Quarry (32/743635) represents one of the best exposures of Upper Ludlow that could be found. Below is a description of the whole quarry beginning at the base at the eastern end with the Lower Ludlow. The dip is $80^{\circ}/90^{\circ}$ with inverted strata.

<u>Bottom, East end.</u>

a) Grey and Khaki green soft, silty shale with nodules of argillaceous limestone and hard shale. There are laminae of silty clay, possibly thin developments of the bentonitic clay bands seen higher in the succession. Many joint planes are infilled with red clay. Towards the top there is a development of discus shaped shaley nodules. Fossils are abundant with bedding planes covered with single species. — 0-40 feet.

b) This division is much the same as the previous one, but the silt and calcium carbonate fraction increases slightly with the result that the beds are more flaggy. Limestone bands and nodules are more frequent near the top. Some of the shale weathers spheroidally, i.e., "onion-skin" fashion. The rock weathers to a buff or light brown colour. At 85 and 92 feet there are 6 inch bands of grey plastic clay weathering to a brown colour. Towards the top, the rock becomes thicker bedded with thin bands of shale and lenses of shelly sandy material. The fauna of this division is very much the same as the previous one with a large number of <u>Dalmanites</u> and <u>Gypidula</u>. — 40-100 feet.

c) Grey-brown, tinted green argillaceous siltstone. Very flaggy with thin shale bands and nodules. There is a definite increase of lime in the form of thin bands and nodules. The rock is well jointed and crumbles very easily, and contains small $\frac{1}{4}$" beads of soft orange sand. White clay bands occur at 100, 108 and 116 feet. The fauna is very similar to the previous divisions except that there is an increase in the frequency of occurrence of Corals, Atrypa and Wilsoni. — 100-160 feet

d) This division starts with a 2 foot band of soapy green-grey to orange clay. The rock has now progressed up from a flaggy muddy calcareous siltstone of the previous division to an impure blue finely crustalline limestone represented in this section. The impurities are principally mud and silt. The rock is massive, well jointed and interbedded with thin $\frac{1}{2}$" - 1" beds of black shale. Pyrites is sometimes found along bedding surfaces. There are bedding planes covered with Cyathophyllum near the base of this division. Camarotoechia nucula and Dayia navicula are abundant near the top - Aymestry Limestone. — 160-240 feet

e) This division is very similar to the previous one, except that the limestone contains a lot more mud and shale bands. The rock is not so hard and crumbles very easily on weathering to a calcareous shaley dust. Dayia navicula common - Dayia Shales. 240-310 feet.

f) The rock gradually becomes more flaggy, less blue and more brown in colour. This is caused by the decrease in lime content and increase of silt. Limestone bands still occur near the base, where they are dove blue-grey in colour weathering to a light khaki green. Towards the top fine sand bands occur. Camarotoechia nucula and Chonetes striatellus common throughout. Serpulites Longissimus characteristic near the top - Upper Ludlow Group. 310-430 feet.

g) White to yellow fine sandstone with numerous carbonaceos inclusions and remains - Downtonian. 430 + feet.

Top.

3) A quarry 400 yds. S.E. of the Talbot Hotel, Knightwick, on the Worcester-Bromyard road (32/736558). offers a section through the upper part of the Ludlow. Phillips[1] describes the section in detail from the base of the Aymestry Limestone to the lowest Downtonian. Unfortunately, the highest Ludlow and lowest Downtonian are no longer visible. The dip of the beds is 60° towards the N.E. and is shown to be inverted, see page 286.

1. Phillips, J. 1848. Mem.Geol.Surv. p. 94 & 98.

4) Burysgate Old Quarry, Little Halesend (32/735492) shows part of the Upper Ludlow sequence.

Top, Western end

Flaggy, fine grained khaki coloured siltstone. Well jointed with numerous small shale bands. Abundant *C. striatellus* and *C. nucula*.	5 feet.
Band of nodular impure dark limestone. Nodules set in matrix of shale.	8 feet.
Well jointed shaley massive limestone. Dark grey blue in colour and finely crystalline. Large amounts of shale.	23 feet.
Thin bands of fine light brown sandstone. Stained chocolate brown in patches.	½ foot.
Flaggy silty limestone. Light brown in colour.	6 feet.

5) Halesend Quarry (32/737487) has already been described by Phillips[1] ,but the writer's brief description is given below.

Top Western End.

Fawn, often chocolate brown, fine sandstone with abundant mica - Downtonian.	3 feet
Ludlow Bone Bed composed of fragmented remains of chitinous skeletons and phosphatic nodules - *Onchus* spines.	

1. Phillips, J. 1848. Mem.Geol.Surv. p. 94 & 98.

Light brown to fawn siltstone with chocolate brown staining. Abundant lenses of Dalmanella and Chonetes striatellus. Sometimes these lenses are composed almost entirely of these two species and sometimes only one of them. — 13 feet.

Unexposed — 60 feet.

Flaggy calcareous shaley siltstones, light brown and dove grey in colour with thin shale and sand bands. Some of the bedding planes with undulated and wrinkled surfaces. Very micaceous. The beds become progressively more calcareous downwards. Chonetes striatellus, Camarotoechia nucula, Dalmanella sp., Dayia navicula, Orthonata sp. etc. — 80 feet

Nodular impure, sometimes flaggy limestone - Aymestry Limestone. — 70 feet approx.

The dip on all these beds is 50° to the west and they are the right way up.

6) Brockhill Quarry shows another good section through the Downtonian and Upper Ludlow Group. Phillips[1] has described this exposure in his work and the present writer's section is below.

Top Western End. — 0 feet.

Yellow, sometimes brown or purple , fine sandstone well bedded and almost flaggy. — 0-16 feet.

1. Phillips, J. 1848. Mem.Geol.Surv. p.97.

Micaceous and with thin, soft, sand partings between the flags. Numerous carbonaceous inclusions.	
Flaggy - lamina bedded (bedding thinning downwards) fine yellow to brown and purple sandstone. Carbonaceous inclusions.	16-22 feet.
Overgrown - presumed position of Ludlow Bone Bed.	22-35 feet.
Thin bedded marly siltstone, yellow to brown. Band of large *C. nuculae* at base.	35-39 feet.
Well bedded hard grey to yellow-brown siltstone or very fine sandstone with thin bands of soft sand. The siltstone is often current bedded and contains a sedimentary rhythm. *C. nucula* common.	39-46 feet.
Overgrown.	46-54 feet.
Similar to 39-46 feet, but this division is partially overgrown.	54-64 feet.
Well bedded brown siltstone. An unweathered surface shows the rock to be grey blue in colour.	64-84 feet.
Dark grey calcareous mudstones. Thin bedded and sometimes silty becoming more calcareous downwards. A limestone band occurs near the base.	84-100 feet.

Similar to previous division, but the beds are more shaley and less silty. 100-115 feet.

The last two divisions represent the top of the Dayia Shales.

Correlation.

The sub-division of the Upper Ludlow Beds into an upper portion with abundant Chonetes striatellus and a lower division Camarotoechia nucula common in the Ludlow district[1] seems to be of local significance, as both species are equally abundant throughout the Upper Ludlow.

The beds in which Dayia navicula is prominent are of the same thickness (50 feet) as in the Ludlow district, but much thicker than in South Staffordshire where they are included in the 25 feet of Aymestry Limestone.

The beds between the top of the Dayia beds and the Ludlow Bone Bed thin eastwards from 260-280 feet at Ludlow to 125 feet at Shelsley and 40 feet in South Staffordshire.

The deposition of the Upper Ludlow Group marks a return to more shallow water conditions, and the final silting up of the old Palaeozoic geosyncline with the introduction of more sandy material into this area.

Palaentology.

Generally speaking the group is characterised by the comparative scarcity of species. The following species have

1. Elles, G.L. and Slater, I.L. 1906. Q.J.G.S. Vol. LXII p.195.

been identified:

Brachiopoda

Orbiculoidea rugata (Sowerby)
Dalmanella cf. lunata (Sowerby)
Camarotoechia nucula (Sowerby)
Chonetes striatellus (Dalman.)
Wilsonia wilsoni (Sowerby)
Dayia navicula (Sowerby)
Atrypa recticularis (Linnaeus).

Mollusca

Murchisonia sp.
Orthonota sp.
Pterinea sp.
Orthoceras sp.
Euomphalus cf. carinatus (Hisinger).

Various

Serpulites longissimus (Murchison).
Various branching Bryozoans.

Lenticular masses of brachiopoda shells normally confined in content to a single species, or one valve of a particular species, are very prominent in the uppermost part of this group.

Most prominent of these "rottenstone" lens are those consisting of complete shells of Camarotoechia nucula. These reach a thickness of 2" in the centre, but do not normally have a large lateral extent. Occasionally lenses of Chonetes striatellus show a parallelism of their hinge lines which presumably come to lie perpendicular to the direction of the prevalent current.

The lenses represent shell banks formed by current sorting and winnowing away of the finer detritus, the composition of any particular shell bank being determined by the specific gravity and shape of the brachiopod valve.

DOWNTONIAN.

It is usual in the Welsh borderland to distinguish an upper Red Downtonian or Ledbury Group, and a lower Grey Downtonian or Temeside Group. Their thicknesses are estimated at about two thousand feet and fifty feet respectively. The grey division is sub-divided into two groups.

Grey Downtonian.

a) Downton Castle Sandstone.

In accordance with the most recent opinions expressed by workers on this subject, the base of the Devonian is drawn at the Ludlow Bone Bed. Recent literature[1,2] has discussed whether to include the Bone Bed within the Downtonian, but for the purpose of this work the matter is relatively unimportant.

The Sandstone exposures are rare in the north, but south of the R. Teme very many excellent sections are to be seen in old quarries. The Sandstone is brown, purple, yellowish, grey or white and laminated. The grains of the sandstone are fine and almost entirely composed of quartz, but mica is plentiful along bedding planes. The beds are thin, and sometimes sufficiently thick to be flaggy, very often there are thin bands of silt and silty marl interbedded with the harder sandstone.

The Downton Castle Sandstone contains few fossils, but those identified include: Thelodont scales, spines of Onchus and Pachytheca sp., for the Bone bed, other fauna found within the

1. White, E.I. 1950. Bull.Brit.Mus. (Nat.Hist.) Vol.II no.3
2. Whittard, W.F. 1952 P.G.A. Vol.63 p.176.

overlying sandstone are Platyschisma sp., Pachytheca sp., Lingula sp., and carbonaceous material probably plant remains.

b) Temeside Shales.

As these were often indistinguishable from the overlying Red Downtonian or Ledbury Group in lithology,the nature of this rock will be described below.

Red Downtonian.

This group is characterised by red and green mottled marls and siltstones with occasional red or purple micaceous sandstones and siltstones which often appear to be lenticular and impersistent[1], and at other times where siltstones appear massive they are persistent and may be mapped as a topographical ridge or ridges for considerable distances. A calcareous cement is often present netween the grains of silt. Fossils are uncommon although fish remains have been found by W. Mykura in the neighbourhood of Barrellhill Farm, Woodbury.

No attempt has been made to sub-divide the Red Downtonian into W.W. King's zones, although in certain circumstances exposures appear to have a resemblance to his described subdivisions.

Occurrence and Boundaries.

The Downtonian occurs along the whole western side of the area. It was mapped by the colour it imparts to the soil,and the relatively flat ground it forms. The Temeside Shales are not distinguishale in all places, this is particularly true in the neighbourhood of the Woodbury Anticline. The Downton Castle Sandstone is succeeded by the deep red and purple marls of the Red

1. Hollingworth, S.E. 1937. Summary of Progress. p.34.

Downtonian, this can be caused by:

i) The Red beds are prematurely developed replacing the Temeside Shales.

ii) The Temeside Shales having been strike faulted out locally.

Important exposures are listed below beginning at the northern end of the area.

1) Walsgrove Quarry (32/744660)

4'6" Massive green silty flagstones.

2 ft. Thin micaceous sandstones and olive green shales.

Thin bedded olive green shales and sandstones with cf. Modiolopsis.

6 ft. Thin Micaceous brown sandstone.

Dark Olive green shaley mudstone.

2 ft. Laminated, micaceous, orange, quartzitic fine sandstone with Lingula sp.

Ludlow Bone Bed represented as a sheath of carbonaceous material.

2) Western flanks of Woodbury Anticline.

In the various stream sections leading down into Kings Wood and Ladywood Common, exposures of mottled red and green micaceous silty marls may be found. In the stream section south of Hillside Farm (32/738643) a coarse grained sandstone is developed. It is at least 8 feet thick, false bedded and quartzitic, it has a dark matrix and contains comparatively little mica. The sandstone becomes finer and more micaceous when traced upwards, grading first into a siltstone and finally into a dark red mudstone. By calculation this bed lies about 900 feet above the Bone Bed and could possibly represent the Holgate Sandstone (I_4)[1].

At Woodbury Quarry (32/743635) the Bone Bed and Downton Castle Sandstone are badly exposed. The beds are represented, as at Walsgrove Quarry, by a carbonaceous sheath of material overlain by dark carbonaceous grits followed by grey quartzitic grits and fine laminated sandstones. Red beds occur within 40 feet of the Bone Bed.

S.W. of Rodge Hill in Pudford Dingle, several dozen feet of sediments are exposed of the usual mottled marls and siltstones of the Ledbury Group. Within this group there is a greater development of calcareous siltstone than is usually found at these horizons.

3) R. Teme Localities.

Several small exposures were found in the neighbourhood of Ham Bridge (32/737611). The two dingles north of Ham Farm and the quarry nearby show a persistent thick sandstone band with minor marl partings. The sandstone is micaceous and often current bedded, varying in colour from deep purple to grey with marl pellets at various horizons. These bands of sandstone could be traced southwards through Ham Wood, across the R. Teme and through Ox Leasow coppice along the eastern banks of the R. Teme. This sandstone is similar to that described above by Barrelhill Farm, Woodbury and is probably another exposure of the Holgate Sandstone (I_4).

1. W. King's notation.

For a quarter of a mile along the R. Teme's banks nearly two hundred feet of the Red Downtonian is to be seen in Ox Leasow Coppice (32/739585), just north of Hill Top Farm. Here the beds are of the usual type, with occasional 1 foot bands of hard green-grey impure limestone speckled purple and with sand grains. These limestone bands form hard resistent spurs which stick out into the R. Teme by Hilltop Farm. Towards the western end of the cliff small minor faults are developed with throws up to 2 to 3 feet.

4) Horsham Localities (32/735591)

In the cutting opposite Horsham House 3 feet of chocolate and grey micaceous sandstones overlie thinly bedded chocolate coloured non-micaceous marls. Some 100 yards north of this exposure on the west side of the road the sandstones pass upwards into sandy micaceous marls showing minor faulting, 80 yards north-east of this exposure another roadside cutting exposes 6 feet of grey and chocolate coloured micaceous sandstones dipping gently to the south-east. Chocolate coloured micaceous marls are also seen in the bank of a pond on the track leading from Horsham Road into Ox Leasow Coppice. The sandstones in these localities contain many small pellets of the underlying chocolate coloured marls, and are those sandstones which were traced from Ham Farm to Ox Leasow Coppice. Owing to their small dip they create a wide outcrop of hard rock which gives rise to the high ground of Hill Top.

Further south between the Knightwick Sanatorium and the R. Teme in the banks of the bridle track running beside the river (32/733567), patches of purple and light grey-green mottled micaceous and often silty marls can be found. It is difficult to decide how far these beds extend up the slope towards the Sanatorium, since a great deal of Llandovery rock has slumped down over the marls.[1]

5) Knightwick Station.

West of the station in Lord's Wood, the railway cutting exposes Red Downtonian. On the south side of the track the beds are purplish red marls with thin greenish marls. They exhibit a steep dip with minor contortions to the N.W., but this is probably false since a great deal of the marl has slumped down the bank. On the opposite side of the cutting, a few thin bands of impure limestone occur, which appear to have no counterpart on the slumped bank of the cutting.

6) Cradley District.

380 yards south of Barrow Mill, Longley Green in the banks of Cradley Brook (32/732496) is a 10 foot exposure of purple marl speckled green in places, with abundant mica. The whole section is overlain with drift material.

Halesend Quarry (32/738487) showed the basal members of the Downton Castle Sandstone including the Bone Bed. The nature of these beds is described in a section of Halesend Quarry given under the section on Upper Ludlow (see page 50).

Further south no evidence of any Red Downtonian was found except for minor outcrops in the banks of Cradley Brook since the majority of the Downtonian is covered by drift.

1. Hollingworth op.cit.

7) Mathon District.

Within this area lie a few excellent disused quarries exposing the lowest beds of the Downtonian.

i. Bag burrow Wood. (32/749454)

On the road between Stockton Coppice and Mathon Court two disused quarries show a yellow to brown thin bedded micaceous fine sandstone. These are described in Phillips' work.[1]

ii. Brockhill Quarry (32/757439)

This has been described by Phillips[2] and Stamp[3]. The section of the Downton Castle Sandstone is described below. West Dip 32°/266.

a. Yellow, sometimes brown or purple fine sandstone, well bedded sometimes almost flaggy. Micaceous with thin soft sand partings	15 feet.
b. Surface covered with carbonaceous material, most likely plant remains.	
c. As for first fifteen feet.	1 foot.
d. Flaggy to laminated fine yellow to brown occasionally purple sandstone. Beds thinning eastwards or downwards.	6 feet.
e. Similar beds to those described in the first fifteen feet. Bedding planes covered with carbonaceous material	13 feet.
f. Thin bedded marly siltstone, yellow to brown.	4 feet.

1. Phillips. op.cit. p.98
2. Phillips. op.cit. p.97.
3. Stamp. L.D. 1923. Geol.Mag. Vol.LX. p.367-370

g. Band of ferruginous Sandstone with large
Camarotoechia mucula (Sow.) 6 ins.

h. Well bedded hard grey to yellow-brown siltstone or very fine sandstone with thin bands of soft sand. Very often current bedded and rhythmically bedded.
Camarotoechia mucula. 7 feet

i. Obscured. 8 feet.

j. Thin bedded soft yellow-brown sandstone.

k. Bone bed represented as a thin sheath of carbonaceous material and rolled phosphatic pellets.

Further south drift covers all the Red Downtonian and even the Downton Castle Sandstone and by Hereford Beacon parts of the Upper Ludlow.

CARBONIFEROUS.

The only members present of this system are the Coal Measures. They occur in the area under discussion in four main districts:-

a) Kingswood and Ladywood Commons, Great Witley.

b) Woodbury Hill, Great Witley.

c) Berrow Hill, Martley.

d) New Inn, Storridge.

a) Kingswood and Ladywood Commons, Great Witley - Hillside Measures.

The beds in this locality were first described by Groom[1]. He showed them to be synclinally folded and stratigraphically equivalent to the Coal Measures of the Mamble Coalfield to the north. W. King[2] later contradicted Groom's ideas and stressed the lithological similarity of the Woodbury and Hillside Measures, concluding that they formed part of the same sequence. Although King noted several steep dips in the Kingswood district, he did not accept that they were synclinally folded. Hollingworth[3] reintroduced the synclinal theory, but this was again repudiated by Falcon[4] who in principal returned to the ideas of W. King. In 1951 W. Mykura[5] gave an account of his mapping and concluded that the Coal Measures were synclinally folded, but did not represent a conformable series as Groom had suggested.

1. Groom, T.T. 1910. Geology in the Field. p.173-6.
2. King, W. 1923. Worcestershire Field Club.
3. Hollingworth, S.E. 1936. Summary of Geological Progress p.45
4. Falcon, N.L. 1947. Geol.Mag. Vol. LXXXIV p.229-240.
5. Mykura, W. 1951. Geol.Mag. Vol. LXXXVIII p.386-392.

The general lithology of the beds consists of a calcareous basal conglomerate overlain by buff and yellow clays with several coals and ferruginous sandstones. A thick sandstone occurs near the top of these measures and Mykura has reported a Spirobis limestone in the Ellbatch Wood district to the N.W.

The basal conglomerate consists mainly of altered igneous material, mudstone and limestone. Downtonian sandstones and siltstones occur but are generally of a larger size. Although most pebbles are sub-angular, the mudstones and sandstones are frequently well rounded. The matrix is calcareous, usually blue-grey in colour and there are sometimes irregular ochre brown patches indicating the presence of ferruginous material. The conglomerate is present everywhere and is well exposed in the two stream cuttings to the north of Hillside Farm where dips are nearly vertical and the bed rests with apparent conformity upon the Downtonian. To the north in Ellbatch Wood, however, Mykura reports an angular unconformity of 30° between the Downtonian and Coal Measures which suggests that the Downtonian was locally folded prior to the Coal Measure deposition.

Following the conglomerate are varying thicknesses of grey-green grits and red and purple siltstones and marls, but in general clays soon replace these basal beds containing bands of high lustre coal. In Ladywood Common a 70° dipping 2'6" coal seam can still be found in a large pit formerly dug by the local people. The coal is well jointed, has a high lustre and appears to be of good quality.

There is a seat earth of pale grey clay and a roof of carbonaceous dark grey shale succeeded by buff clay. This coal seam can be mapped over short distances since it creates a dark streak across ploughed fields.

Groom[1] suggested that the measures forming the Kingswood syncline belong to the lowest division of the Highley or Sulphur Coal group of the Mamble and Wyre Forest Coalfield. Mykura[2], however, recognises an unconformity within the Coal Measures of Kingswood and suggests that Middle Coal Measures (Kinlet Group) might be present and form part of the beds seen. The present author's evidence, however, is inconclusive as to the age of the beds and he therefore accepts the beds as being (at least in part) Upper Coal Measures as deduced by previous authors.

b) Woodbury Hill, Great Witley.

These measures outcrop around the south-western side of Woodbury Hill and appear from the mapping to lie unconformably upon the folded Silurian rocks. Mykura[3] proved by a series of auger holes that the coal measures were more extensive and crop out farther to the east than hitherto mapped. He also showed that the measures consisted of conglomerates, grits, yellow clay and ochreous sandstone. Apart from fragments no other evidence of the measures could be found except for the remnants of two disused shallow pits.

1. Groom, T.T. 1910. Geology in the Field. p.173-6.
2. Mykura, W. 1951. Geol.Mag.Vol. LXXXVIII p.391.
3. Mykura, W. Information communicated to me verbally. See also map on page 387, Geol.Mag. Vol. LXXXVIII.

W.W. King has recorded a 2-3 foot conglomerate exposed in a trench, but gives no locality. A 6" coal which has been mined has been stated to occur near the top of the series[1]. W. W. King also stresses the lithological similarity of these beds to those found to the west, the Hillside measures.

From measurements taken from the map, it is estimated that the Coal Measures here have a thickness of 50 feet. This is not necessarily the true thickness since there is no proof that these beds are not folded (see page 102).

Murchison[2] records an exposure of Coal Measures at Walsgrove Quarry (32/744660) and states: "Grits of the Coal Measurea adhere in broken patches to the side of the elevated mass and small troughs of coal have been worked out in the depressions on the eastern side of the ridge." Coal Measures cannot be found in the quarry now and it is suggested that they have since been eroded away, or as Groom[3] suggested, been mistaken for Downtonian shale.

c) Berrow Hill, Martley.

Several small patches of Coal Measure clay appear between Kingswood Common, Martley and the southern end of Berrow Hill (32/745599, 32/745596, 32/745592, 32/743587, 32/742583). Records of workings for coal on the western flank of Berrow Hill are found in the writings of the earliest workers in this district[4]. The sites of

1. King, W.W. 1923. Worcestershire Field Club.
2. Murchison, Sir R. 1839 "Silurian System". p.421.
3. Groom, T.T. 1910. "Geology in the Field". p.724.
4. Phillips, J. 1849. Memoir Geol.Survey.

these workings are still to be seen, but are now completely overgrown by thick vegetation. Evidence of the measures, however, is still to be seen in sheep tracks and the marshy, badly drained land formed by the clays.

The clays are grey, red and yellow when fresh but quickly weather to a duller colour with a more brittle texture.

The most northerly patch (32/745599) reveals a 4 foot section in a cutting on the fenced track 300 yds. north-east of Birch Hill Coppice. The clays here appear to be horizontal and of a similar type to those already described. Recent clearing of the land to the north by Ladywood Common, Martley, has shown grey clay to exist here too.

Hollingworth[1] writes that auger holes have proved the existence of Coal Measures surrounding the Martley syenite exposure and further, the Measures occupy a strip of land 30 to 40 yards wide running to the south between the Downtonian marls and Triassic sandstone. Towards Berrow Farm the strip widens and the measures seem to be conformable with the Downtonian.

No macro-fossils have been found, but by extracting a large number of clay samples with boiling caustic soda and sieving, a few micro-fossils have been identified, they include:-

Echinoderm fragments.

Small shells, possibly the initial stages of gastropods.

The presence of Echinoids suggests open sea conditions

1. Hollingworth, S.E. 1937. Summary of Progress. Geol.Survey p. 34.

contrary to the deltaic facies associated with Coal Measure deposition. No conclusion, however, is proposed since the appendages might be derived material.

d) New Inn, Storridge.

A small patch of Coal Measures occurs at the southern end of Storridge Hill in a little stream close to the New Inn, on the road between Storridge and Worcester (32/759494). Murchison stated that coal was once worked near Old Storridge Hill[1] but Phillips did not mention them at all.

These beds consist of a light grey and yellow clay dulling on weathering. There are numerous inclusions of carbonaceous material, possibly plant remains, but the bedding of this mass could not be discerned.

The relationship of this clay with the adjoining Silurian Wenlock Shale is not clear, but the Keuper Marl appears to lie conformably upon the Measures, although no great importance is attached to this exposure since the Clay and Marl appear to have slumped down over the steep banks of the stream. There does not appear to be any breccia between the Carboniferous and Triassic deposits as might be expected from accounts of other exposures of the Boundary Fault (see page 179).

1. Murchison, Sir R. 1839. "Silurian System". p.135.

PERMO - TRIASSIC.

Within this chapter are described the following formations:-

4) Keuper Marl.

3) Keuper Sandstone.

2) Bunter Sandstone.

1) Haffield Breccia.

1) Haffield Breccia.

The breccia consists of stratified sub-angular fragments up to 18" or more in length of pre-Cambrian gneisses, and volcanic rocks; Silurian limestone (most of it resembles Wenlock), sandstones and shales; and purple and green grits and sandstones of Old Red Sandstone age all cemented in a matrix of red sand and sandy clay. The fragments are frequently stained with iron oxide and are, in general, poorly graded, although there does appear to be a tendency of gradation near the top.

The origin of this breccia and similar beds that are exposed in S. Staffordshire, has given rise to some discussion in the past. The core of the Malvernian Hills is composed of pre-Cambrian Volcanic rocks and Murchison[1] , knowing this and being aware of the close connection between the Malvern and Abberley Hills, and also the composition of the breccias, supposed the outcrops of the breccias to be evidence of a similar pre-Cambrian core in the Abberley Hills. He called the rock "Trappoid Breccia" in recognition of this. This explanation does not account for the

1. Murchison, Sir R. 1854 "Siluria".

stratification very satisfactorily and later writers attributed the breccia to glacial action, the view being also upheld by the diversity of the size of the particles.

The modern theory is to interpret the formations as a deposit laid down by swift temporary torrents off scree material that has been split off from the rocks of desert regions. It is possible that large blocks up to 18" could have travelled 15 miles from the present position of the Malvernian, but hills, now buried beneath the Triassic, much nearer the deposits, may have been the source of these breccias.

The age of the breccia is still disputed and in the absence of fossils only broad limits can be given to the formation's age. On Woodbury Hill the breccia rests on the Upper Coal Measures. The unconformity between the breccia and the Upper Coal Measures has been shown by W. W. King[1] to be represented in South Staffordshire by more than one thousand feet of sandstone, marls, etc., in some places king adds that at the top of these Staffordshire rocks is the Clent Breccia, similar in composition to that at Woodbury.

Fleet[2] carried out an investigation of the heavy minerals of the sandy matrix of the Clent Breccia and the breccias of the Abberley range. He showed the breccia of Alfrick to be different from those of Knightwick, Berrow, Woodbury and Abberley in that the Alfrick deposit was devoid of calcite, but all had an overall resemblance in mineral content to the Clent Breccia and were presumably the same age. In the present author's mind this is fallacious, as any scree deposit would contain the same suite of

1. King, W.W. 1899. Q.J.G.S. p.101.
2. Fleet, W.F. 1927. P.G.A. p.1.

minerals, provided that the screes were derived from the same sort of rocks, irrespective of time of erosion of the hills. The author suggests that screes of the same material might be formed over large time intervals.

Groom[1] states that the breccia of Osebury Rock (immediately south of R. Teme) is overlain with apparent conformity by Upper Bunter Sandstone. Groom claims that the fact that the Haffield Breccia of Knightwick shows no transition into the sandstone indicated that the breccia cannot represent the variable base of the Triassic in this area, unless this breccia represents a Triassic horizon lower than the Lower Bunter which rests unconformably upon Haffield Breccia in other localities. Careful investigation of the boundary between the breccia and the sandstone, however, reveals that there is a complete upward transition from the breccia. This is clearly seen in the road cutting opposite the two small cottages 300 yards N.E. of Knightwick Station. The normal Osebury type of Haffield Breccia (see description below) dips at 17° towards the S.E. and throughout a vertical thickness of 12 feet the matrix becomes more sandy, both the number and size of the pebbles show a steady decrease, until it passes upwards into normal Bunter Sandstone. A lenticular band of sandstone occurs near the top of the breccia. Under no circumstances can this exposure be interpreted in the light of Groom's explanation which is, therefore, rejected.

If Groom's identification of the overlying sandstone as Upper Bunter in age is correct (Groom, p.187), then the Haffield Breccia

1. Groom, T.T. 1900. Q.J.G.S. p.189.

of Osebury Rock might be partly or wholly of Bunter age. This evidence, however, is insufficient to give an exact age to the Haffield Breccia and the only conclusion that can be arrived at is that it is post-Coal Measures and pre-Keuper Sandstone.

It must be added that the breccia of Osebury Rock is somewhat different from exposures of breccia found in other localities. That of Osebury has a tougher and darker matrix than those breccias found elsewhere, although the included fragments have the same composition. Thus, conclusions arrived at for the Osebury breccia are not necessarily applicable to the breccia of other outcrops. It might be that these softer deposits represent horizons stratigraphically lower than this harder variety. An alternative view is that the Haffield Breccia may represent a diachronous facies whose age is not identical in separate areas, but whose total formation life may be comparatively large.

Occurrence.

There are eight principal exposures of Haffield Breccia within this area:

a) Woodbury Hill.

The breccia here rests unconformably on the Coal Measures. Most exposures give little indication of stratification, but the breccia in an old pit near the road junction at the north end of Woodbury Hill (32/750654) shows signs of irregular bedding. Alternate lenses of sandy material and ungraded larger fragments may be seen within this small pit.

b) Berrow Hill.

Here the breccia forms the elongated mass of Berrow Hill rising sharply above the surrounding Downtonian and Triassic beds, lying with apparent unconformity upon the Coal Measures. No large exposures were seen except for an overgrown pit S.S.W. of Berrow Hill (32/742581) which showed strata similar to that described at Woodbury Hill. Calculations from stratum contours on the mapped boundary of the breccia show that the base of this bed dips at about 20° in the direction 105°.

c) Collins Green.

Mention is made elsewhere of this exposure under "Structure" p. 122 and all that need be added is that there is no evidence for the continuity of the outcrops of breccia at Collins Green and Berrow Hill as indicated on the Old Series Map of the Geological Survey (sheet 55 S.E.) which shows a thin continuous strip of breccia between the two. A further comparison with this same map will reveal that the Collins Green outcrop, as mapped by the writer, has a considerably shorter southerly extension than is shown by the Survey. A good exposure of this patch of breccia is to be seen in the quarry within Tinkers Coppice (32/740574).

d) Knightwick Station.

The rock of this locality forms the eminence of Osebury Rocks which rise to a height of from 150-200 feet above the River Teme. This rock is tougher and darker than those found elsewhere and this is attributed the dark red haematitic matrix of the breccia which makes the rock particularly resistant to weathering. The pebbles range from a fraction of an inch to 18 inches, grading to larger sizes upwards. Thus as one traverses along the face of Osebury Rocks from N.E. to S.W. the average size of the fragments increases since this face shows progressively younger rocks in this direction.

The breccia dips at between 15° and 65° in a general direction of 135°. Estimates of the thickness of the beds are uncertain since it is impossible to tell whether the formation is faulted, but assuming no faulting, drawn sections show the breccia to be 400 to 450 feet thick.

e) Ravenhills Green.

This patch of Haffield Breccia has not been described by previous observers. It is situated 300 yards S.W. of Ravenhills Green (32/738540) lying with apparent unconformity upon Woolhope Limestone and adjacent to the Keuper Sandstone. There is very little evidence to show the nature of the dip of this patch since its area of outcrop is small.

f) The Bridges Stone Locality (32/749522)

The Haffield Breccia forms a narrow outcrop faulted between the Silurian to the west and the Triassic sandstone to the east. It it well exposed in and around Leigh Brook, but away from the stream the outcrop is masked by superficial drift deposits, so its extent cannot be stated with certainty.

The junction between the breccia and the sandstone can be seen in the road section above Knapp Farm, the breccia's dip is 65-70°

W.S.W. whereas the sandstone is dipping 10-20°E.N.E. The breccia is weathered to a yellowish colour at the junction, which suggests that the sandstone was deposited unconformably upon an eroded breccia surface, but in the light of other evidence, it is much more probable that the junction is faulted (see p.148).

Exposures at the side of the path leading from the road down to the brook show the breccia to be dipping at 35-70°W.N.W., whereas in the stream section, the dip is 80-90 E.N.E. In places, there occur bands of purplish and greenish grit with flattened pebbles, which appear to have no counterpart at Knightwick. Most significant is the presence of a small patch of sandstone which lies unconformably upon a weathered surface of breccia. At one point, the sandstone is clearly contorted, but elsewhere there appears to be no irregularities in the bedding.

g) Whippets Farm Locality.

Above Whippets Farm on the hillside there is a small irregular deposit of Haffield Breccia (32/76248). The pebbles are quite similar to those found elsewhere, but the matrix is of soft orange to deep red unconsolidated sandy material, often with a small percentage of clay.

h) North Hill.

No evidence of this patch of breccia could be found, but Phillips reported one on North Hill. It has most likely been eroded away.

2) Bunter Sandstone.

According to Groom[1] the sandstone overlying the Haffield Breccia "... agrees in every way with the Upper Soft Red Bunter sandstone of the surrounding districts of Worcestershire generally". Groom states that the absence of the Lower Mottled Bunter Sandstone and the Pebble Beds is characteristic of the whole Malvern range of hills, throughout which the Upper Bunter Sandstone appears to represent the base of the Triassic deposits. The present writer has no such extensive knowledge of the Triassic deposits of Worcestershire and is therefore unable to comment upon this similarity.

Some 300 yards N.W. of Knightwick Station in the "Gravel Pit" (32/735553) on the northern edge of Lord's Wood, there is an exposure showing 25 feet of Bunter Sandstone dipping $17^{\circ}/165^{\circ}$. The dominant bedding of the sandstone is massive, but very fine current bedding is also shown. The sandstone is bright red to orange in colour with coarse, well rounded, loosely packed grains, having a high content of weathered felspars.

Although the road cutting gives an almost continuous exposure throughout the sandstone, dips are difficult to obtain owing to the false bedding. It will be seen from the map that the overall dip is in a direction 120°.

Assuming an average dip of $20^{\circ}/120^{\circ}$ and no faulting, an approximate estimate of the thickness of this Bunter Sandstone outcrop may be given as 300 feet.

The only other occurrence of this formation is that reported by A.M. Davies in which he states having seen a face of Archaen rock

1. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.186.
2. Davies, A.M. 1947. Geol.Mag. Vol.LXXXIV. p.320.

plastered with what appeared to be Bunter Sandstone. The locality was uncertain and the exposure only temporary.

3) Keuper Sandstone.

These comprise loosely cemented mainly dull brick red sandstones, but pinkish white and dull white sandstones can also be found. It differs from the sandstone described as Bunter in that it is much duller and the grains exhibit an angularity which in no way resembles the well rounded Bunter grains. The sandstone is fine grained and current bedded. The grains are of variable composition and often contain a little mica.

As seen in a quarry the rock is generally massive bedded with beds up to 10 feet thick; other beds, especially those near the top of the formation are more flaggy and are separated by thin beds of red marl. Conglomeratic lenses containing quartz pebbles and chips of marl are present in the lower part. Certain parts of the sandstone have fissured and the fissures are infilled with sand and calcite. When weathered such fissures stand out in relief from the normal sandstone which has a predominantly ferruginous cement. Honeycomb weathering has been produced where sets of these fissures intersect.

A white, fine grained false bedded sandstone occurs towards the top of the sandstone and has been extremely useful in tracing the boundary between the sandstone and the overlying Keuper Marl. Phillips[1] also recognised this horizon in his "Newent Sandstone and Conglomerate" where he estimates it to be about 10-20 feet thick.

1. Phillips, J. 1848. Memoir Geol.Survey. p.114 & 116.

Towards the bottom a breccia occurs which is composed of angular fragments of sandstone and other rocks set in a matrix of soft red sandstone. This is often referred to as the Keuper Breccia.

Occurrence and Details of Exposures.

a) Great Witley District.

Keuper Sandstone is found to the N.W. of a line joining Woodbury Hill and Redmarley and bounded on the west by the older rocks. Further exposures lie in the east around Witley Court.

Beds exposed in the road cutting 300 yards west of the Hundred House (32/747662) and in a small pit 150 yards east of the road cutting (32/749662) show a dark red, fine grained current bedded massive sandstone. Small fragments of a similar type were found just north of Walsgrove Farm.

b) Martley-Berrow Green District.

The best exposures of the sandstone within this district are to be found around Martley.

The road section between Martley village and the Noak (32/752602) shows how the sandstone grades up into the overlying marls. Opposite the "Tan House", the road section shows lenticles of fine conglomerate up to 18" in width. The pebbles in the main are composed of altered igneous rock, limestone and mudstone and sometimes attain a size of $\frac{3}{4}$". Besides the lenticles there are persistent bands of calcareous grit which stand out in relief upon weathering. Quarries to the south of this road show a similar type of sandstone, the rock being particularly massive in some cases and with coarse joints. The road cutting opposite Martley school also shows a type common to that just described.

300 yards N.E. of Birch Hill Gravel Pit there is a small disused quarry or pit (32/746600) containing a massive white to pink fine current bedded sandstone which passes downwards into the dull red common variety. Within 30 yards of the white sandstone purple spotted green marls were found. From this evidence it is assumed that the sandstone just described represents an horizon near the top of the Keuper Sandstone. This assumption has been verified by examining other exposures of the same rock.

Other small exposures of Keuper Sandstone have been found in lane cuttings by Kingswood Common, Martley, in the lanes immediately to the south of Martley and in those lanes to the east of Berrow Green. In the last named, another exposure of the buff and white sandstone was found which must have represented the uppermost Keuper Sandstone since purple marl was found within 100 yards of this sandstone exposure.

215 yards W.S.W. of Nipple Well in a small stream cutting, a massive fine grained grey-green sandstone weathering to the usual dull red colour is seen. Within the sandstone are embedded lenses and bands of conglomerate. The pebbles comprising these lenses are sub-angular and mainly composed of altered igneous material very similar to the fragments of Haffield Breccia. The fragment sizes range from $2\frac{5}{8}$" to $\frac{1}{2}$" with 1" as a common size. In general these pebbles are larger than those found elsewhere within the Keuper Sandstone.

c) Knightwick Station.

In this locality a lower horizon of the Keuper is recognised, that of a breccia. These breccias are best seen by the railway bridge (32/738552) in the road cutting.

The breccias bear a most striking resemblance to the Haffield Breccia of Osebury Rocks, both in their pebble content and in their surrounding matrix which is, however, rather brighter in colour and more sandy in parts than that of the Haffield Breccia. The most common fragments are the fine light coloured volcanic ashes which are so characteristic of the Haffield Breccia. Groom[1] has observed that the Keuper breccias contain a greater proportion of quartzite fragments than do the Haffield Breccia, but the writer has failed to produce any evidence in support of this observation.

The sandstone often lies with apparent unconformity upon the underlying Keuper breccia. This is admirably shown in the road cutting described above where the surface netween the breccia and sandstone is irregular, possibly representing an old land surface. The base of this sandstone contains many fragments of the underlying breccia.

d) Bridges Stone Locality.

The Keuper Sandstone forms a strip of rock adjacent to the Silurian, stretching from Upper House Farm, Alfrick, to Long Coppice, Old Storridge. Typical massive, brick red, fine sub-angular grained Sandstone forms a cliff by Knapp Farm which is very similar to that found at Knightwick Station.

1. Groom, T.T. 1900. Q.J.G.S. Vol. LVI. p.186.

Exposures found in the lane running by Knapp Farm show a similar sandstone intercalated with thin bands of breccia. Just south of Patches Farm in the same lane the breccias form a prominent ridge with a N.W. - S.E. strike.

West of Long Coppice by Upper Sandlin the white sandstone which is typical of the Upper Sandstone series can be found.

e) North Hill, Malvern and Whippets Farm, Cowleigh Park.

Two patches of typical Keuper Sandstone were found:-

i) Immediately east of the Haffield Breccia exposure above Whippets Farm, Cowleigh Park (32/763484).

ii) Plastered on the fault plane of Archean in the quarry on the Great Malvern - West Malvern road (32/769471).

4) Keuper Marl.

The Keuper Marl is a chocolate coloured marl with variegated bands of grey-green marls and grey, red and white sandstones called "Skerries". The term "marl" appears to be a misnomer since the marls contain very little calcareous matter.

Good exposures are few, but the marls' position is easily recognised by the heavy chocolate coloured soils which characterise its outcrop. In general it forms flattish land with ridges of the more resistant skerries.

Occurrence and Details of Exposures.

The Keuper Marl is seldom far from the Silurian rocks and occurs wherever the lower Keuper Sandstone is absent. Only the more important outcrops will be listed below.

i) Witley Court, Great Witley (32/757648)

A short sequence in the transition beds at the base of the Marl is exposed in a small pit, 300 yards S.W. of Witley Court.

Silty Mudstone.

6" Skerry - white compact sandstone with carbon fragments.

3' Dark Red laminated siltstones consisting of alternate argillaceous and silty layers.

1" Dark red Sandstone.

Red Mudstones.

ii) Knightwick Station (32/738551)

The railway cutting by the station and in the embankment on the roadside just outside the station, shows the transition beds and chocolate marls dipping to the S.E.

iii) Belmont Brickworks, Malvern. (32/770475)

These disused works show a cliff of red and green Keuper marls. The green marls either occupy regular bands within the red marls, or appear as blotches in the red deposits. Step faulting with small downthrows to the east can easily be seen.

iv) The Railway Cutting, Malvern Wells. (32/774436)

These deposits are exactly similar to those described at the brickworks.

Thickness of the Keuper.

Owing to the formations being incompletely exposed, it is impossible to calculate the exact thickness. Phillips suggests a thickness of 400 feet for the sandstone and about 750 feet for the marl. The Martley road cutting reveals at least 250 feet of sandstone.

POST TRIASSIC.

Under this heading, the rocks of Pleistocene and Recent age are considered. In the course of field work only the present day alluvium of the River Teme and Cradley Brook was mapped, ignoring the higher terraces - "Head"[1] deposits covered patches of low lying ground in the vicinity of Woodbury Hill. Drift of a red sandy clay gravel was often encountered by Bridges Stone, Alfrick, Cradley and particularly in the Colwall district.

1. Hollingworth, 19420. Geol.Mag. p.214.

STRUCTURE AND TECTONICS.

THE KINGSWOOD SYNCLINE.

This structure lies ¼ mile west of Walsgrove Hill and extends from immediately S.W. of Hillside Farm, Woodbury, to beyond the Great Witley - Bromyard Road.

The Downtonian and Upper Coal Measure strata west of Walsgrove Hill are folded into an asymmetrical syncline with a steeply dipping and sometimes inverted eastern limb, and a western limb with a small dip. The synclinal axis here corresponds with the outcrop of Coal Measures and strikes N. - S. Superimposed on the western limb is a subsidiary anticline whose axial trend is also N. - S.

The relationship between the Downtonian and Coal Measures has been a matter of dispute in the past. Briefly, there are those[1, 2] who think it to be an unconformably junction with the Downtonian strata folded prior to the deposition of the Coal Measures, the steep dips in the Carboniferous being only superficial and attributed to slumping. The other school of thought[3,4] recognise that the Coal Measures are folded with the Downtonian. Mykura suggests that although there is apparent conformity between these two beds at Hillside, Woodbury, farther north in Elmbatch Wood an angular unconformity of 30° can be seen which suggests that the Downtonian was locally folded prior to the Coal Measure deposition. The present author's evidence

1. Falcon, N.L. 1947. Geol.Mag. Vol.LXXXIV p.229-240.
2. King, W. 1923. Worcestershire Field Club.
3. Groom, T.T. 1910. "Geology in the Field" p.173-6.
4. Mykura, W. 1951. Geol.Mag. Vol.LXXXVIII p.386-392.

shows:-

1) No discordance of dip between the Downtonian and Coal Measures as seen in three stream sections along the eastern limb of the structure.

2) The basal members of the Coal Measures are practically vertical. One stream section showed a 12 foot high conglomerate with no alteration in dip over its length. Soil creep would probably cause the beds to turn over near the ground surface.

3) The coal seam mentioned in Mykura's paper[1] was visited and the exposure showed the bed to be dipping at 70° , the pit was surrounded by flattish ground.

The author, therefore, concludes that the Coal Measures were folded with the Downtonian, although minor flexuring might have occurred prior to the deposition of the Measures.

The Downtonian - Coal Measure contact on the western limb dips at between 5-30° but does not map as a sinuous line over the relatively deep valleys (100 feet). It is suspected that there might be a N. - S. strike fault along this western contact.

<u>Summary</u>.

1) The Coal Measures and Downtonian are folded synclinally with a minor anticline on the western limb.

2) There is apparent conformity between the Coal Measures and Downtonian within this area described.

3) There is a possibility of a N. - S. strike fault along the western side of the structure.

1. Mykura, W. 1951. Geol.Mag. Vol.LXXXVIII p.386.

WOODBURY ANTICLINE.

The author has given the name of "Woodbury Anticline" to that structure which has been mapped between the Bromyard-Great Witley road and Hillside Farm, Martley. Thus it is seen from the map that this structure is a little over 3 miles long and never exceeds 1 mile in width.

It is convenient at this point to consult the map on page 227. This map shows the main structural units of this district, these may be summarised as follows:

1) The folded foreland.

2) First thrust mass of Aymestry Limestone and Lower Ludlow Shales.

3) Second thrust mass of Wenlock Limestone and Wenlock Shale.

4) Unconformable area of Haffield Breccia.

Considering first that portion of the structure west of the thrust masses (1 above).

An inspection of the dips within this part of the structure, particularly those in the Wenlock Limestone and the northern part of the Aymestry, suggests that the anticline is overfolded, with its axial plane dipping to the east, and the western limb partially inverted.

Considering the western limb in detail, we see that the competent Upper Ludlow and Aymestry Limestone is dipping at 60° to the east, i.e., inverted at Walsgrove Hill. Further south the limestone becomes less inverted until it becomes vertical at Pudford Hill and 40° W. just south of this. This apparent rotation of the western limb as one proceeds from north to south along the present day erosion surface may be due to either a pitch in the fold, or an actual rotation of the axial plane.

The present day erosion surface represents an approximate horizontal plane through the structure, and inspection of the pattern the western limb makes on this plane gives us the idea of the solid form of the overfold. It is noted that:

a) The main Aymestry Limestone outcrop forms an elongated letter "S" in plan view.

b) The positions where the Aymestry Limestone is furthest west (i) Walsgrove Hill and (ii) Rudford Hill, represent areas where thrusting has been particularly active, and further in these areas the limestone is overturned.

These conditions might be satisfied by:-

a) A southerly pitching anticline from Walsgrove Hill to Rodge Hill and a steep northerly pitch from Rodge Hill to Hillend. This is true if the apical portion of the fold is considered (see diagram on page 228).

b) A northerly pitching anticline from Walsgrove Hill to Rodge Hill and a steep southerly pitch from Rodge Hill to Hillend. This is the opposite to (a) and would necessitate considering the basinal portion of the fold (see diagram on page 228).

c) A fold which is not pitching particularly in either direction, but whose surface of the axial plane is sinuous, bulging westwards at Walsgrove Hill and Hillend.

It would require more information concerning the eastern limb to decide the exact nature of the fold. As this data is not visible at the surface, the present writer considers solution (c) to best fit the facts observed.

Eastern Aymestry Outcrop.

To the east of the main Aymestry outcrop, an interrupted band of the same limestone is found dipping to the east. It has in the past been held that this eastern band forms the normal limb of a tight isoclinal fold whose axial plane trends through the Lower Ludlow Shales outcropping between the two limestones. The following evidence shows that the "eastcrop" is itself inverted.

1) No Upper Ludlow beds have been found to the east of this outcrop, only evidence of Lower Ludlow Shales was found.

a) 900 feet N.N.E. of Easthope Farm less than 100 feet below the Aymestry Limestone (32/744652)

b) 1,700 feet N. of Easthope Farm, 200 feet below the Aymestry Limestone. This small exposure contained light green calcareous silty mudstones and occasional bands of nodular limestone. A large coral found at this exposure had its roots uppermost suggesting that the beds were inverted. Fauna recognised were Heliolites sp., Strophonella euglypha, Atrypa reticularis, Leptostrophia filosa, Leptaena rhomboidalis, Crispella crispa, Dalmanites sp. These beds resemble in lithology those found below the Aymestry Limestone in Woodbury Quarry (32/744654).

c) Numerous holes drilled for telegraph poles to the N.E. of Easthope Farm have yielded Lower Ludlow silty mudstones.

d) Two pits dug on the eastern flanks of the Aymestry Limestone ridge to within 50 feet of the top showed no signs of Upper Ludlow beds as shown in Groom's section[1]. These exposures only showed typical Lower Ludlow Shales. (32/743653)

e) 300 feet E.S.E. of Rodge Hill Farm two small pits have been dug beside the track leading to the farm. These pits how Lower Ludlow Shales with an easterly dip, the true dip has been distorted by soil creep.

2) In a pit 875 feet N. of Easthope Farm, that is a small distance <u>west</u> of the limestone, Lower Ludlow Shales are found which are quite unlike the calcareous silty shales immediately beneath the Aymestry Limestone, but resemble in lithology those shales found just above the Wenlock by Wallhouse Plantation (32/744653).

3) A bedding plane exposed in Easthope Farm Quarry contains a large number of <u>Atrypa</u> whose convex valves face westwards. The lithology of these beds very often shows the presence of bottom currents, which would be sufficiently strong to orientate the pedicle valves to a more stable position, i.e., convex uppermost[2].

4) Resitivity traverses carried out across the Aymestry Limestone eastcrop, revealed a series of profiles suggestive of a limestone band sandwiched between shales, the high resitivity of the

1. Groom, T.T. 1900 Q.J.G.S. Vol.LVI. p.174
2. Shrock. "Sequence in Layered Rocks" p.314 et seq.

Upper Ludlow beds was absent, but was replaced by the lower value of the Ludlow Shales (see p. 270).

The above evidence leads to the following conclusions:

a) The Lower Ludlow Shales between the two Aymestry Limestone outcrops forms an inverted conformable series underlying the western band of limestone.

b) The inverted "eastcrop" is bounded on its west by a fault.

The theory that the eastern Aymestry Limestone outcrop is a development of limestone within the Lower Ludlow Shales is not seriously considered since the acceptance of this idea would necessitate an abnormally thick Lower Ludlow series of at least 2,000 feet.

Evidence for the direction of downthrow and nature of this fault are discussed below.

East Outcrop Boundary Fault - Easthope Fault.

Three possibilities are drawn to show how the "eastcrop" may be faulted. The first one (p. 229) with a downthrown eastern limestone band is not seriously considered due to its unusual low angle. The second diagram on page 230. illustruates two possibilities with a downthrow side on the west. The two alternatives are:

1) A normal fault dipping to the west.

2) A reverse fault dipping to the east.

Field evidence to substantiate the choice of the reverse fault is given below:

1) The occurrence of limestone at the surface by the normal fault, in the position of the "eastcrop" and its persistence laterally is too fortuitous. That is, any difference in throw of the fault would cause a comparatively large stratigraphical change, whereas variations in throw on the reverse fault cause only small stratigraphical differences (see diagrams mentioned above).

2) Results of compressional stresses are seen along the whole length of the Malvern-Abberley chain, particularly in the Malvern district, where thrust and high angle reverse faults with N. - S. strikes can be found. This strike fault would be considered a direct effect of the forces creating the recumbent fold.

3) Further evidence of compressional stresses is shown by the number of transcurrent E. - W. faults found along the "eastcrop" which apparently do not affect the western outcrop at all, although north of Easthope Farm one of the faults has a movement of 600 feet horizontally. Such tear faults would more likely affect the hanging wall than the foot wall.

4) Assuming the fault passing by Barrellhill Farm and Lippett's Farm is a normal one (see p.101), the displacement of the strike fault is such that it dips to the east.

In Mykura's recent paper a section is drawn in which a normal fault is thought to be responsible for the repeated Aymestry Limestone. On this same section Mykura recognises the presence

1. Mykura, W. 1951. Geol.Mag. Vol.LXXXVIII p.386-392.

of minor thrusts in the Lower Ludlow and a thrust in the Wenlock Limestone.

Summarising, it is seen that the Aymestry "eastcrop" is faulted from the main outcrop by a reverse strike fault dipping to the east.

Walsgrove Hill Area.

In this region the trend of the Abberley fold axis swings from N. - S. to E.N.E. - W.S.W., the latter being the dominant trend of the Abberley Hill structure.

On the hill itself both the main and faulted eastern outcrops of Aymestry Limestone appear, but the features they form are truncated north-eastwards by a fault (see page 98).

Investigation of Walsgrove Quarry (32/745660) shows that inverted Upper Ludlow beds and Downton Castle sandstones dipping at 42°/114° are faulted against Aymestry Limestone dipping at 75°-85°/100°. The limestone must be considered inverted as the beds forming the N.W. wall of the quarry yield abundant Dayia navicula and the beds that appear above this wall are lower horizons of Aymestry Limestone together with the bands of white clay characteristic of the lower part of the limestone. Outside the quarry to the N.W. fragments of Upper Ludlow can be found, this proves that the Aymestry is inverted.

The fault plane exposed in the quarry strikes at 060°, but its dip direction is difficult to decide. Close inspection of the quarry's south face shows that the fault probably dips in roughly the same direction as the dip of the Aymestry Limestone. This is the conclusion that Groom[1] arrived at, and from his section of the quarry

1. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.172.

it appears that it was less overgrown than it is nowadays.

Assuming the attitude of the fault is as stated above, it follows that the Aymestry must be on the downthrow side (the beds are inverted) thus making the fracture a reverse one. This would make it roughly parallel to the Eastern Aymestry Limestone Boundary fault described in the previous section.

Investigation of the Coal Measure - Downtonian boundary S.W. of Walsgrove Quarry, shows no evidence of any faulting as might be expected if the Walsgrove Quarry fault were continued along its strike direction. Therefore, it is suggested that this fault's strike curves to the south, roughly parallel to the bedding and the other reverse fault (Easthope fault , immediately east of Walsgrove Hill.) The tracing of this fault within the Downtonian is impossible due to the lack of exposures, but it may account for the thin development of Grew Downtonian.

In a N.W. Direction, the Aymestry Limestone of Walsgrove Quarry is cut off abruptly and it has been suggested by Groom[1] that the fault plane exposed within the quarry, may swing to the N.N.E. and terminate the limestone. Aymestry Limestone, however, may be found in tree roots etc., on the eastern flanks of the quarry indicating that no such curvature of the fault plane exists.

In the road ditch north of the quarry, Red Downtonian marls and sandstones dipping at a low angle occur. The difference in dip between these and the beds exposed in the quarry, together with the fact that the thickness between the Aymestry and Red Downtonian is

1. Groom, T.T. 1900 Q.J.G.S. Vol.LVI. p.173.

greatly reduced, indicates that a fault is present.

It is suggested that the N.W. trending fault that truncated the limestone of Walsgrove Quarry passes west of this Downtonian outcrop, and this purple marl belongs to the structure associated with Walsgrove Farm.

South of Walsgrove Hill the Aymestry "eastcrop" apparently widens and changes direction from N. - S. to N.E. - S.W. Resitivity traverses over this part of the Limestone suggest that a series of tear faults might displace the Aymestry sinistrally. The Aymestry "westcrop" might be faulted in the same way, as there are minor displacements in the ridge of the main Aymestry outcrop.

Summarising the structure of Walsgrove Hill, it is seen that a reverse fault curves round the N.W. side of the hill roughly parallel to the strike direction of the beds. The fracture exposed in the quarry repeats part of the inverted Downtonian and Ludlow sequences. A section through this part of Woodbury Anticline is shown on page 232.

<u>The Walsgrove Farm District.</u>

The ridges formed by the main and eastern outcrops of Aymestry Limestone are truncated immediately west of Walsgrove Farm (32/745658) to form rounded spurs pointing N.E. It is suggested by the present author that these Aymestry ridges have been faulted by a N.N.W. - S.S.E. fracture.

The area is bounded on the east by the Malvern Boundary fault and on the west by the N.N.W. - S.S.E. fracture described above. The area is badly exposed and four pits and two resitivity traverses were made in order to help elucidate the geology. Summarising its structure, it consists of a conformable series of beds ranging from the Downtonian to Wenlock Limestone, dipping at between 30°-40° to the N.N.W. with a possible strike fault in the Lower Ludlow to account for this bed's exceptionally thin development. Evidence for the occurence of these beds is given below:

1. Downtonian. This bed is presumed to exist in the very north of the area by the brook and pond, since many fragments of a micaceous purple siltstone were found in the numerous mole hills and in a pit that was dug for drainage purposes. The soil had a characteristic deep purple colour.

2. Upper Ludlow Beds. Immediately south of the pond mentioned above there is a marked feature running E.N.E. - W.S.W. on which a put was dug. This excavation showed a buff to grey, thin bedded micaceous siltstone, with shale partitions. The rock was stained chocolate brown and yielded characteristic Upper Ludlow fossils, namely Camarotoechia nucula and Chonetes striatellus. Between this ridge and the edge of Walsgrove Farm orchard, there is a depression. The only idea of what lies in this low ground was from fragments found in the roots of a large tree. These fragments were also of Upper Ludlow age similarto those described above.

3. Aymestry Limestone. Along the edge of the orchard a band of Aymestry Limestone is thought to exist, since:-

a) In the N.W. corner of the orchard there is a small exposure of Aymestry Limestone with an approximate dip of 40° to the N.W., but this inclination may have been considerable altered by hill creep.

b) A pit dug along the northern edge of the orchard revealed hard blue Aymestry Limestone at a depth of 5 feet.

c) Two resitivity traverses across the supposed position of the limestone revealed profiles similar to those obtained at Woodbury Quarry (see p. 269), with a "high" representing the limestone.

d) There is a low topographical ridge running E.N.E. - W.S.W. across the N.W. corner of the orchard.

4. Lower Ludlow Shales. There is a good outcrop of grey-green shale dipping at 40° to the N.W. about 80 yards S.W. of Walsgrove Farm in the steep banks of a pond.

Fauna collected from this exposure included:

Atrypa recticularis (Linn).
Leptaena rhomboidalis (Wilck).
Strophonella euglypha (Dalm).
Meristina tumida (Dalm).
Delthyris crispa (His).
Goniophora sp.
Modioliform
? Fenestella sp.
Orthoceras ibex (Sow).

5. Wenlock Limestone. Further south still, in a ploughed field immediately adjoining the farm, the ground rises steeply and Wenlock Limestone is believed to occur within this field because:

a) There are numerous fragments of this limestone on the highest part of the hill.

b) Two pits dug to a depth of 5 feet yielded an earthy limestone with buff to light green shales. The limestone yielded two corals Heliolites cf. megastoma (M'Coy) and Favosites cf. gotlandicus (Linn).

c) A topographical ridge elongated in a N.- S. direction with a steep E. - W. bank on its northern termination. This ridge is covered to the south and east by Haffield Breccia characterised by its large sub-angular fragments and dark red soil.

The observations outlined above have been discecribed in detail, since no previous author has apparently recognised all the evidence before. Phillips considered the area to be covered by Lower Ludlow, as did Groom and Mykura, but these last two authors recognised the presence of Wenlock Limestone in the south, but with a N.- S. strike.

Considering the structure of this area again, we see from the map that the Lower Ludlow is thinner than would be expected, 550 feet instead of 700 feet usually found. A strike fault or faults are thought to exist within this shale formation, possibly of a reverse nature.

The relationship of this area to that of Walsgrove Hill is uncertain. The present author feels sure the boundary between the two areas is a fault, as stated previously on page 93 , and field evidence is given below to substantiate the claim that it is a tear fault.

1) The fault's strike is approximately at right angles to the strike of the bedding. Reverse faults with this relationship are not found in the Malvern-Abberley district, therefore it is inferred that this fault must be either normal or transcurrent in nature.

2) From the structural similarity of this fault to others in the neighbourhood of Easthope Farm, the author suggests that this fault

at Walsgrove Farm is transcurrent in nature.

Further investigation to the north of this area would no doubt provide additional information regarding this fault.

A section through this area is given on page 232.

Easthope Farm District.

Most of this has been outlined in the section dealing with the Aymestry Limestone eastern outcrop (see page 89), but further observations are outlined below.

1400 feet north of Easthope Farm (32/744653) there is a minor ridge developed on the dip slope of the eastern outcrop of Aymestry Limestone. No exposures are visible, but it is suggested that this ridge represents a local development of the more calcareous beds within the upper Lower Ludlow, or more probably, a minor thrust repeating locally a portion of the more resistent Lower Ludlow Shales that appear near the top of this formation.

North of Easthope Farm an oblique left handed tear fault displaces the Aymestry Limestone outcrop 600 feet. This fault may be traced to the unconformable contact of the Haffield Breccia, but no evidence has proved the fracture's existence within the breccia.

At Easthope Farm itself the limestone is again displaced, this time only 150 feet. This must be considered another left handed tear fault, similar to the previous fracture described above. Immediately south of any one of these two displacements the Aymestry Limestone eastern outcrop is thinner as shown by the decrease in the width of the topographical ridge the limestone produced. That is, the strike fault cuts more of the Ludlow succession out, south of any one of these fractures. This suggests that there was a slight upward movement of the hanging wall along the strike fault on the side of the tear fault that had moved westwards relative to the other side of the transcurrent fault. This is made clear by consulting the diagram on page 234 .

South of Woodbury Hill (32/744643), the Aymestry Limestone disappears entirely. This is thought to be due to another tear fault and the slight upward movement of the hanging wall which has been displaced westwards. Only high horizon Lower Ludlow Shales are found on the south side of the fracture, these are seen in a stream 800 feet south of Woodbury Hill Farm dipping at 70°to the east (32/745642).

A N.E. - S.W. trending fault extends from 100 yards south of Barrellhill Farm to Lippets Farm, and appears to continue within the Haffield Breccia. Examining the field evidence, it is seen that this fracture:-

1) Displaces the main Aymestry Limestone by Barrellhill Farm, a horizontal distance of 130 feet.

2) Creates a valley between Barrellhill Farm and Lippets Farm.

3) Apparently is post Haffield Breccia of Woodbury, since there is a well defined col and valley on the hill along the strike direction of the Silurian fault. The horizontal displacement of the base of the breccia is hard to decide since hill-wash obscures the contact.

If the fracture is considered a tear, similar to the three previously described by Easthope Farm, an age later than the Haffield Breccia would have to be considered for the faulting. This is not in accordance with ages of other compressional faults found in the Malvern-Abberley district. An alternative is to consider the fracture a normal one dipping to the north with an apparent downthrow of a maximum of 250 feet in the Silurian. The Haffield Breccia, however, only appears to have a relatively small displacement and it is suggested that:-

1) The fault is hinged.

2) Has two periods of movement, pre and post-Haffield Breccia

or 3) The direction of movement of the fault has a lateral component, displacing the N.W. side westwards relative to the S.E. side.

The thrid solution would not necessitate a very large throw and the writer accepts this as being the possible nature of the fault. Sections through this part of the structure are shown on page 233.

<u>Woodbury Hill District.</u>

The prominent feature of Woodbury Hill is almost entirely composed of Haffield Breccia. The dip of the beds cannot be determined from the exposures seen, but inspection of the map shows that it has an apparent low dip.

The breccia lies unconformably upon Coal Measure horizons which outcrop along the west and south-west boundaries of the Haffield Breccia.

The relationship of the breccia to the Coals Measures has been discussed on page 72. Groom stated that these measures lie with apparent unconformity upon the folded Silurian[1], but to the present author's mind this is not proved to be a "cap" to the underlying folded beds by just stating that "the base (of the Coal Measures) tends to follow the contour lines".[2]

The resistance to weathering of the overlying apparently flat dipping Haffield Breccia most likely governs the contact of the Coal Measures with the Silurian.

Murchison's[3] account of a Coal Pit on Woodbury Hill is worthy of inclusion in this argument. "The Coal which was extracted on the western slopes of Woodbury Hill, and south of the Hundred House, consists merely of thin shreds of carbonaceous strata, thrown up in elevated positions, or rather squeezed up into separate patches between the trap (Haffield Breccia and Silurian.)"

To the south, at Berrow Hill (32/744586), a similar succession of beds can be seen, that is, Haffield Breccia resting on Coal Measures and the whole apparently lying unconformably upon folded Downtonian. Hollingworth[4], by a series of auger holes, came to the conclusion that the Coal Measures were possibly conformable with the Downtonian.

The present writer, therefore, concludes that there is no reason to believe that these Measures of Woodbury Hill lie with major unconformity upon the underlying Silurian.

1. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.175.
2. Groom, T.T. op.cit. p.166.
3. Murchison, Sir R. 1839. "The Silurian System". p.135.
4. Hollingworth. 1937. Summary of Progress. Geol.Surv. p.34.

These Measures may:-

1) Have been folded elsewhere, possibly further east, and thrust to their present position.

2) Have been deposited on a minor folded Silurian and Downtonian sea bed prior to the major earth movements.

The second theory is substantiated by Mykura's[1] observations. He gives an account of a 30° unconformity between the Downtonian and the Coal Measures in Ellbatch Wood. Such an unconformity is illustrated in the diagram on p. 235.

King[2] thought these beds of Woodbury to be lithologically similar to those found at Hillside to the west, and therefore suggested that they were of the same age.

Summarising, the present author cannot find any evidence in Groom's theory of two periods of Coal Measure deposition, but he believes they are all part of the same series and have been folded during the major earth movement with the underlying Downtonian and Silurian strata.

The Wenlock Limestone - Woodbury Hill to Hope Orchard.

The geology described in this section deals with the structures found within the Wenlock Limestone and the structural relationship of this bed with the neighbouring formations.

The Wenlock Limestone emerges from beneath the unconformable cover of Haffield Breccia at the south end of Woodbury Hill. Along the western edge of Wallhouse Plantation (32/752637), the beds strike

1. Mykura, W. 1951. Geol.Mag. Vol. LXXXVIII p.386.
2. King, W. 1923. Worcestershire Field Club.

015° from the northern end of the outcrop to the latitude of the quarry west of the Plantation. South of this the strike varies between 015° and 025°, but in the southern 400 feet of this line of old quarries, the strike is irregular but mainly N. - S. and even round to 355°. The dip varies between 30° and 50° easterly. South of Fetterlocks Farm (32/752633) the strike is mainly 000°, but near Hope Orchard the strike alters to 340°. The dips are variable, principally to the east except in the quarries immediately to the south of Fetterlocks Farm and those in Dundridge Coppice, where the dips are to the west.

To the west of the main line of quarries of Wallhouse Plantation another small outcrop of Wenlock Limestone is exposed, apparently isolated from the main quarries. The field evidence to deduce the structure and relationship of these Limestones is listed as follows:-

1) By means of studying a sedimentary rhythm displayed in the Limestone series (see p. 285), it was shown that the beds along the western edge of Wallhouse Plantation were probably inverted.

2) Brachiopod orientation within the limestone of the quarries along the eastern margin of Wallhouse Plantation suggested the beds were the right way up.

3a) Within the quarry west of Wallhouse Plantation a recumbent anticline of Wenlock Limestone is exposed. It has an almost horizontal axial plane which pitches slightly to the N.N.E. and a N.N.E. - S.S.W. striking crest which swings to the N.E. in the north end of the quarry. The normal limb of the fold is truncated by a low angle thrust fault which brings Lower Ludlow mudstones into contact with various beds of Wenlock Limestone. In the southern part of the quarry the normal limb of the anticline has almost been completely cut out by the fault.

b) Just above the thrust plane two small bands of white bentonitic clay are found in the easterly dipping Lower Ludlow.

c) Grinding and etching of limestone specimens from this quarry and examining the sedimentary rhythm, showed the bottom beds of the quarry to be inverted, whilst those at the top were the right way up. A photograph of this fold and thrust is shown on page 275.

4) Within the main line of quarries on the west side of Wallhouse Plantation, a 6 inch band of white clay can be traced along the whole length of the quarry face. It appears in the main to be parallel to the bedding, but in the southern 100 feet of quarry, there is a discordance of dip and strike, above and below the clay band.

i) above the clay $44^{\circ}/097^{\circ}$.
ii) below the clay $57^{\circ}/080^{\circ}$.

5)370 yards N.W. of Blackmoor Barn (32/752638), a well had been dug just above the Triassic boundary. This revealed a calcareous, flaggy olive green shale, but no fossils were found in the meagre fragments.

6)Immediately to the south of Wallhouse Plantation the ridge formed by the Wenlock Limestone disappears, and there is subdued topography.

7) The quarries immediately to the south of Fetterlocks Farm show

a) An anticline with an axis striking in the direction 345°. This anticline appears to be truncated along its southern edge.

b) The Wenlock Limestone exposed within these quarries shows intense folding with digitations and brow folds, suggesting that the structural forces acted in an E. - W. direction.

c) Grinding and etching limestone specimens from these quarries showed small scale current bedding which denoted that the beds were the right way up.

d) Lower Ludlow mudstones were found in the road cutting above the Wenlock Limestone to the S.E. of Fetterlocks Farm.

8) The Limestone - Lower Ludlow contact appears to dip at a much shallower angle than the bedding. Thus the contact "V's" eastwards at every dip valley, and in some cases where the topography is very low, the contact exists so far eastwards that only a small width of limestone is found west of the Triassic fault. Such occurrences are a) North of Dundridge Coppice where the limestone is practically non existent, b) immediately south of Dundridge Coppice and c) at the southern end of this section at Hope Orchard.

9) An anticline exists within the quarries of Dundridge Coppice and may be mapped along its axis for about $\frac{1}{4}$ mile. The anticline is again associated with numerous contortions and would appear to have an axial plane striking N. - S. and a shallow dip to the east.

Interpretation of this field evidence is given below:-

1) The Wenlock Limestone - Lower Ludlow Shale contact is represented by a plane dipping to the east at an angle which appears

to be in many places much less than the bedding. Further, this contact truncated many of the structures and bedding planes found within the Limestone. Towards the western edge of this contact, the Limestone is turned over into a recumbent fold, with many other digitations superimposed on this anticline. All the axial planes are dipping east. Calculations from stratum contours show the contact dips at between 12° and 20°, although it must be remembered this would only be an approximation, since the contact may not be a perfectly plane surface. From these observations it is deduced that this contact is a thrust fault.

2) The crest of the recumbent fold may be traced through Dundridge Coppice, the quarries south of Fetterlocks Farm and is presumed to exist along the centre of Wallhouse Plantation.

3) A low angle thrust exists within Wallhouse Plantation and is exposed in the quarries along the western edge of this location. Other thrusts might exist within the Lower Ludlow that separate the Wenlock Limestone from the N. - S. strike fault (Easthope Fault).

4) Another recumbent fold exists in the quarry west of Wallhouse Plantation, the normal limb of which has been faulted and overthrust by Lower Ludlow Shales.

Sections are shown drawn through Wallhouse Plantation, Fetterlocks Farm, and Rodge Hill Farm on pages 236, and 240. A detailed section of the quarry west of Wallhouse Plantation is given on page 237, and a sketch map of the Fetterlocks Farm district is shown on page 238.

Rodge Hill District.

South-west of Rodge Hill in the Southwood district (32/745622), there is an apparently thick development of Upper Ludlow beds. This is attributed either to 1) a tight minor fold or ii) a faulted fold, the eastern limb being the one that has fractured. The topography suggests that (ii) is possibly the true structure, since a valley exists with a strike parallel to the supposed fold's axis in the position of the fault.

It is not certain whether this fault cuts the Aymestry Limestone, but to the N.W. of Rodge Hill Farm there is a col on the limestone ridge. The limestone here at this col is thought to be vertical and therefore any fault other than a tear, would not cause any appreciable surface displacement of the limestone ridge.

To the N.E. of Rodge Hill (32/749626) a thin band of Aymestry Limestone is exposed striking N. - S. This is thought to be structurally similar to the bands of limestone running by Easthope Farm, Woodbury Hill. The only dips available on this outcrop show it to dip at 40° and 55° to the east. It is represented on the ground by a prominent scarp face running through Rodge Hill Farm and it is apparently truncated 1700 feet north of the farm.

The re-appearance of the limestone is presumed to be due to a transcurrent fault, similar to those by Easthope Farm. It was stated on page 99, that left hand tear faults caused the Aymestry Limestone to thin southwards due to slip on the N. - S. strike fault. It would seem that the tear fault north of Rodge Hill Farm has a right hand displacement with the associated slip on the strike fault, in such a manner as to make the Aymestry Limestone of Rodge Hill Farm structurally higher than those beds found north of the transcurrent fault.

North of this tear fault a broad hump is the only remnant of the Aymestry ridge that can be seen. This corresponds with high horizon Lower Ludlow.

250 yards south of Rodge Hill Farm the limestone ridge dies out. At first sight this would appear to be due to another left handed tear fault butcloser investigation shows that:-

1) There is no broad hump of high Lower Ludlow as found in the Woodbury Hill district.

2) The Aymestry Limestone ridge is not truncated sharply but fades out into flat country.

It is suggested therefore that the reverse fault along the western boundary of the limestone, alters its strike slightly from N. - S. to N.N.W. - S.S.E. in a curve and disappears under the overthrust Wenlock Limestone by Hope Orchard. This problem will be discussed further in the next section dealing with Hope Orchard.

A section through Rodge Hill Farm is shown on page 240.

Hope Orchard and Penny Hill Districts.

The area described here is structurally complex and the reader is referred to pages 241 and 244 where detailed maps of this district are shown.

The structure may be briefly des cribed as two N. - S. striking bands of Wenlock Limestone truncated in the Hope Orchard district by a N.N.W. - S.S.E. fault. A portion of the western limestone band is displaced westwards immediately west of Hope Orchard. Field evidence is given below to substantiate this structure and to show the relationships of the various beds.

Considering the eastern band of Wenlock Limestone, it is seen that the beds dip at between 20°- 45° to the east. They are well exposed in Hope Orchard as old quarries, but when traced southwards exposures are rare, since the ground is covered by a vast amount of quarry tip. Murchison[1], however, shows a small sketch map of this district in which he recognises Wenlock Limestone dipping eastwards at 20°. This author also observed the beds to be the right way up since he reports having seen shales of Wenlock age beneath this limestone. The southern extremity of this eastern limestone band is truncated by the Triassic fault which here strikes N.E. - S.W.

The western limestone band also dips eastwards, but at a much steeper angle, between 45° and 80° with 55° as a common dip. These beds are here thought to be inverted, since:-

1) In Penny Hill Quarry a large bedding plane exists upon which about 200 brachiopods are visible. Most of these are of the genus <u>Atrypa</u>. In the majority of cases the more convex valve (dorsal) faces downwards into the rock which suggests the rocks are inverted[2].

1. Murchison, Sir R. 1839. Silurian System. p.421-422.
2. Shrock. "Sequence in Layered Rocks" p.314.

2) Numerous (nearly 50) stromatoporoid colonies occur on a bedding plane in Penny Hill Quarry, in which the convex surface is directed downwards and the concave surface is uppermost. It is usual to find them the other way up.

The southern extremity of this limestone band is truncated, apparently by a fault, but not the Triassic fault as is the eastern band.

West of Hope Orchard the western limestone band is displaced 250 feet horizontally. This fault must be transcurrent since a normal fault would have to have a throw of several hundred feet in order to displace beds dipping at 60°-80° 250 feet. Such a normal fault would cause some disturbance to the main Aymestry Limestone ridge to the west. It is therefore deduced that this fault is a left handed tear fault striking 105° through Hope Orchard.

To the north, this displaced band of Wenlock Limestone is truncated by a fault whose strike, by surface features appears to be N.N.W. - S.S.E.

Between these two major bands of Limestone there are a few exposures of a dark olive green, flaggy, calcareous shale. The best exposure of this shale is to be seen immediately to the east of Penny Hill Quarry, where a pit has been dug. This pit shows shale, as described above, dipping at 50°/084° and can be traced westwards up into the Wenlock Limestone of Penny Hill Quarry. As it has already been proved that the limestone of this quarry is inverted, it follows that this shale is probably Wenlock Shale.

The structure deduced from the field evidence outlined above is given below.

It is suggested that the thrust underlying the Wenlock Limestone of Dundridge Coppice continues through Hope Orchard and along the eastern flanks of Penny Hill. At a point where this thrust cuts the road leading to Penny Hill Quarry, the strike of the fault alters to N.N.E. - S.S.W. curving round the southern end of Penny Hill to terminate the western band of Wenlock Limestone. The writer believes that the Wenlock Limestone of the western band is conformable with the Ludlow which rests upon the limestone. The displaced portion of this western band is believed to be truncated by the "Easthope" strike fault at its northern extremity (see page 109.)

South-west of Penny Hill, a small isolated quarry containing Wenlock Limestone dipping 37°/326° is to be found. This limestone grades apparently upwards into olive green shale. The shale's age was hard to decide and in the absence of orientation criterea, no order could be given to the succession.

The relationship between this small isolated region and the main Penny Hill Structure must be a faulted one. There is evidence for this fracture in the form of a depression running N.N.W.- S.S.E. between the main hill and this quarry. The author suggests that this mass of limestone and shale is a small portion of an overthrust mass and the fault along the depression is a tear.

Sections and maps of this district are shown on pages 242 &244

<u>Summary of Structure of Woodbury Anticline.</u>

1) The Aymestry Limestone along the western edge of the district forms the western limb of an asymmetrical anticline whose axial plane dips eastwards.

2) An easterly dipping strike fault repeats the Aymestry Limestone and Lower Ludlow Shales.

3) The Wenlock Limestone is overthrust along the eastern margin of the area.

THE HILLEND OVERTHRUST.

The structure about to be described is to be found in the triangle of country between Hillside, Tee Bank Coppice and Kingswood Common, Martley (32/748607). It is mapped as part of the overthrust mass which bounds the eastern margin of Woodbury Anticline. It is described here separately from the anticline, since it forms a definite structural unit.

This mass is composed entirely of a grey to green calcareous shale with limestone bands. Examination of many exposures, especially those on the east banks of the River Teme (32/745603) and in the road cutting leading to Clifton upon Teme (32/745605), has yielded the following fauna:

Cyathophyllum sp.
Favosites sp.
Orbiculoidea sp.
Camarotoechia cf. borealis (Schloth).
Atrypa recticularis (Linn.)
" imbricata (Sow.)
Leptaena rhomboidalis (Wilck.)
Strophonella euglypha (Dalm.)
Bilobites biloba (Linn.)
Eospirifer radiatus (Sow.)
Parmorthis elegantula (Dalm.)
Gypidula sp.
Plectodonta cf. transversalis (Dalm.)
Orthis antiquata (Sow.)
Dalmanites vulgaris (Brunnick).
Proetus sp.
Euomphalus sp.
Dawsonoceras sp.
Bryozoa.

The Strophonella euglypha resembles the varieties collected from other exposures of Wenlock Shale.

Tracing this mass of shale eastwards it is apparently overlain by Wenlock Limestone immediately south of Penny Hill (32/752611).

From the evidence given above the author concludes that the shale is of Wenlock age and is apparently the right way up.

This mass of Wenlock Shale could represent:

1) An up-faulted area from the adjacent Woodbury Anticline.

2) An overthrust mass on to the western limb of Woodbury Anticline.

If it was assumed that this was an upthrown mass, the Downtonian - Wenlock fault would represent a vertical fracture of enormous throw, somewhere in the order of 1,200 feet. Such a fault is not impossible close to the Malvern Boundary Fault, but the author feels sure that further evidence of the existance of such a fault would have been found in the formations to the north, where the fault would presumably continue.

Evidence to substantiate the second theory, that this represents an overthrust mass is given below:

1) The base of the Wenlock Shale appears to have a dip of between 15-20° to the S.E. This was deduced from stratum contours on the field map.

2) The western edge of the Wenlock Shale is folded into a recumbent anticline with its axis dipping at a low angle to the S.E. (See section on page 243).

3) From the mapping the fault appears to be the continuation of the thrust fault along the eastern margin of Woodbury Anticline (see diagram on page 227).

The fold mentioned in (2) above is well exposed in the road cutting between The Noak, Martley and the River Teme. Another anticline has been mapped immediately to the east of the one just described. This second one is much broader and has an axial plane whose strike is approximately N.E. - S.W. W.W.King[1] recorded a shallow dip to the S.S.E. immediately west of the Noak which would substantiate the eastern limb of this fold.

Between these two minor structures, a fault is thought to exist, since (a) there is a discordance of dips between the structures and (b) topographical evidence in the nature of a depression.

There are admirable exposures within Kingswood Common, but unfortunately the shale has slumped down the banks of the R. Teme, and its dips have been ignored, although they all appear to conform with those found S.W. of the road. Due to this slumping, the Wenlock Downtonian boundary by Kingwood Common was impossible to trace, but it must exist on the east bank of the R. Teme since a small exposure of Red Downtonian was found just below Ham Mill on the Martley bank of the river.

A detailed map of this district is to be found on page 244.

1. W.WKing. From unpublished maps he has kindly lent.

HORSHAM ANTICLINE.

This structure is only revealed within the Downtonian. It was mapped from just north of Ham Farm (32/738600) to Horsham (32/738578), a distance of 2 miles. Evidence for the existence of this fold is given below.

1) 200 yards N.N.W. of Ham Farm quaquaversal dips on red micaceous siltstones were found in a stream section (32/740602)

2) Quarry and bridle track exposures immediately to the S.W. of Ham Farm showed similar siltstones to (1) forming the apical portion of a fold, i.e., dips to the E.S.E. and W.S.W. (32/737598).

3) Dips in Ham Wood show a dip of $50^{\circ}/253^{\circ}$ (32/735595).

4) Exposures seen in the banks of the River Teme by Ox Leasow Coppice reveal a complete section through the apical portion of the fold. In general the dips were between 15° and 70° at 090° for the eastern limb and between 20° and 60° at 240° for the western limb, with small N.N.W. dips in the crestal regions. Further, a dip of $9^{\circ}/210^{\circ}$ was recorded at the western extremity of Ox Leasow Coppice suggesting that the western limb might not be just a part of a simple fold (32/738585).

5) 535 yards S.W. of Berrow Hill, a dip of $11^{\circ}/070^{\circ}$ was recorded on a purple soft micaceous sandstone. This would represent part of the eastern limb (32/742582).

This field evidence leads to a conclusion that an anticline exists, whose western limb is steeper than its eastern counterpart, i.e., asymmetric with an easterly dipping axial plane. A particularly prominent band of hard purple siltstone, possibly the Holdgate Sandstone, was traced through the northern part of Ox Leasow Coppice to Ham Farm and back through Ham Wood to the southern part of Ox Leasow Coppice, i.e., the band "V's" to the north, this suggests that the fold plunges to the north, at least in its northern extremity. The strike of the axial plane is approximately N.N.W. - S.S.E.

A syncline is presumed to exist between this anticline and the Woodbury anticline or rather, the position the Woodbury structure would occupy if it were not truncated by the Malvern Boundary fault at Kingswood, Martley. A dip of 53°/274° on the Downtonian 1040 yards north of Berrow Hill could be on the western limb of Woodbury Anticline or the eastern limb of the proposed syncline.

A small area of uppermost Ludlow and Lower Downtonian exposed S.S.W. of Ankerdine Hill may be considered associated with Horsham Anticline. Field evidence shows:-

1) The Upper Ludlow and Aymestry exposed in the quarry by the Bromyard Road south of Ankerdine Hill shows the Ludlow to be dipping at 54°/054°(32/736558).

2) From etched ground sections small scale current bedding has shown the beds to be inverted, see photograph on page 286.

This small area could represent a portion of the western limb of the Horsham Anticline, provided the plunge to the north was sufficient to expose the Silurian at the surface south of Ankerdine Hill. Assuming the silty-sandstone exposed at Ham Farm by Martley is the Holdgate Sandstone, the plunge would have to be at least 4^{o}. This explanation of the small area of Ludlow S. of Ankerdine Hill, is only a suggestion, since there is very little field evidence and a great deal of the ground between this small area and Horsham is obscured by the Ankerdine structure and its many faults. For further considerations of this patch of Ludlow see page 127 where its relation to the Knightwick Station area is considered.

Immediately east of Birchhill Coppice, the Downtonian is separated from the Triassic by a band of Coal Measure clay which according to Hollingworth[1] rests with apparent conformity on the Downtonian Marl.

The Martley "Gravel Pit" (32/745595) exposure of syenite resting on quartzite has been described by Groom [2] as an epitome of the history of the Malvern-Abberley range. He observes that in the Malvern area it is a common feature to find Cambrian quartzite overthrust and thus overlain by rocks of Malvernian age, and by an estimate from the records of exposures no longer visible, but recorded by earlier workers, Groom drew a section now illustrated in his work.

Both the presence of a green schist, observed at the base of the Malvernian and the crushing and fracturing observed in the quartzite and syenite favour the interpretation that during a period of intense folding, the Malvernian was thrust over the Cambrian, shearing at its base having produced the schistose structure.

1. Hollingworth, 1937. Summary of Progress Geol.Surv. p.34
2. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.163.

It is suggested by Groom that this overthrust series, together with the overlying Downtonian formations was subsequently folded along a north-south axis, consequent upthrust and secondary folding produced an anticlinal structure with quaquaversal dips.

Criticism of this interpretation could only be substituted by speculative theories, except for two points made clear to the author from field evidence:-

1) The isolated exposure of old rocks must represent some sort of overthrust mass.

2) The thrusting probably occurred after the deposition of the skirting Coal Measures[1] since a) the Coal Measures do not appear to contain any fragments from the older mass and b) the syenite boss appears to stand higher than the surrounding Measures.

Separating the Triassic from the Downtonian at Berrow Hill, is a large high mass of Haffield Breccia which apparently lies unconformably upon the Upper Coal Measures, the latter exposed in patches along the eastern boundaries of the Breccia, very similar to that described for Woodbury Hill.

Sections through the structures outlined above are shown on page 246 .

1. Hollingworth. op.cit. By augering he has proved Coal Measures to surround the syenite boss.

THE STRUCTURE OF ANKERDINE HILL AND COLLINS GREEN.

In this chapter the structure of the Llandovery and Wenlock Series of Ankerdine Hill and Collins Green will be discussed.

Inspection of the 6 inch map and the sketch map of Collins Green on page 247 shows that it is a region of faulting. Exposures are very few and the author was obliged to use the evidence of fragments, pits and physical features. Thus the interpretation is only a suggestion, particularly with regard to the nature of the faults. Phillips realised the boundaries of all the formations were faults and wrote of Ankerdine Hill[1] "... it is composed of an anticlinal mass of Caradoc strata having a north-south axis and being bounded by four faults each downthrowing the adjacent strata. The Caradoc Sandstones are controted in places, and it is significant that the adjacent Ludlow, Wenlock and Downtonian formations dip towards, as if to pass under the older rocks of the Caradoc".

The main problem of this area is the large stratigraphical separations between the Llandovery and Ludlow in the South, and Llandovery and Downtonian in the west. Assuming the western boundary to be a normal fault, as proposed by Phillips, a throw of up to 1,200 or even 1,500 feet would be needed. Such an apparently large fault, although not impossible adjacent to the Malvern Boundary Fault, has an analogy to the fault that bounds the western margin of the Pre-Cambrian rocks of the Malvern Hills. A recent theory proposed by Raw[2] suggests that a large overthrust mass or nappe of Pre-Cambrian

1. Phillips, J. 1848. Mem.Geol.Survey p.149.
2. Raw, F. 1952. Proc.Geol.Assoc. Vol. LXIII p.227.

and Palaeozoic rocks was once thrust over the area now occupied by the Malvern-Abberley range and subsequent normal faulting let down portions of this nappe to form the present Malvern Hills. The present writer suggests that part of this nappe might have been downfaulted to form Ankerdine Hill and the country around Collins Green.

The chief exposures that were found in the Collins Green area are listed below.

a) At Collins Green itself there is a quarry exposing Haffield Breccia and Wenlock Limestone. The breccia is composed of rounded to sub-angular pebbles of Uriconian, and what appears to be material resembling cornstones of the Devonian, set in a matrix of marly sand, all with a purple colour. There are numerous thin bands of grey clay material running in haphazard directions through the breccia, these are possibly the products of roots from trees growing at the top of the quarry.

Underneath the breccia is a flaggy and nodular limestone interbedded with a calcareous shale, the whole stained purple. The limestone has the characteristic of Wenlock and when traced laterally northwards, it can be seen to rest on Wenlock Shale.

Separating the breccia from the limestone is a 9 inch band of white to light grey clay. As far as can be judged the band is parallel to the bedding. There is also a vertical separation between the breccia and limestone, but above the clay band. The clay band mentioned above persists beyond this vertical plane into the Wenlock Limestone, and thus separates limestone from limestone. Beneath this prominent band of clay are other minor clay bands of a similar nature.

The author at first thought that this clay band represented the position of a thrust dipping to the east, but the writer now believes the contact to be an unconformity and the vertical face part of an erosion channel. If the clay represented the plane of a fault, one would expect it to be oblique to the bedding. Chemical tests made on the clay show it to contain practically no calcareous matter and to be typical of the numerous absorptive bentonitic type clays found in the Silurian.

The possibility of the breccia being of Pleistocene age was considered, but the similarity of the lithology and the high topographical position of this exposure favours Haffield Breccia for this formation.

A photograph of this quarry is shown on page 279.

b) 910 yards N.5°W. of Nipple Well, i.e. 200 yards N.W. of Tinkers Coppice quarry, there is an exposure of calcareous grey shale interbedded with thin bands of muddy limestone. Fossils from this exposure include:

Atrypa recticularis
Leptaena rhomboidalis
Strophonella euglypha (Wenlock variety)
Bilobites biloba
Cyrtia exporrecta
Eosperifer radiatus
Dalmanites vulgaris
Proetid tail
Meristina sp.
Skenidioides sp.
Crinoid ossicles.

The dip on the beds is $18^{o}/294^{o}$ and when these beds are traced upwards they appear to pass into the Wenlock Limestone. This is best seen in a road-side exposure 880 yards N.10^{o}E. of Nipple Well, where 3 feet of flaggy limestone is seen and 15 feet beneath it is a small pit containing a buff calcareous shale. The author believes this shale to be of Wenlock age.

c) 900 yards N.W. of Nipple Well numerous fragments of a closely jointed calcareous grey siltstone with remnants of a grey shale could be seen in numerous uprooted trees. These fragments are correlated with the uppermost Wyche beds.

These are the only satisfactory exposures found and to account for their relationships, a complex series of faults are necessary. For the benefit of the reader, the faults are numbered on the sketch map and will be discussed in order.

Fault 1.

This is the Malvern Boundary fault and separates the Triassic from older formations. It is not exposed anywhere along this stretch of country.

Fault 2.

This fracture separates Downtonian from Llandovery and Wenlock formations. Its nature has already been discussed above. It is conceivable that the line of separation might be the actual thrust fault, but from the mapping the fault line is far too straight to be interpreted as a thrust and is probably a normal fault dipping at a high angle to the east. It does not appear to disturb the

Haffield Breccia at its N.E. end, and is therefore presumed to be prior to this formation. It is possibly terminated to the S.W. by the normal fault of post Keuper Sandstone age which is thought to fracture the western margin of Ankerdine Hill (see below on page 130).

Fault 3.

1,100 feet N.W. of Collins Green the fracture previously described (Fault 2) is displaced by a N.W.- S.E. striking fault. The continuance of this fault eastwards to Collins Green is not certain, but a depression and scarp on top of the ridge, along which the road runs, suggests that this fracture probably terminates against the Malvern Boundary Fault. Its age is post fault 2 and it is uncertain whether it faults the Haffield Breccia of Collins Green or not, but its presumed position is very close to the western extent of the breccia. This fault, if it is normal in nature, dips to the south.

Fault 4.

A line of separation exists along the north side of Hay Wood, which is interpreted as a fault. Formations of Wenlock Age are found against beds of Llandovery Sandstone 900 feet N.NW. of Collins Green. In the extreme north the fracture is represented by depressed ground, and the termination of a ridge on the east side of the fault. It is uncertain whether this fault displaces faults 2 and 3 and the Breccia of Collins Green, but as the line of separation and the edge of the breccia are on the same strike, it is possible that the line represents a continuous fault.

Fault 5.

Between the Llandovery of Tinkers Coppice and Wenlock Shale above it, a fault is postulated. A direct sequence from Uppermost Llandovery to Wenlock Shale is not thought to exist here, since there is no evidence of any Woolhope Limestone. This fault could represent either a minor thrust of the Shale over on to the older Llandovery or another normal fault dipping eastwards with an upthrown side to the west. If it is a thrust, it might be that faults 4 and 5 are the same fractures and both represent part of the same thrust.

Structures within the Wenlock.

The Wenlock Limestone of Tinkers Coppice reveals a small anticlinal structure with a small core of Wenlock Shale between the limestone limbs. Dips of $22^\circ/175^\circ$ and $40^\circ/70^\circ$ for the southern and northern limbs respectively have been recorded.

Structures within the Llandovery.

As has already been stated, Phillips[1] considered the Llandovery an anticlinal mass. Inspection of available dips revealed nothing of this nature, but rather indicated a regular dipping mass of sandstone with an inclination of 30°- 45° to the N.W. Successively higher beds within the Llandovery were found on traversing through Hay Wood, until almost the top of the Wyche beds was reached in Tinkers Coppice.

1. Phillips, J. op.cit. p.149.

The Llandovery-Ludlow Boundary at Knightwick.

The relationship between the strata at the southern extremity of Ankerdine Hill is uncertain. The line of separation between the Llandovery and Ludlow is obviously a fault. It is best considered a normal fault dipping to the S.W., down-faulting part of an overthrust nappe as discussed at the beginning of this chapter.

THE STRUCTURES OF THE KNIGHTWICK STATION LOCALITY.

The area here described lies immediately south of the River Teme. The district is exceedingly complex and is principally composed of fault blocks of Silurian and Permo-Triassic formations. The relationships between these masses are difficult to interpret, and the writer was obliged to analyse the geology by comparing it with analogous regions in the Malvern-Abberley region, thus the geological sections given on page 249 must be considered as suggestions rather than direct interpretations. The reader is referred to the sketch map of this district on page 250 , where the principal faults have been numbered to facilitate their description in the text.

Groom[1] published a map on the 6" scale, showing the faulted region within the Permo-Triassic, but the map fails to show any of the geology within the Silurian. The present writer's work does not disagree radically with the mapping of Groom's faulted Permo-Triassic, but is principally concerned with the Silurian and its structure.

The faults are a mixture of tensional and compressional fractures. Those that displace the Mesozoic strata are taken to be tensional associated with the Malvern Boundary fault movement, whilst those faults affecting the older formations may be interpreted as either the effects of compression or tension.

The tensional faults found in the Mesozoic are numbers 1, 2, 3, 4 and 5, of these 1 and 2 appear to be the most important.

1. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.185-187.

<u>Fault No.1.</u> Considering fault number 1 in detail we find:

a) At the northern extremity of the map, at the eastern end of Osebury Rock, Haffield Breccia dipping at 62°/141° adjacent to white to pink thin bedded siltstones displaying ripple marks interbedded with purple and green marl, the latter formation was found in a pit dug for this investigation. The marly beds were correlated with horizons at the junction of the Keuper Marl and Sandstone.

b) A scarp face striking N.N.E. through the field N.N.W. of Knightwick Station. Within this field there are a few exposures of both Haffield Breccia and sandstone formations.

c) Evidence for this fault can be seen in the road and railway cuttings by Knightwick Station. An erosion channel marks the actual site. In both places homogenous sandstone is faulted against sandstone with breccias and by reference to the situations of these fault exposures, a N.N.E./S.S.W. strike of the fault plane can be deduced.

This fault probably continues northwards across the River Teme and is represented east of Ankerdine Hill by the fault which separates the Triassic from the Llandovery formations. Southwards from Knightwick Station, this fault forms the boundary between the Mesozoic and Palaeozoic formations - Malvern Boundary Fault.

<u>Fault No. 2.</u> The railway cutting W.N.W. of Knightwick Station shows Silurian shales adjacent to a Permo-Triassic sandstone. The strike of this fault is approximately 330° and evidence of the

continuance of this fracture can be seen in the wood to the north of the railway line and in the fields S.W. of the station.

A fault of this nature if presumed to be part of the Malvern Boundary Fault since it has the general characteristic of Mesozoic beds against those of Palaeozoic. It would, therefore, probably have a downthrow to the east.

Such a fault would be expected to extend a considerable distance along its strike. It is, therefore, proposed that it continues across the River Teme, possible truncating the transverse fault number 9 and may be the fracture that separates the Llandovery of Ankerdine Hill from the Downtonian on the hill's western flanks. Southwards this fault is presumed to join the normal fault number 1, south of Knightwick Station.

Faults 3 and 4. It has already been stated that the author believes the relationship between the Haffield Breccia and Triassic sandstone (Possible of Bunter age), in the road cutting N.W. of Knightwick Station, to be a conformable series of beds (see page 74). This contact which is dipping at about 15° to the S.S.E. would presume to "V" up the valley beside the road and expose Haffield Breccia on the opposite side of the valley. Only fine red sandstones can be found on the west side of the stream and, therefore, a fault is proposed which truncates this conformable contact - fault number 3.

Tracing this contact to the N.W. shows that it must be truncated since only Haffield Breccia dipping uniformly to the S.E. can be found. A scarp face striking S.E. - N.W. can be found within the Breccia at the western end of Osebury Rock which might be the result of this fault - Fault number 4.

Both these faults are thought to be terminated in the N.W. by fault 8 and to the S.E. by fault 1. These fractures have their downthrow sides to the S.W. and, therefore, if the faults are normal in nature the fault plane would dip to the S.W.

Fault 5. Although there is no exposure at the surface of the fault separating the Keuper Sandstone from the Keuper Marl, the fact that Keuper Marls are found outcropping at a horizontal distance of only 50 yards from the basal Keuper Sahdstone, excludes the possibility of a complete series, and necessitates the presence of a fault or faults. Two minor faults can be seen in the sandstone opposite the platform of Knightwick Station. The uppermost beds of the exposed sandstone in the station cutting show a white to pink sandstone very similar to horizons at the Keuper Sandstone - Marl junction. There is a lack, however, of the thin bedded sandstone at the base of the Marl and becuase of this a fault is proposed. Other faults probably exist within the Keuper Sandstone to account for the apparently thin development of this formation.

Faults 6 and 7. These faults are inferred from the observations made in the railway cutting west of Knightwick Station. This cutting will be described in detail below.

Eastern End (32/736552)

Fine red Sandstone dipping at $40^{o}/069^{o}$

Fault number 2.

Grey and lavender coloured shales with thin bands of flaggy calcareous siltstone which becomes coarse in texture near Fault 2. Fossils identified from the shale include Fardinia sp., Leptaena sp., Chonetes sp., Chonetoidea greyi. The shales have a similarity to the Woolhope Shales with which they are correlated. These shales dip at 85°/045°, but become steeper and even overturned towards fault 2.

Presumed Position of Fault 6.

Massive pink sandstone band and minor purple marls in the northern bank of the cutting. Further purple and green silty marls were found in the southern bank. A Lingula sp. was found in the massive sandstone. This outcrop is thought to be of Downtonian age. A dip on the massive sandstone showed it to be dipping 35°/327°.

Presumed Position of Fault 7.

Nodular argillaceous blue-grey limestones and thin bedded grey shales, grading upwards into flaggy siltstones typical of the Upper Ludlow formation. Fossils found include Dalmanella sp., Serpulites longissimus, Dayia navicula, Murchisonia sp., Chonetes striatellus, Camarotoechia nucula. The writer does not think the horizons exposed adjacent to Fault 7 are sufficiently low to be called Aymestry Limestone, but are probably best correlated with the Dayia Shales. Tracing the Upper Ludlow upwards the equivalent to the bone bed was found in the south bank of the cutting. Above this are found representatives of the Downton Castle Sandstone and the red and purple marls of beds higher in the Downtonian sequence. Dips on the Upper Ludlow and Downtonian are between 36° and 67° in a direction 275°.

Evidence for the extension of these faults to the north and south of the cutting, is small and a great deal of the mapping was made upon fragments and small pits. Such evidence is listed below:

a) North of the cutting, exposures are few, but the wooded land appears to be covered almost entirely with fragments of Upper Ludlow. A depression, which the author has associated with the two faults, curves round and abuts against fault 2.

b) Immediately south of the railway cutting there is ample evidence of the existence of the Llandovery Shales, Downtonian marls and Upper Ludlow.

c) 200 yards south of the cutting in a steep bank of a hedge, the Llandovery was again seen, but no evidence of any purple marls of the Downtonian could be found.

Measurements taken from the stratum contours off the map, showed that these faults dipped at an angle of approximately 40^{o} in a direction to the N.N.E. These fractures might be normal in nature, but the writer believes they are both reverse or thrust faults, analogous to other overthrust masses adjacent to the Malvern Boundary fault, see pages 136,145 and 152.

The apparent absence of Downtonian in the extreme south is thought to be due to the upper overthrust mass of Llandovery extending further to the west and entirely obscuring the lower mass of Downtonian.

Comparing this small thrust area with that district south of faults 9 and 10, i.e., the area described in the following chapter entitled "Ravenshill Wood Overthrust", it is seen that the two areas bear a remarkable similarity. They are both composed of Llandovery overthrust masses dipping to the N.E., but that one south of faults

9 and 10 is larger in extent.

Fault 8. A fault is proposed somewhere in the Teme valley, but as it is obscured by alluvium it is difficult to decide its exact position and nature. The deep valley carved by the river through the Abberley range at this point, was thought by Phillips[1], Bennett[2] and Gray[3] to be a significant factor in interpreting this physical feature as the result of a series of transverse faults. The vertical face of Osebury Rock suggests a fault scarp running in a N.N.E. direction, and the author believes that this might be a possible strike direction for this fault.

Fault 9. This fault truncates the high ridge of Aymestry Limestone north east of Hanging Bank Coppice, and also appears to terminate the Ludlow and Llandovery of the railway cutting. The fracture is possible a tear fault with a right hand displacement. Thus the Upper Ludlow exposed north of the fault in the railway cutting is thought to be part of the Upper Ludlow that strikes through Hanging Bank Coppice, displaced eastwards relative to that found south of the fault.

The Ludlow of Hanging Bank Coppice strikes at 024° and is inverted. One quarry exposing Upper Ludlow 730 yards W.S.W. of the "Fox and Hounds", Ravenshill Green, shows beds which are extremely contorted and covered with slickensiding.

Fault 10. This fault strikes at 030° and forms a well defined feature S.E. of Hanging Bank Coppice. Evidence for its existence

1. Phillips, J. op.cit. page 149.
2. Bennett, A.J. 1942. "The Geology of Malvernia".
3. Gray, J.W. 1919. Proc. Cotswold Club. p.112.

is listed below.

a) At its western extremity the Aymestry Limestone ridges of Hanging Bank and that of the main ridge are displaced 700 feet horizontally bringing Upper Ludlow against Lower Ludlow Shales and Wenlock Limestone.

b) N.W. of the Pheasantry the overthrust mass of Ravenshill Green is truncated. This is apparent in the mapping by noting that the Woolhope Limestone of this thrust mass apparently abuts against the Aymestry Limestone ridge.

The fault appears to have a downthrow to the S.E. (the strata are inverted north and south of the fault). This would require a N.W. dipping reverse fault or a S.E. dipping normal fault. Of these alternatives, a reverse fault with this dip is unusual, and for this reason the fracture is thought to be normal in nature. If it were transcurrent, evidence of Wenlock Limestone and the overthrust mass might be expected to occur north of the fault. It is suggested that this normal fault is a development of the Malvern Boundary Fault

THE RAVENSBANK OVERTHRUST.

The central part of Ravenshill Wood is an exceedingly difficult tract, densely overgrown with brambles, brushwood and young trees, and this, coupled with the absence of exposures has prevented a positive conclusion being reached regarding the geology. Surface fragments, small pits and topographical features afforded the only information available.

Phillips mapped the entire area as Wenlock Shale and it appears as such on the 1" Survey sheet, but to the present writer this state of affairs seems rather unlikely, since most of the ground is high with well developed ridges.

The three most important geological features observable in the district are:-

a) A scarp face running from Hanging Bank Coppice round the west and south-west side of the Pheasantry, and curving eastwards into Ravenshill Wood. Many fragments of a closely jointed calcareous siltstone were found on this scarp face and the author believes this face to be of Wyche Beds.

b) Striking N.W. - S.E. through the Pheasantry is a well defined topographical ridge. Nowhere is the rock of this feature exposed, but numerous fragments of a nodular ferruginously stained limestone were found along this ridge, especially in the lane leading to the Pheasantry. The author believes this ridge represents a limestone band.

Immediately to the S.W. of this ridge, the ground is flat and south of the Pheasantry the land is even depressed into a valley striking N.W. - S.E. Possibly this represents a shaley horizon between the limestone and Wyche Beds, perhaps the Woolhope Shales.

c) N.E. of the Limestone band previously described, the land slopes rapidly downwards, until it forms a low lying patch of boggy wooded ground. Two patches of fragments were the only clues as to the nature of the rock that lay here. In both cases the fragments showed a grey green shale.

From the foregoing evidence, it will be appreciated that a variety of interpretations could be given concerning the structure, but the one given below is thought to be the simplest.

Stratum contours drawn on the Llandovery boundary mentioned in (a) above, show it to be dipping at 15°-20° in a direction 125°. Of course this is only an approximation, but the mapping does show the Llandovery boundary to be a low dipping surface sloping eastwards. The limestone is probably Woolhope and the shale of Wenlock age, thus making the whole a conformable series from Wyche Beds to Wenlock Shale overthrust on to the Wenlock Shale of the Round Hill structure (see page 140.)

Northwards the overthrust mass is truncated by a N.E. - S.W. striking fault, immediately east of Hanging Bank Coppice. This fault is discussed in the previous chapter, see p. 134.

Phillips[1] describes the same succession as that found by the present writer, but does not comment on the nature of the boundary

1. Phillips, J. op.cit. p.87.

faults. All that is shown on the sketch map in Phillips work is that the area is "upcast".

Immediately east of the Malvern Boundary Fault the Triassic is represented by Keuper Sandstone which is contrary to Phillips mapping. Two wells which have been dug very recently, within 50 yards of the fault, have shown the usual red sandstone associated with this formation.

STORRIDGE ANTICLINE.

The description of this structure is best followed from the sketch map given on page 251. This map marks all the areas separately described in this chapter.

The anticline stretches from Ravenhills Green in the north (32/735545) through the districts of Alfrick, Alfrick Pound and Storridge to Cowleigh Park. The structure is terminated northwards by the complicated structures of the Knightwick Station area, but southwards there is no definite limit, and the anticline continues along the western edge of the Malvern Hills to form the Malvern Anticline, which is described later on page 169. Thus it can be seen from the map that this structure is about 4¾ miles in length and never exceeds 1 mile in width within the Silurian.

The axis of the fold strikes at 165° and is thought to be symmetrical except for the portions in the extreme north by Round Hill and in the south by Cowleigh Park. The fold is pitching to the north, since successively older beds are seen along the line of the axis when traced southwards. Calculations show this pitch to be approximately 2-3°.

A subsidiary anticline with its complimentary syncline is superimposed on the western flank of the main fold. This minor fold has an axis with a strike of 185°. The present author believes this smaller fold develops southwards into the Mathon anticline which is described later.

Detailed descriptions of separate structural areas of the main fold are described below, beginning at the northern end of the area.

Round Hill (32/733537)

The Storridge Anticline is represented by N - S striking Ludlow, Wenlock and Woolhope beds. Lower beds might be represented along the eastern margin if it were not for the overthrust mass of Ravensbank.

A close examination of the map of this district shows in plan:

a) A thin development of Lower Ludlow Shales (270 feet)

b) A thick outcrop of Wenlock Limestone (570 feet)

c) Two bands of quarries within the Wenlock Limestone, the dips of the eastern band being much steeper than those inclinations found in the western band along the same dip direction.

Field evidence of these Limestone bands shows that:

a) Numerous inverted Stromatoporoid colonies exposed on large bedding surfaces showed the eastern band of limestone to be inverted in its northern extremity where it dips to the east. Further south, where the dip is to the west, the beds are presumed to be the right way up.

b) Similar evidence to that outlined in a) showed the western band to be the right way up north of Round Hill, where the limestohe dips to the east. Further south the same band dips westwards and is therefore presumed to be inverted. Analysis of a microscopic rhythm within the shaley limestone showed these easterly dipping beds of the western limb to be inverted. (See Appendix page 219).

c) South west of Round Hill, the boundary between the western limestone band and the Lower Ludlow Shales is a steep scarp face. The normal contact between Wenlock Limestone and the overlying Ludlow Shale is shown topographically as a smooth, concave surface with a slight steepening of the slope as the beds become more limey. This scarp face is interpreted as hard limestone against normal Lower Ludlow without any of the transition beds. The author believes this contact to be a strike fault. Traced northwards this contact becomes a normal concave surface associated with a normal succession.

d) A minor displacement of the two limestone bands can be observed immediately west of Round Hill. This is possibly a sinistral tear fault. It is interesting to note that north of this fault the two limestone bands alter their "way up" with respect to the bands south of this fault.

The structure proposed by Phillips[1] and accepted by the present author is that the Wenlock Limestone is here synclinally folded. North of Round Hill this minor fold is overturned with its axial plane dipping to the east. A strike fault, probably reverse in nature, eliminates portions of the Lower Ludlow and the complimentary anticline to the fold described above.

It is interesting to note that the greatest amount of overturning, i.e., north of Round Hill, occurs immediately opposite the Ravensbank Overthrust or where the E. - W. compressional forces were greatest.

Sections through this part of the structure are given on page 252.

1. Phillips, J. 1848. op.cit. p.87.

Crews Hill (32/734532)

A sketch map of this district is given on page 253. This map shows that the syncline within the Wenlock Limestone described in the previous section, persists to at least the wood south of the road, but is terminated some little distance south of this by a N.E. - S.W. trending fault. The probable nature of this fault was deduced from the field evidence outlined below.

a) The syncline cannot be traced south of the fault, but may be present within the Wenlock Shale, since this formation appears to have a much greater development in this neighbourhood than elsewhere. This favours an upthrown side south of the fault. (Syncline dipping to E.)

b) Tracing the line of the fault westwards proves that it does not fracture the Aymestry Limestone ridge in any way, but further south in the locality N.N.W. of Upper Tundridge Farm (32/732514), the Lower Ludlow becomes very thin (300 feet) in plan view. Elimination of part of the Lower Ludlow could only be brought about by a reverse strike fault. The author suggests that this strike fault is the continuation of the Crews Hill fault.

A normal fault with a dip to the N.W. would cause a greater thickness of Lower Ludlow to be seen in plan view in the neighbourhood of Blackhouse Farm (32/731526).

South of the fracture the Wenlock Limestone dips normally at between 50° and 60° to the west. Dips on the Aymestry Limestone range from $70^{\circ}/281^{\circ}$ at The Steps (32/728527), to $48^{\circ}/233^{\circ}$ at Longley Green.

Ravenhills Wood (32/738537)

The area under consideration in this section is very poorly exposed, and only fragments of rocks could be found. The little evidence that was seen, is outlined below.

a) Between the Ravensbank Overthrust mass and a point 3,000 feet S.S.W. of the Fox and Hounds, Ravenhills Green, the ground is high and is covered with fragments of limestone resembling Woolhope. A small pit 1,950 feet S.S.W. of the Fox and Hounds showed a nodular limestone stained dark purple and green, apparently unfossiliferous. The colouring is due to neaby Haffield Breccia.

b) South of Ravenhills Wood the core of Storridge Anticline is revealed in the form of Llandovery with flanking bands of Woolhope Limestone.

Between the exposures described in a) and the structure outlined in b), a possible fault might exist to account for the apparent complete coverage of Ravenhills Wood with Woolhope Limestone. It is suggested that the N.E. - S.W. striking fault of Crews Hill continues through Ravenhills Wood downthrowing the strata to the north, and is itself dipping to the S.E.

Structures within the Woolhope Limestone of West Alfrick.

An examination of the sketch map on page 283, shows that Woolhope Limestone is present along the whole western flank of Storridge Anticline from Ravenhills Wood in the north to Mousehole Bridge (32/739515) and beyond in the south. Closer inspection of this band shows that this limestone is fractured by a number of what the present author believes to be transverse faults.

These small fractures were easily mapped. The limestone formed a well defined feature and any displacement was recognised by an offsetting of the ridges and sometimes a depression in the line of the fault. All these fractures have left hand displacements except for the two biggest ones which are dextral in nature.

Some of the displacements create limestone bands with differing strike directions on either side of the fault. This is particularly seen in the fracture immediately north of Mousehole Bridge. Whether the compressional stresses actually altered the strike of the limestone, or the fractures are the result of a tight fold or wrinkle superimposed on the main fold, is a debatable point, but it is possible that one of these displacements, such as the one north of the bridge, might be the continuation of the fold seen at Crew's Hill. Of course the Crew's Hill folds might die out within with Wenlock Shale and not be represented by any distortion within the Woolhope Limestone.

Structures of the Alfrick Pound District.

This section discusses the structures within the Woolhope Limestone and neighbouring formations which form the eastern flank of Storridge anticline. The beds are fairly well exposed in the numerous small lanes of this district.

The map shows the Woolhope Limestone to strike at 185° from Bowel House (32/744525) to the Pound (32/744522). It forms a wide outcrop owing to the shallow dips between 5°- 10° to the east and the ground itself sloping in the dip direction.

It is quite possible that minor flexuring and faulting has distorted the limestone in places. This is suggested in a roadside exposure 540 feet E.N.E. of "New Inn", Alfrick Pound, where the Woolhope Limestone can be seen to steepen its dip from 5° to one of 40° in a distance of 20 feet. Phillips also describes this exposure as having a normal fault to the west and gives a section of the roadside when it was fresh and exposed [1] more.

The limestone from the Pound to Bridges Stone (32/749521) alters its strike and curves in a direction 075° and then turns sharply southwards to a direction 138°. Thus, in plan view the limestone forms a broad "S" shape or represents a minor anticline and syncline.

South of Alfrick Pound, the beds forming the axial region of Storridge Anticline become progressively older, represented first by the Woolhope shales exposed in Cradley Brook and the lane leading soutwhards from the Smithy, and secondly by the Wyche Beds seen further south in old quarries which border the brook S.S.W. of Bridges Stone.

<u>The Alfrick Overthrust.</u>

This structure borders the eastern limb of Storridge Anticline between Alfrick Court (32/745533) in the north and Birchenhall Farm (32/752515) in the south. It is entirely composed of easterly dipping Wenlock Shale, and terminates the Woolhope Limestone at Bowel House and Bridges Stone. Evidence for this structure was obtained principally by correlating similar lane sections that disect the Alfrick district. These sections are given below.

1. Phillips, J. 1848. op.cit. p.76.

a) The Upper House - Workhouse Bank lane shows no recognisable feature that could be associated with the Woolhope limestone, but instead creates a deep concave surface associated with a hard formation against a softer one. Examination of the lane's banks shows grey-green calcareous shale fragments at the eastern end of the section, and hard grey closely jointed calcareous siltstones by Workhouse Bank, that is at the western end of the section.

b) A section immediately to the south along the lane from Upper House to Bowel House was very well exposed. The eastern end of the lane revealed an 8 foot section of an olive green jointed calcareous shale which weathers to a buff chalky dust. Fossils collected from this locality include:

Strophonella euglypha (Wenlock var.)	Leptaena rhomboidalis.
Cyrtia exporrecta.	Dalmanites vulgaris.
Atrypa recticularis.	Craniops implicata.
Bilobites biloba.	Plectodonta tranversalis.

The dip on this exposure is 28°/064°. Further westwards there is another exposure of the same shale, here the dip is 18°/082°. Immediately west of this outcrop the ground steepens.

At the road junction by Upper Norgrove (32/744527) there is another section which is described in detail.

Top.	Road Junction. Section along line 316°, dip on beds 25°/098°. Dark purple with grey speckling soft thin bedded sandy shale.	10 feet+
	Grey and purple shale interbedded with an impure	8 feet

dark grey crystalline limestone. The limestone is very closely jointed forming cubes no greater than 1 inch cube, and has a closely set rhythm of alternate white and dark grey lines.

Similar to previous exposure, except the fine silty limestone is more predominant and has many micaceous layers. The rhythm is also more pronounced. 13 feet

Hard fine flaggy sandstone with very thin bands of sandy shale. The sandstone is often banded. 4 feet+

Bottom.

The author believes that the section just described can be correlated in lithology to beds in the lower Woolhope Shales and upper Wyche Beds. The olive green shale described at the beginning of the lane section is thought to be Wenlock in age, and therefore a fault must exist between these set of exposures.

c) The lane leading from Bridges Stone to Old Storridge Common is not so wellexposed as the previous lane, but the presence of a fault is just as easily deduced.

260 yards S.S.E. of New Inn, Alfrick Pound, the lane cutting shows a 50-60 foot incomplete section of a softish calcareous mudstone weathering to a light buff colour with occasional nodules of an impure nodular limestone. Fossils from this exposure include:

Atrypa recticularis
Leptaena rhomboidalis
Strophonella euglypha (Wenlock var.)
Bilobites biloba
Meristellid
Craniops implicata
Sowerbyella cf. quinquecosta M'Coy.
Skenidioides sp.
Dalmanites sp.
Kionoceras sp.
Acidaspid.

The dip on this shale is $34^{o}/083^{o}$.

5 feet above these olive green shales, the same bank of the lane showed typical Wyche beds of thin bedded sandstones. These revealed:

Atrypa recticularis.
Favosites sp.
Parmorthis cf. elegantula.
Strophomena sp.

70 yards west of the shale exposure there are a series of old quarries which show Wyche beds dipping at 10°/088°. As the Wyche Beds have such a low angle of dip, it is improbable that higher beds than this formation would outcrop between this line of quarries and the Malvern Boundary Fault. Again this lane section must be interpreted as Wenlock Shale faulted against Llandovery beds.

The line of separation between the Wenlock Shale and older horizons can be mapped with fair accuracy by the marked change in slope. This is particularly true in the north by Workhouse Bank and in the south by Old Storridge Common. Stratum contours drawn upon this contact show it to be dipping at 10°- 20°in a direction 080°. Such a contact is probably a low angle thrust.

It is uncertain what happens to the contact at Bridges Stone since there is a covering of Haffield Breccia and alluvium in this area.

<u>The Bridges Stone district</u> (32/749522)

A sketch map of this district is given on page 255. From this map it is seen that the structures are principally within the Permo-Triassic formations and the field evidence for deducing the relationship between the various beds is given below.

The vertical junction between the Haffield Breccia and the Keuper Sandstone can be seen in the road section above Knapp Farm; the breccia is dipping at 65°- 70° W.S.W., whereas the sandstone is dipping 10°- 20°E.N.E. The breccia is weathered to a yellowish colour at the junction. The angular relationships between these two formations suggests that the junction is a fault.

Exposures at the side of the path leading from the road down to the brook show the breccia to be dipping at 72°/295°, whereas in the stream section, the dip is 80°- 90°E.N.E. In places there are bands of purplish and greenish grit with flattened pebbles which appear to have no counterpart at the other exposures of the Breccia .

A steep gulley occurs at or near to the Silurian-Breccia contact between the road and the brook. Most significant is the presence of a small patch of sandstone which lies with apparent unconformity upon the breccia. The sandstone is soft, white with purple streaks and spots and crumbly. Its dip is approximetely 60°/085° and is separated from the breccia by a thin soft grey and khaki-brown clay. The dip on the breccia is difficult to decide. The age of this sandstone and its relationship to the breccia is uncertain, but as the clay band has no appreciable dip, it is suggested that the sandstone lies unconformably upon an eroded Haffield Breccia land surface.

Small exposures of Woolhope Limestone and Wenlock Shale were found immediately west of the gulley. It is suggested, therefore, that a branch of the Malvern Boundary Fault downfaults the Haffield Breccia and Sandstone to the east from the Wenlock formations.

South of the brook, only evidence of shales of Wenlock age could be found. The Haffield Breccia is terminated in some way in the vicinity of the brook. It is suggested that the breccia might form a lens shaped mass in plan view and be part of a horst structure.

<u>Coneygore Coppice</u> (32/745510)

The geology described in this section is comparatively straightforward, and is confined to the Llandovery and Woolhope formations.

Cradley Brook which flows between Tor Coppice and Coneygore Coppice shows a great number of exposures within the Llandovery, principally in the Wyche Beds. Their dips vary between 5° and 60° and their directions of dip between 210° and 265°. From this it can be seen that the main structure of Storridge anticline is by no means a simple fold, but is possibly represented, at least here, as a small anticlinorium.

The Woolhope Limestone is faulted in four places between Mousehole Bridge and Shuttifield Coppice (32/743503) and the author suggests that these fractures are transverse in nature, similar to those found to the north at west Alfrick. All these faults were mapped on the displacement of the Woolhope Limestone ridge and an associated topographical depression along the strike of the fault.

<u>Mallins Wood Area</u> (32/745498)

A sketch map of this district is shown on page 257 and the reader can see that the structure is principally concerned with folded and faulted Woolhope and Llandovery beds.

Close examination of the brook that runs along the western edge of Mallins Wood showed that the Woolhope Limestone and overlying Wenlock Shale were tightly folded into a syncline and anticline with axes striking in a direction of 185° , that is oblique to the main Storridge anticline by 15°. The syncline, which is the fold that lies to the east of the two, is so tightly compressed that its axial region might be faulted, since both limbs of the fold become vertical in dip in the axial region.

The western limb of the anticline is at one point overturned and shows a dip of 70°/086°. The folds are therefore assymetrical, at least at this point, with easterly inclined axial planes.

The folds are easily mapped, since the Woolhope Limestone forms a prominent ridge which is arranged in a flat "S" shape. Immediately north of this section, there is another stream section through Woodhouse Dingle (32/745501) where the two folds are again seen, this time in beds of Woolhope Shale and Wyche Bed age.

When the Woolhope Limestone is traced northwards along the well defined topographical ridge, a point is reached 750 feet S.E. of Batchcomb Farm, where the limestone band is displaced indicating an oblique fault. Discussion of this fault is made in a later chapter (see page 166). The author concludes that this is a reverse fault dipping westwards and thus has a downthrown east side.

South of Mallins Wood in Merryhill Common (32/748491) the Woolhope Limestone is again displaced by an oblique fault, possibly another tear or reverse fault similar to those described for other dislocations of the Woolhope Limestone.

Birchwood Overthrust (32/757497)

A detailed sketch map of this district is given on page 258. Evidence for this structure in terms of field observations is given below:

a) The limestone exposed in the numerous quarries of Limekiln Coppice has lithological and thickness similarities to Wenlock Limestone.

b) The limestone exposed on the main road and the topographical ridge which obliquely cuts the road is undoubtedly Woolhope in age, since it is underlain by typical Wyche Beds exposed in Doddenham's Grove, further westwards towards Storridge. The same reasoning is applied to an exposure of Woolhope Limestone exposed north of Limekiln Coppice.

c) The boundary along the western edge of the Wenlock Limestone is a scarp face curving eastwards north and south of Limekiln Coppice, cutting obliquely across the bedding of the Wenlock Limestone.

d) Wenlock Shale is exposed in a stream section between the main road and Limekiln Coppice. This exposure is along the strike direction of the Wenlock Limestone exposed in Limekiln Coppice to the north. Clearly a fault separates the two exposures.

e) The Woolhope Limestone ridges appear to abut against the high ground formed by the Wenlock Limestone.

f) N.E. of the Wenlock Limestone the ground is relatively flat, and contains numerous shale fragments. A pit dug in this area showed a clacareous grey-green thin bedded shale; fossils were scarce, but those identified include:

Atrypa recticularis
Leptaena rhomboidalis.
Bilobites biloba
Cyrtia exporrecta
Eospirifer cf. radiatus.

Assuming the Wenlock Limestone is the right way up, the shale would be Wenlock in age.

From this, the present author concludes that the Wenlock Limestone and Shale is overthrust on to the Woolhope Limestone and Wenlock Shale of the eastern limb of Storridge Anticline. From stratum contours drawn on this fault plane, it was calculated that the plane is dipping at 15-20° in a direction 065°.

Phillips[1] does not record this complication; but shows the beds in an ordinary succession from Llandovery to Wenlock Shale. Groom[2] suggests thrusting has taken place, but does not show that the thrust mass extends as far westwards as the Woolhope Limestone of Limekiln Coppice.

The stream section 300 feet N.W. of New Inn is not part of the overthrust, but is described in this section due to its proximity to this fault. The section is incomplete and extends over about 50 feet.

1. Phillips, J. 1848. op.cit. Map at back of memoir.
2. Groom, T.T. 1900. Q.J.G.S. Vol.LVI. p.198.

East end. Purple marls - Keuper.

Grey, but sometimes light green or brown, soft sticky clay with numerous carbonaceous inclusions. This is correlated with clays of similar lithology found by Kingswood Common, Martley - Carboniferous.

Soft grey-green calcareous shales with occasional nodules of impure limestone. Dip 24°/009°. These shales are probably Wenlock in age since they pass downwards into Woolhope Limestone when traced westwards - Wenlock Shale.

Western end.

The contact between the Triassic and Carboniferous is seen in the banks of the stream and is shown as marls resting against grey clay without any contact phenomena. It is uncertain how much slumping has occurred at this point. The other contact is obscured.

Westwards of this area, the core of Storridge Anticline was investigated in the stream section which runs besides the main road in Doddenham's Grove (32/756489). The western end of the Grove showed that the Llandovery beds were flexured into a number of tight wrinkles and folds.

<u>The Wildgoose and Whitman's Hill Districts.</u>

The structures about to be described are found in the Wenlock Limestone and Lower Ludlow shales. The structure consists of a syncline with a complimentary anticline to the west and an apparent left hand displacing fracture on the anticline's western limb. The strike of the fault is parallel to the folds' axes and are oblique to the main trend of Storridge Anticline.

Little can be said that the map on page 2-2 does not show. The rocks are exceedingly well exposed within the numerous old quarries. In many places the actual core of the anticline was exposed, these include:

a) 888 yards 5°N. of W. of Whitkans Hill Farm (32/744473)

b) 950 yards S.W. of Whitmans Hill Farm (32/744478)

c) 1,000 yards N.E. of Cradley Church (32/745475)

North of Wildgoose Hill the mapping is not quite so distinct since it is masked by low lying boggy ground (32/744489).

South east of Whitman's Hill in the neighbourhood of Upper Vinesend Farm, there are numerous old quarries in the upper part of the Wenlock Limestone which show bedding planes which are flexured into corrugations or rolls. None of these minor folds have amplitudes greater than a foot or closures larger than about 3 feet. These wrinkles may be attributed to drag during the major folding movement.

<u>Rough Hill Wood and Cowleigh Park Districts.</u>

Part of this district is shown on the sketch map on page 261. Examination of the 6 inch map shows that this section deals mainly with the Woolhope and Llandovery series that form the western limb of the main anticline.

Considering first the Woolhope Limestone, we see it to be dipping at between 20° and 35° in a direction roughly 260° by Hill Farm (32/757483) in the north. The limestone steepens southwards until it is inverted by the road at Cowleigh Bridge. Further to the south the limestone assumes a normal dip of between 30° and 40° to the west.

The most conspicuous fact about the Llandovery of this district, is the pink grit which strikes roughly N.- S. through Cowleigh Park and Rough Hill Wood. Mention has already been made to this horizon on page 13, By the appearance of the scarp face, it would appear that the grit is overturned in most places, it would at least have a very steep dip, since there is only 540 feet of rock between the grit and the base of the Woolhope Limestone at Cowleigh Bridge (32/759478). The pink grit band curves eastwards north of Rough Hill Wood suggesting that the storridge anticline pitches to the north, at least in this locality.

Only two fractures could be found in this district.

The first was mapped as an oblique fault by Hill Farm. There is a well exposed section of the Woolhope succession S.W. of the farm in a track. Investigation of this section showed normal Woolhope limestone grading downwards into normal Woolhope Shales. At a point in the section outside the farm, there is a small exposure of limestone similar to that found in the track to the S.W. of Hill Farm, i.e., Woolhope Limestone. Associated with this small exposure of Woolhope Limestone, there is well defined topographical ridge striking southwards through Rough Hill Wood to the Cowleigh Park road. The present author does not attribute this limestone ridge to part of another development of limestone within the Woolhope Series since this would necessitate a thickness of between 200 and 300 feet for the Woolhope Shales, which is uncommonly large. The present writer, therefore, suggests that the Woolhope Limestone has been repeated by a fault. The Woolhope feature which strikes from Storridge is terminated 1,100 feet S.S.W. of Hill Farm by a N.N.E. - S.S.W. depression, which suggests the limestone is faulted. It is quite possible that this fracture is the one that repeats the Woolhope at Hill Farm. The same fault may extend northwards along an associated depression in the Llandovery to Doddenham's Grove.

It is obvious that this fault has a downthrown side to the east and thus could represent a reverse fault dipping westwards or a normal fault dipping eastwards. Both these trends are possible, but as the author has proposed that similar trending faults found to the north by Alfrick in the Woolhope are tear faults, he suggests that this fracture under discussion is of a similar nature.

The second fault is situated in High Wood S.W. of Cowleigh Park. Here the Pink Grit and Woolhope Limestone are displaced by a right handed tear fault.

Groom[1] unlike Phillips recognised two other faults. The first north of Rough Hill Wood is tear in nature and terminates the pink grit and Woolhope Limestone by Hill Farm. This is not

1. Groom, T.T. 1900 op.cit. p.157 & 197.

conducive with the present author's mapping. The second fracture lies along the line of Whippets Brook and is also supposed to be tear in nature. Close inspection of Grooms map shows an anomalous interpretation. The displacements on the Woolhope and pink grit by Cowleigh Bridge are practically negligible, whereas a large throw would be needed west of the bridge, where Wenlock Shale is seen against Cowleigh Park grits. The present writer cannot find any evidence for the inclusion of this fault.

The Cowleigh Park and Whippets Brook Districts.

This section is concerned with the district immediately north of North Hill and east of the Pink Grit mentioned in the previous section. A sketch map of this area is shown on page 261, and the tectonics associated with this district are part of those of the main Malvern Hills described later in this thesis.

The area is exceedingly complex, dissected by numerous faults and bears no relationship to the main structure of Storridge Anticline to the west. Exposures are very few and resort had to be made to fragments and topographical features for the delineation of the structure.

The most striking features of this area are the masses of syenite east of the road. These masses are mapped as two lens shaped areas, the northern one elongated N. - S. across Whippets Brook (32/762480), and the southern one extending also N. - S. cuts the North Malvern-Cowleigh Gate road (32/763477). The rock has previously been discussed on page 9 , and a pre-Cambrian age was concluded due to their lithological similarity to the Malvernian of North Hill.

It is quite obvious that the boundaries between these two masses and the younger rocks must be faulted, the nature of which will be discussed later. East of this faulted area, Groom[1] recognised synclinally folded Wenlock and Ludlow beds, but the present author does not find enough field evidence to substantiate this claim. Mapping shows the presence of a series of N.N.E. - S.S.W. striking beds dipping to the E.S.E. at an angle of 30-40°. Evidence to prove this is given below.

a) 330 yards E.N.E. of Cowleigh Bridge, typical Wyche Beds were found in a 4 foot pit. These beds were grey calcareous siltstones with sandy and limestone nodules. Many fragments had the rhythmic bedding common to horizons belonging to the Upper Wyche Beds.

b) S.W. of the pit mentioned in a), there is a high ridge striking N.E. - S.W. covered with limestone fragments. This "rusty" limestone had the lithological characteristics of the Woolhope Limestone. This ridge appears to be terminated 450 yards E.N.E. of Cowleigh Bridge.

c) Between the ridge mentioned previously and the high feature through Mill Coppice, there is a marked topographical depression. A small exposure in the track leading from Mill Coppice to Cowleigh Park Farm showed a grey-green calcareous shale stained purple. The dip on these beds is 35°/100° and fossils

1. Groom, T.T. 1900 Q.J.G.S. Vol.LVI. p.157.

collected from this exposure include:

- *Chonetes lepisma*
- *Atrypa recticularis*
- *Bilobites biloba*
- *Cyrtia exporrecta*
- *Leptaena* sp.

d)The south eastern flanks of the ridge through Mill Coppice are covered with limestone fragments, typically Wenlock in age with its numerous crinoid remains and fragmented fossils. A particular peculiarity is its oolitic nature, but this is not abnormal, since there are many exposures showing both oolitic and pisolitic limestones at West Malvern, less than one mile from Mill Coppice.

The observations on the road section between Cowleigh Park Farm and Cowleigh Bridge are in agreement with those illustrated by Phillips[1] , except that the limestone he calls Woolhope is thought to be Wenlock in age by the present author.

Examination of the facts already outlined shows that the mapped thickness of Wenlock Shale is abnormally small (300 feet) and that the Woolhope Limestone is not persistent along its strike. An oblique reverse fault is proposed with a dip to the E.S.E. as shown on the map. Another fault must also exist along the line of the road immediately N.W. of Cowleigh Park Farm, since sandstones of Llandovery age are found on the south side of the lane and horizons of Wenlock age are to be seen in the northern banks of the road. This is probably a left handed transverse fault with a throw of at least 1200 feet.

1. Phillips, J. 1848. op.cit. p.37.

Considering the relationship of this area to the rest of the structure, the reader is reminded of the numerous occurrences of patches of complex geology along the eastern margin of the Malvern and Abberley Hills and their interpretation as thrusts. The present writer therefore proposes that this area under discussion also represents a portion of an overthrust which has subsequently been lowered to its present position by a normal fault, represented as the western margin of the area. Thus this small district may be considered an epitome of the whole Malvern Range, and shows the possible relationship of the beds beneath the Triassic east of the Malvern Hills.

The tracing of this normal fault northwards from Whippets Brook is uncertain, but it no doubt joins the Eastern Boundary north of Whippets (32/762485). The southern extension of the same fault from the southernmost syenite mass is equally as uncertain, but probably merges with the fault that bounds the western limit of the Malvern Hills.

MATHON ANTICLINE AND SYNCLINE.

A large sketch map of this district is shown on page 262.

These structures lie to the west of the Malvern Hills in the district of Mathon. Here the Ludlow and Downtonian strata have been folded into a western anticline and an eastern syncline with N. - S. striking axes. Normal faults have subsequently fractured the folds into the pattern seen today.

The reader is reminded of a series of descriptions that have been made in this thesis, of disturbances on the western limb of the Storridge Anticline. These include the Wenlock Limestone at Whitman's Hill (32/744478) (see page 154), Woolhope Limestone at Mallins Wood (32/745498) (see page 150), and a possible disturbance on the eastern limb at Bridges Stone (32/749521). All of these structures have included a syncline, anticline and fault with fold axes striking 185^{o}. The author believes all these structures to be part of the same fold system which has, at Mathon, folded the Ludlow and Downtonian. A brief account of the field evidence that was found is listed below:

a) The synclinal portion of the system was comparatively easy to map. The north end of High Grove Wood (32/748467) showed a set of dips on the western and eastern limbs and the axial region, all recorded on the Lower Ludlow Shale.

The eastern limb of the fold is well defined by a N. - S. striking ridge of Aymestry Limestone which passes immediately west of Bank Farm, through Stockton's Coppice to outcrop in a quarry by the main road at Pemberton Cottages. The dips on this limb are between 20° and 28° in a direction approximately 240°.

The western limb is not so well defined, but can be traced through the eastern edge of High Grove Wood, to a point west of Long Grove (32/747459), where it is faulted. This limb is much steeper than its eastern counterpart, dips of 52° and 65° were recorded in a direction aproximately 090°. The syncline is therefore asymmetrical with its axial plane dipping to the west. The southern end of the western limb curves to the west and shows a portion of the crestal region of the anticline. A dip of 9°/162° was recorded on the Lower Ludlow Shale, 450 yards E.S.E. of Cockshot Hill, which must represent an outcrop not far removed from the axis.

The syncline forms high ground with a concave surface on top of the Hill. Phillips[1] recognised Downtonian in the central portion of the syncline, but the present author has only found beds as high as the Upper Ludlow in age.

The syncline is faulted obliquely south of Long Grove, but the presence of this structure south of the fault can easily be seen in Bagburrow Wood (32/749455) where the dip is 40°/077° and in Littley Coppice (32/755453) where the dip is 27°/242°. The section across the fold south of the fault, is one structurally higher and exposes Downtonian in the axial region.

b) The anticline of the fold system lies to the west of the syncline described above. The western limb of the fold can

1. Phillips, J. 1848. op.cit. Map at rear of Memoir.

be traced through Hill Wood (32/741469) and Cockshot Hill (32/742464) as a high ridge of Aymestry Limestone. Dips on the limestone and Upper Ludlow range from 60° to 85° in a general direction 255°. At one point immediately soŭth of Hill Wood the limestone is overturned by 10°.

South of Cockshot Hill the anticline is faulted obliquely in two places, and the fold re-appears in Rowburrow Wood. Old quarries and recent clearing of this wood have shown exposures on the western limb and crestal regions of the anticline. Dips on this western limb show it to be dipping at between 15° and 30° in a generel westerly direction. This western limb is truncated by an oblique fault N.W. of Mathon Court (32/746455).

Dips along the road side by Rose Farm show that the eastern limb is dipping at up to 60° in a direction 085°.

The fault system, although apparently complex is comparatively simple and made up of two principle N.W. - S.E. normal faults and a N. - S. reverse fault. The faults on the sketch map (see page 264) are numbered, and descriptions of these fractures will be given below, beginning with the normal faults.

Fault 1. This fault strikes from Cockshot Hill through the northern part of Rowburrow Wood to Littley Coppice. It is mapped on surface features, such as the truncation of limestone ridges, and surface depressions. The fracture has a downthrow side to the S.W. and it is suggested that it is normal in nature, since it is parallel to another great normal fault 3. Thus the author believes this fracture to be normal in nature dipping to the S.W.

The fault is thought to change its strike direction slightly at the southern end of Long Grove, and cut the eastern limb of the syncline by the main road. This change in direction may be due to difference in competency of the rocks. Thus the strike under the proposed conditions would have a bigger easterly component, the greater the competency of the rock. This is seen again when the same fault is believed to cut the Wenlock Limestone further to the S.E. at Colwall Stone (32/763435.)

Fault 2. A deep topographical depression striking 080° through the northern edge of Rowburrow Wood is thought to be the position of another fault. Additional proof of this fracture is that it truncates an Aymestry Limestone ridge. Also north of the proposed fault an excellent exposure of Upper Ludlow was found dipping at 28°/304°, and south of the depression there were numerous exposures of Lower Ludlow. Fauna collected from these localities include:

North of the Fault.	South of the Fault.
325 yards S.S.E. of Cockshot Hill.	420 yards S.S.W. of Cockshot Hill
Dip 28/304°.	Dip 26/306°.
Chonetes Striatellus.	Delthyris elegans.
Dayia navicula	Craniops implicata
Leptaena rhomboidalis	Dalmanella sp.
Dalmanella sp.	Berychia machoana
Murchisonia sp.	Cornulites ?
	Acidaspis sp.

From the map it is seen that this fault also has a downthrow side to the south, and the author suggests that this fault is a fork of fracture 1 and is exactly the same, both in nature and dip direction.

Fault 3. This fault is a major fracture and may be mapped from Overley Cottages (32/738462) to Gardeners Common (32/754421) a distance of 3 miles. Along its whole length it truncates the limestone ridges of the Silurian formation. In this locality it terminates the western limb of the anticline at Overley Cottages and Mathon Court and the eastern limb of the fold to the south of Bagburrow Wood (32/750448).

Downtonian strata is found south of the fault, and thus the fracture has a downthrow side to the S.W. In a later section, the nature of the fault is discussed, and the probable throw established (see page 172).

Faults 4, 5 and 6. These three faults are part of the same fracture which has itself been faulted by faults 1 and 2.

The evidence for 4 and 5 cannot be seen in the field, but are inferred from the close similarity of the complete Mathon fold system to these systems found to the north at Whitmans Hill and Mallin's Wood. Close inspection of the areas just mentioned shows that along the western limb of all the anticlines there is a fault obliquely cutting the formations and striking parallel to these folds' axes. Such a fault is presumed to continue to the Mathon district and appear by Cockshot Hill. The normal fractures 1 and 2 would fault it to a position west of Rowburrow Hill, where a fault is actually mapped from field evidence.

The fault west of Rowburrow Hill (6) is substantiated by finding Lower Ludlow apparently resting upon Upper Ludlow. The Lower Ludlow has already been established (see fossil list under fault 2) and ample exposures of Upper Ludlow and Aymestry Limestone exist east of the Lower Ludlow in Rowburrow Wood. All of these formations are dipping to the west. The Ludlow formation has obviously been repeated by a strike fault with downthrow side to the east.

In considering the nature of this fracture, there are the alternatives of either a normal fault dipping to the east or a reverse fault dipping to the west. The fault has a strike which is persistently parallel and close to the fold axes, and the present author believes that this fault was the result of some compressional earth movement that created these folds. The fracture would, under these conditions, be reverse in nature and dip to the west.

Fault 7. Within the fault block bounded by faults 1 and 2, there are two distinct series of Ludlow beds, all dipping to the west. The idea that they might be parts of limbs of recumbent folds is not seriously considered since the Ludlow formations are repeated in such a way as they both young westwards. Such an arrangement is the result of a strike fault. The mapping of this fracture is by no means certain and can only be ascertained by surface feature. It appears to be truncated by faults 1 and 2 and to be parallel to faults 4, 5 and 6, and for this reason, is taken to be another reverse fault dipping westwards

Summarising it is seen that the Mathon anticline, syncline and reverse fault on the western limb have been normally faulted by N.W. - S.E. striking and S.W. dipping faults.

MALVERN ANTICLINE.

This chapter deals with the structures in the Silurian rocks on the west side of the Malvern Hills. These strata are part of the western limb of an anticline, the central and eastern regions of this fold have been overthrust and faulted away from its original position. The formations near to the pre-Cambrian are generally overturned and show a high dip to the east. The whole structure has been subdivided into sections which will be described below.

West Malvern District.

The Silurian rocks are, in this district, dipping uniformly to the west. The Wenlock Limestone has a dip of between 30° and 50° in a general direction 250°, and appears to be completely unfaulted from Whitman's Hill in the north to Colwall Stone (32/764435) in the south. In the region of Park Wood and Mathon Park, the limestone appears to have a much thinner development than elsewhere, but this point has been discussed on page 29 .

The Woolhope Limestone is overturned along its whole length of outcrop, apart from the district around Birches Farm (32/760468). Like the Wenlock Limestone, the Woolhope is comparatively free of fractures. The Woolhope Limestone was mapped as a sharp change in topographical slope which passed through the town of West Malvern, Park Wood and Upper Wyche.

The Wenlock Shale is inferred to exist between the Woolhope and Wenlock Limestones. There are no exposures, but the ground is covered with numerous fragments of an olive green shale. At times the shale maps as a much thinner bed than that found to the north in the Storridge district. It might be possible that it has been tectonically squeezed, and part of it eliminated during one of the great compressional folding movements.

Beneath the Woolhope, there are a few exposures of Llandovery. Groom[1] in his paper made particular note of several exposures of Llandovery rocks, especially those close to the pre-Cambrian. Unfortunately, most of these exposures have since disappeared, or the quarries built on or filled in. There are, however, two interesting exposures that are still visible and these will be described below:

a) 620 yards W.N.W. of North Hill fragments of Llandovery sandstone were found 80 yards from the pre-Cambrian-Silurian boundary. Closer investigation showed that these fragments coincided with a topographical depression striking N. - S. and separated a mass of pre-Cambrian from the main mass of North Hill.

b) A great deal has been written about The Dingle, West Malvern (32/765456), but here again most of the exposures have since become obscured. One interesting fact still remains however, and that is the apparent inclusion of a band of Llandovery Sandstone within the pre-Cambrian and 20 feet above the eastern margin of the Silurian.

The inclusion of these masses of Llandovery within the pre-Cambrian can only be explained by faults. Whether they resulted from the overthrusting and form part of an imbricate zone, or resulted from

1. Groom, T.T. 1900. op.cit. p.149-155.

the later normal faulting is very difficult to decide.

The Colwall Stone and Upper Wyche Districts.

This section is concerned with the faulted districts of Brockhill, Colwall Stone and The Wyche.

Beginning with the Ludlow formations and particularly the Aymestry Limestone, it is seen that these formations dip at between 25° and 35° in a general direction 264° from Mathon to Brockhill Coppice. South of this location, the limestone curves westwards and alters its dip direction to 278°. 350 yards S.E. of Brockhill Farm the limestone ridge is terminated by a N.W.- S.E. striking fault - the Colwall Fault.

The mapping of the Wenlock Limestone showed a similar change of strike direction comparable with that found in the Aymestry Limestone. The strikes were 264° in the region of Park Wood and Colwall Coppice, but suddenly changed to 312° in the region of The Quarry. The change is very sudden and the region of the change is marked by a deep topographical depression striking at 315°. The author believes the Wenlock Limestone is faulted at this point. The fault has a downthrow to the S.W. and is probably normal in nature, and appears to be parallel to the Colwall Fault. The author also suggests that this particular fracture may be a continuation of fault number 1 described in the Mathon Anticline and Syncline (see page 164). A continuation of this fracture along its strike eastwards, shows that it also dislocates the Woolhope Limestone at a point 550 yards S.S.W. of the Wyche cutting (32/766433). Although the Woolhope Limestone is inverted at this point, it is displaced in such a manner as to suggest that the fault has a downthrow side to the S.W., which is in agreement with that deduced previously.

An interesting feature about the Wyche Pass (32/768437) is the occurrence of a patch of Llandovery sandstone close to the western opening of the cutting. According to Phillips[1], this is embedded in the crystalline rocks. This author reproduces a sketch of the section and a list of fossils collected from the sandstone, he shows the Llandovery to be almost vertical (inverted at the top), and to belong to the upper part of the Wych Beds. The present author was not fortunate enough to find evidence of these bedded rocks, but was able to find numerous fragments of a sandstone similar in lithology to the Llandovery sandstone.

Detailed mapping of the district between the Wenlock Limestone and the pre-Cambrian was made by the Geological survey in connection with their survey of the Malvern railway tunnel. The result of this work was published in "Summary of Progress" for 1925[2]. In this work the author reproduces a section along the line of the tunnel, which shows numerous faults and minor folds within the Wenlock Shale.

The fault at the mouth of the tunnel (the Colwall Fault) was regarded by Phillips as a sharp flexure accommpanied by squeezing out of the beds[3], but was more correctly mapped by Holl as a true fault. All subsequent workers have termed the separation as a fault. The excavations for the tunnel showed that the fault at this point was vertical and separated rocks of ages i) Upper Wenlock Shale from ii) Old Red Sandstone equivalent to an horizon 300 feet above the

1. Phillips J. op.cit. p.64
2. Robertson, T. 1925. "Summary of Progress" Mem.Geol.Surv.1926
3. Phillips, J. 1848. op.cit. p.136.

base of the Old Red Sandstone. Estimates of the throw of this fault show it to be nearly 2,000 feet. The present author suggests that it is normal in nature and is apparently terminated to the east by the Western Boundary Fault.

Linden Manor District.

This section deals with the fault system mapped in the vicinity of the Linden Manor Hotel (32/764426). A sketch map of this district is shown on page 266 . Basically, the area is composed of the major Colwall fault and three minor faults.

The Colwall fault strikes at 150^{o} from the railway cutting, through the grounds of Winnings Farm and Linden Manor to a point on Gardener's Common where it is terminated by the pre-Cambrian boundary. Along its course it truncates the Aymestry and Wenlock Limestone ridges south of the fault and the Woolhope Limestone north of the fracture. It is easily mapped by the surface depression it forms. The apparent surface displacement of the Woolhope Limestone by this fault is considerably less than displacements on beds higher in the Silurian formation. This is thought to be due to the very steep dip of the Limestone and possibly to the change of dip direction from inverted at the surface to steeply dipping normal beds below the ground. It is uncertain whether this fault is part of the Western Boundary Fault or is actually terminated by this fracture, or even continues to dislocate the pre-Cambrian rocks of the Malvern Hills.

North of the Colwall Fault, the Woolhope Limestone is dislocated by three faults. All of them were mapped from surface features, such as the displacement of the ridge associated with the Woolhope Limestone. All of these fractures are thought to be part of the same movement that brought the Colwall Fault into being. It is interesting to note that the Geological Survey also mapped these faults and detected their presence in the Malvern tunnel within the Wenlock Shale[1].

Between the Colwall Fault and Evendine, the geology is comparatively simple. It is composed of uniformly dipping beds, which are apparently free of fractures apart from one. This fault is described in the next section.

The beds become steeper in dip the closer they are to the pre-Cambrian. The Ludlow dips at between 37° and 50° in a general direction 285 , the Wenlock Limestone 60° to 80° in the same direction (it is overturned in one place in Hanway's Coppice) and the Woolhope Limestone is completely overturned and dips at about $50^{\circ}/115^{\circ}$.

Hereford Beacon District.

The mass of Hereford Beacon stands out and forms a summit which is apparently $\frac{1}{4}$ mile west of the main Malvern chain. Mapping the contact this mass makes with the Silurian rocks leaves no doubt that this boundary represents a low angle thrust. Blyth[2] deduced that this thrust plane dipped at about 15°- 20° to the east. Further evidence that this boundary is a fault is shown by the fact that

1. Robertson, T. 1926. Mem.Geol.Survey. Fig.17.
2. Blyth, F.G.H. 1952. Geol.Mag. Vol.XC.p.185.

various members of the Silurian formation abut against the mass. This is admirably seen in the Woolhope Limestone south of Hereford Beacon.

As might be expected, such thrusting caused effects in the Silurian rocks close to the mass, and field evidence shows that the Wenlock Limestone bulges to the west, and is apparently faulted and folded further to the West. Immediately north of Hereford Beacon, two N.W. - S.E. striking faults were mapped. These two faults are discussed below:

a) The northernmost fault displaces the western pre-Cambrian boundary, the Woolhope Limestone and the Wenlock Limestone, but not the Aymestry Limestone. All of the fractured formations are displaced dextrally and it is suggested that this fault is tear in nature.

b) The second fault is not so easy to define. The Aymestry Limestone ridge ends in the vicinity of Evendine (32/756412), but only a subdued feature could be found immediately south of the fault. This was also true of the Wenlock Limestone. As far as could be estimated the Wenlock and Aymestry Limestones had been displaced to the east south of the fault. This evidence shows the presence of a fault striking N.W. - S.E. Continuing this fault along its strike to the S.E. shows that it corresponds with a marked depression in the pre-Cambrian and marks the northern limitof the Uriconian. It therefore appears to be at least later in age than the Western Boundary Fault (see page 188) and is possibly normal in nature with downthrow to the S.W.

The Wenlock Limestone becomes overturned by as much as 45° in a position opposite Hereford Beacon.

It has already been stated above that the Aymestry Limestone feature is somewhat subdued south of Evendine. It is quite possible that part or even the whole of it might be strike faulted out by a N.- S. trending reverse or thrust fault, the Lower Ludlow being pushed over on to the Upper Ludlow. Such a fault was mapped striking up through News Wood to the west of the Wenlock Limestone. This fault's extension across the Ledbury road to Halfield Coppice is uncertain. The geology of this small area, comprising the northern end of News Wood and Cathy Croft, could not be satisfactorily mapped, since the author believes the nature of the numerous faults present, could only be deduced by mapping the Wenlock Limestone to the south.

Chance's Pitch and Barton Court Districts.

A broad ridge stretches from Cathy Croft (32/757402) to Chance's Pitch (32/743403). Small quarries of Aymestry Limestone could be seen along the whole length of the ridge, and showed this formation to be dipping in a general northerly direction. The dip on the beds became progressively less when traced westwards from 20° to 11°. The Aymestry Limestone appeared to be poorly developed in this locality.

The district of Barton Court shows some excellent exposures of Upper Ludlow. The strike on the beds here, and along the northern flanks of Chance's Pitch, shows that this formation, and no doubt the Downtonian, is folded into a syncline in the vicinity of Netherpaths (32/752409), and an anticline at Cummings Farm (32/738409). A fault might exist to the west of Barton Court which obliquely faults the western limb of the anticline. This fracture is substantiated by the existence of a scarp face striking N.N.W. - S.S.E. to the west of Barton Court.

Colwall Syncline and Ledbury Anticline.

The structures south of the Colwall fault consist of a broad syncline flanking the Malvern Anticline, and an anticline lying to the west of the syncline.

Both of these structures have N. - S. striking axes and the present author suggests that they may be the expression of the folds that lie to the north of the Colwall fault. That is, the Mathon anticline and syncline may be the equivalent structures found on the upthrow side of the fault.

STRUCTURES WITHIN THE TRIASSIC.

The structures on the western side of the Malvern Boundary fault, that is, those in the Palaeozoic, do not appear to influence the structures found within the Triassic to the east of the fault.

Considering the Triassic on a regional scale, it appears to be dipping eastwards at a very small angle. Progressively older beds appear as one approaches the Malvern Hills from the east. How much of this dip may be attributed to an initial dip or depositional dip, is difficult to say, but geophysics has established that a depositional basin once existed in the position of the Worcester plain.

Close to the Malvern Boundary Fault the Triassic formation is locally folded and faulted. The exact nature and trend of these folds is difficult to decide, but the faults all appear to be normal in nature with downthrow to the east, no doubt part of the Tertiary earth movements that affected the Boundary Fault.

THE EASTERN BOUNDARY FAULT - MALVERN FAULT.

An examination of a small scale geological map of this area will show a line of separation between the Haffield Breccia, Palaeozoic and older rocks and the Triassic strata extending for about 40 miles. This separation is particularly evident in the area under discussion where pre-Cambrian is seen against Triassic formations. This fundamentally important problem has long exercised the attention of workers in this area and a brief resume of their theories will be given.

Murchison [1] and Hull[2] contended that the Mesozoic strata were laid unconformably upon the older rocks.

Phillips[3] does not appear to be consistent in his writings. He interprets the line of separation as an unconformity in some cases (diagram on page 82 of his work, page 268 of this thesis) and in others a fault; he does, however, recognise the existence of some faulting. Phillips stated that a fault of pre-Haffield Breccia age had formed a scarp which acted as a shore line for the deposition of the Triassic, basing this conclusion upon the fact that the line of the "fault" is extremely sinuous, showing in some parts bays in which Breccia was deposited (being partly derived from the neighbouring land itself). In some of these bays patches of Lower Silurian rocks are still visible marking the original greater extension of these formations to the east. Phillips considered the existence of a fault was required to explain the presence of "fault breccias" seen in a few localities near Malvern

1. Murchison, Sir R. 1839 "The Silurian System".
2. Hull, E. "Triassic & Permian of the Midlands". Mem. Geol.Survey 1869. p.16, 62 & 67
3. Phillips, J. op. cit. p.146-147

and also to explain the scarp-like face of the pre-Cambrian rocks seen in the same area. When he does consider fracturing he suggests that the fault arose as the result of accommodation to the general flexuring along a north-south axis which brought the range into being. Phillips thus saw evidence for both an unconformity and a fault and in general, but not consistently, interpreted the line of separation as a pre-Haffield Breccia fault with overlying unconformable Triassic formations.

Groom[1] interpeted the line of separation solely as a fault. He draws attention to the lack of any marginal characters in the Triassic and asserts that the presence of sandstones and breccias close to the hills is no proof of a shore line in that direction, but is the chance result of post-Liassic elevation of the range. He finds no evidence for the derivation of the majority of the contained materials of the breccias from denudation of the Malvern-Abberley range itself, but admits that in pre-Triassic times the "Mercian Highlands" may have been continuous with, or very near to, the eastern boundary of the range. Groom refers to several localities where a fault breccia of both Archaen and Triassic rocks may be seen and thus deduces the post Triassic age of the movement. Groom, therefore, postulates post Triassic faulting, but emphasizes that previous estimates of the throw are greatly exaggerated.

Groom's interpretation has been accepted by most subsequent writers and even reiterated in writings such as Arkell's,[2] who further

1. Groom, T. 1900. Q.J.G.S. Vol. LVI.
2. Arkell, W.J. 1933. "The Jurassic System in Great Britain".

considered it to be hinged. The fault, he calculated, had a throw of only 100 feet at Newnham in Gloucestershire, but increased to a maximum of 1,000 feet near Malvern. He further added, "It seems to be entirely post Triassic, for the Triassic adjoining it is of the normal thickness and is not banked up against it, moreover, there seems to be no marginal change of facies. From these facts it is inferred that the Triassic must have formerly extended well over the site of the Malvern and Abberley Hills on to the area of the Old Red Sandstone".

Falcon[1] criticised his predecessors and re-introduced the idea of an unconformity, which has been modified by local minor post-Triassic faulting. Falcon does not exclude the possibility of any pre-Triassic movements, but asserts that there is no evidence either in favour or against such a possibility. He suggests that Groom and Phillips may have mistaken for a fault breccia what is, in fact, an erosion breccia and notes that Groom himself admits that the course of the boundary line follows closely the western boundary of the range - a fact which suggests an unconformably relationship rather than a fault.

A year later the findings of a gravity survey were published by Cook and Thirlaway.[2] They found that the Mesozoic-Palaeozoic boundary creates an anomaly of 30 mgals. with a maximum intensity at longtitude $2^{o}20'$ W., this approximately corresponds with the surface position of the fault. They assumed a constant density

1. Falcon, N.L. 1947. Geol.Mag. p.229 Vol. LXXXIV.
2. Cook, A.H. and Thirlaway, H.I.S., 1948. "Recent observations of Gravity in Wales and its Borders". Internat.Geol. Congress 18th session.

difference of 0.33 gms./cc between the Mesozoic and Palaeozoic rocks, and showed that the change of gravity over the Malvern line could be represented by a slope of 45° to the east on the pre-Mesozoic surface. They also calculated that this slope extended to a depth of 3,000 metres, but added that such an extensive slope could hardly be a surface created by a normal or thrust fault and considered it most likely to be the top of a step fault complex. The authors discuss the age of the fault and give arguments against pre- and post-Triassic movements, and put forward the idea of contemporaneous fracturing with sedimentation, subsidence of the crust occurring because of the sedimentary load and lateral pressure.

In 1949, Kent[1] published a paper discussing pre-Permian land surfaces. This author evidently favours Falcon's views, since he states "..... the Keuper appears to have a partly faulted contact with the older rocks". Kent goes on to say that the Keuper and Bunter are likely to total some 3,000 feet a little east of the Malverns and shows in his accompanying map that the pre-Permian surface slopes steeply eastwards. On page 96 of his work, Kent admits that the relationship of the Malverns to the downward movement of the Worcester basin is far from clear.

Blyth last year suggested that the boundary and other faults were created in Alpine times by a N. - S. compression acting on earlier faults, opening them up after the manner of tension fractures.

1. Kent, P.E. 1949. Structure Contour map of the surface of the Buried Pre-Permian rocks of England & Wales. P.G.A.p.95
2. Blyth, F.G.H. 1952. Geol.Mag. Vol.LXXXIV p.185.

Results of a further gravity survey were published also last year[1]. These observations agreed with those published in 1948 and showed a deep depression in the pre-Triassic surface east of the Malvern line.

The most recent contribution to the fault problem is that written by F. Raw[2]. This author suggests two periods of tensional stress which brought into being normal faults along the eastern boundary of the Malverns. The first of these earth movements occurred during the Armorican stage and resulted in a slip of several thousand feet along the fault plane. A tertiary movement was responsible for an additional throw along the fault plane with a combined movement of about $2\frac{1}{4}$ miles for the two slips.

The results and conclusions of the present writer's mapping will be enumerated below:

1) The boundary in some places is sinuous, but this does not necessarily mean that the pre-Triassic surface is sloping eastwards at a relatively low angle such as an unconformity. In many places the mapped contact could be represented by a series of N.N.W. - S.S.E., N.N.E. - S.S.W. intersecting faults, their intersections masked by uncertainties of the mapping.

2) There appears to be no evidence of a marginal facies within the Triassic near the boundary. The exposures investigated were:-

a) 300 yds. west of the Hundred House, Great Witley,

1. Cook, A.H., Hospers, J. and Parasnis, D.S. Q.J.G.S. 1952 Vol. CVII p.287.
2. Raw, F. P.G.A. Vol. LXIII p.227.

within 100 yds. of the boundary - fine current bedded red sandstone.

b) 200 yds. S.S.W. of Prickley Farm, Martley Hillside, less than 10 yds. from Wenlock Limestone - soft fine red sandstone.

c) The road section between Martley Village and the R.Teme shows normal Keuper Sandstone although only 50-100 yds. from the Wenlock Shale.

d) 300 yds. N.E. of Birch Hill Gravel Pit, Martley.

e) Nipple Coppice, Ankerdine Hill within 20 yds. of the boundary.

f) Knightwick Station (see page 128).

g) Knapp Farm and the lane from here to Patches Farm, Alfrick shows normal Keuper Sandstone although within 100 yds. of the boundary.

h) New Inn, Storridge (see page 154).

i) "Belmont Brick Works", Malvern Link, shows Keuper Marl completely devoid of Archaean fragments although this exposure is only ½ mile from North Hill which towers 700 feet above the marl pits.

j) The railway cutting S.E. of Upper Wyche where Keuper Marl is exposed without any Archaean fragments in spite of the fact that the crest of the Malvern Hills is only ½ mile to the west.

3) Wherever the boundary is seen the contact appears faulted

a) Knightwick Station (see page 129)

b) Alfrick Pound (see page 148).

c) Malvern Link where a breccia of angular fragments of Archaean and Triassic is seen plastered on to the pre-Cambrian rock.

The faulted surface here dips north eastward at 65° - 75° . It is therefore presumed to be a normal fault.

Five other exposures of the contact have been seen in the past by other authors.

a) Eastern side of Midsummer Hill where a fault breccia was seen by Groom[1].

b) The fault itself was apparently seen by Phillips on the eastern side of some portion of the Malvern Range, where it dipped 60° eastward[2].

c) In constructing the old railway tunnel between Malvern Wells and Colwall in 1860, Symonds and Lambert investigated the excavations and reported that they saw 24 yds. of tunnel with "Keuper Marls and Sandstone, twisted and broken, sometimes nearly horizontal and sometimes with a dip of 50°" followed by 20 feet of brecciated Archaean.[3]

d) The new railway tunnel built parallel and a few yards from the old one in 1926, was investigated by members of the Geological Survey. They reported seeing 30 feet of beds affected by the fault, although the beds were only broken for 21 feet of this thickness. They reported seeing the fault plane dipping to the east at 45°. [4]

1. Groom, T.T. Q.J.G.S. Vol.LV, 1899, p.129.
2. Phillips, J. Mem. Geol. Surv. Vol.ii 1848 pt.1. p.140
3. Symonds, W.S. and Lambert, A. "Malvern & Ledbury Railway Tunnels". Q.J.G.S.
4. Robertson, T. Geol. Surv. Summary of Progress 1925. p.162-173.

e) A temporary exposure was described by Davies "... in the rear of the westermost row of buildings of Great Malvern." This exposure showed a very steep face of Archaean with remains of a plastering of what appeared to be Bunter Sandstone.[1]

4. Wherever Keuper Sandstone occurs on the east side of the boundary some outcrop of Haffield Breccia is found in a corresponding position on the west side of the contact. These places include a) Woodbury Hill, b) Berrow Hill, c) Collins Green, d) Knightwick Station, e) Ravenshill Green. (The breccia and sandstone have not been reported here before). f) Alfrick Pound, g) Whippets, Cowleigh Park, h) Norther Malvern where Phillips[2] reported a patch of Haffield breccia now eroded away. As it has already been proved (see page 74) that the stratigraphical separation between the Keuper Sandstone and Haffield Breccia is very small (possibly only 300/500 feet) the movement on any fault would be relatively small compared with those proposed by some former workers who thought several thousand feet a fair estimate.

The following conclusions are made from the observations of former workers and the present author.

1) Exposures of the boundary show that faulting has occurred in post Triassic times and that its apparent throw was the stratigraphical separation between the Haffield Breccia and Keuper Sandstone. According to Groom the thickness of the Haffield

1. Davies, A.M. The Malvern Fault. Geol.Mag. 1947 Vol.LXXXIV p.320.
2. Phillips, J. Mem.Geol.Surv. Vol.ii 1848.
3. Groom, T.T. 1900. Q.J.G.S. Vol.LVI p.188

Breccia is 200 feet, the Bunter between 0 feet at Bromesberrow in the south and 300 feet at Kidderminster in the north and the Keuper Sandstone 400 feet. This gives a maximum thickness or throw of 900 feet which is of the order of Raw's Tertiary movement of 750 feet.

2) There must have been a previous period of major faulting prior or during Triassic times to account for the great thickness of Triassic deposits which have been estimated by Kent to reach "... some 3,000 feet a little east of the Malverns[1]" and the large gravity anomaly.

It is seen, therefore, that the problem is still conjectural. More detailed geophysics, particularly using seismic methods, might reveal the nature of the pre-Triassic surface immediately east of the boundary, as also would a more detailed local study of the palaeogeography of the Triassic formations.

The location of the western limit of the Permo-Triassic basin of deposition and the thickness variations of these Mesozoic deposits might help in determining the nature of the pre-Permian land surface.

1. Kent, P.E. 1949. P.G.A. Vol. LXXXVI p.95.

THE WESTERN BOUNDARY FAULT.

The nature of the boundary between the pre-Cambrian and Silurian rocks along the western edge of the Malvern Hills has, like the Eastern Boundary Fault, been a controversy in geological literature. It has not dominated the literature to such an extent as its counterpart to the east of the Malverns, but the present author believes that the interpretation of the nature of this boundary to be an important link in elucidating the origin of the Malverns.

The boundary has been accepted as a fault for some considerable time, since the field evidence can support no other theory. Such evidence is briefly outlined below:

1) The transgressive nature of the boundary.

2) Lack of marginal facies in many of the formations adjacent to the pre-Cambrian.

The boundary is therefore a fault, and a close examination of the map shows that the fracture may be divided into two regions:

1) The region where the fault has obviously a dip of a low angle to the east, such as at Hereford Beacon and at Chase End Hill[1].

2) The region where the fault has possibly a steep dip and is in places vertical.

Hereford Beacon is a detached area and lies to the west of the Malvern axis, and is interpreted as an overthrust mass (see page 174) produced by tangential forces acting in an E. - W. direction. A steeply inclined fault appears to separate the detached area from the main Malvern Axis. This separating fault is possibly the southerly extension of the

1. This district lies to the south of the area described in this thesis, but is described by Groom, T.T. 1899, Q.J.G.S. Vol. LV. p.129-69.

steeply dipping fault of region 2 (see above).

In considering region 2, quarry exposures have shown the fault to be practically vertical and substantially parallel to the bedding in the Silurian. Groom in his papers frequently comments on this. The dips, as calculated from the evidence of the tunnels, show that the fault is practically vertical in the old excavation, and 75° or 80° to the east for the new tunnel.

The nature of the fault has always been interpreted as a reverse fault dipping to the east, but quite recently Raw[1] has suggested that the fracture is actually a normal fault, down-faulting the pre-Cambrian to the east. Raw states that the steeply dipping fault is out of harmony with the low angle thrust faults at Hereford Beacon and Chase End Hill, and strongly suggests that they were brought into being by tensile stress.

The field evidence found by the present author hasnot revealed any information which enables a conclusive answer to be drawn over the nature of the fault. The evidence that has been found by former workers is outlined below.

1) The tunnel excavations show little brecciation at the western contact of the Malvernian. The syenite was followed immediately by fossiliferous Llandovery, from which was secured a specimen of Pentamerus laevis. Whereas, at the eastern boundary, the Keuper Marl was succeeded by 20 feet of breccia with a marly base[2].

Raw suggests that the increase in thickness of breccia on the

1. Raw, F. 1952. Proc.Geol.Assoc. Vol.LXIII p.227-239.
2. Robertson, T. 1926. Summ. Prog. Geol. Surv. (1925) p.162-73.

eastern side of the pre-Cambrian was the result of a bigger throw that took place on the eastern fault[1].

2) The Western Boundary fault is parallel in strike to its counterpart to the east, and both dip eastwards.

The author accepts the theory of Raw's normal fault in preference to Groom's idea that the fracture is reverse in nature. The structural interpretation of many of the areas bordering the eastern margin of the Malvern and Abberley Hills can be explained as down-faulted overthrust masses or nappes, analogous to the origin of the Malvern Hills as proposed by Raw. Further discussion of Raw's theory is made in the section on "Geological History" see page 200.

1. Raw, F. 1952. op.cit. p.233.

THE RELATIONSHIP OF THE STRUCTURE OF THE MALVERN AND ABBERLEY HILLS TO THE NEIGHBOURING DISTRICTS.

The Malvern-Abberley line separates two very different types of country: rolling, hilly country occupied by Palaeozoic rocks to the west, and the flat Vale of Evesham occupied by Mesozoic strata to the east. Beneath the latter the older rocks are almost certainly folded on the same structural pattern as in the Malverns themselves.

This line, which scarcely deviates by more than 2 miles from West Longtitude $2^{\circ}20'$, has been a dominant line of movement from early times.

If this line is traced southwards it is found to coincide with notable contrasts in topography and stratigraphy until it crosses the coast about 5 miles east of Weymouth. Prof. H.L. Hawkins pointed out some of these contrasts in his presidential address in 1942[1], and the present author outlines some of these below:

a) The Malvernian gneisses and syenites have basal Cambrian and Valentian against them which suggests that the Malvern district has been a region of uplift prior to Cambrian and Silurian times.

b) The Silurian, Devonian and Carboniferous rocks of Somerset swing round to follow a N. - S. line with high dips in the region of this continued Malvern line.

c) The Carboniferous of the Forest of Dean and Bristol Coal-fields shows steady thinning and overstep towards the line from the west. Analysis of the Pennant Grit along the eastern fringe

1. Hawkins, H.L. 1942. Presidential address Q.J.G.S. Vol. XCVIII p.49.

of the Bristol Coalfield shows this grit to contain fragments of pre-Cambrian material.

d) Just south of Gloucester, the scarp of the Cotswolds approaches the line, and turns promptly from the Caledonian trend to follow a N. - S. direction past Bath, Frome and Bruton to the S.E. corner of Somerset, a distance of some 55 miles.

e) Certain rock types fail to "cross the line" - Reading Beds, London Clay, Gault, Upper Greensand, Wealden and Lower Greensand.

Welch and Crookall[1] show that the Bath and Lower Severn axes of Somerset unite northward to form a Malvernoid trend. These authors suggest that the Bath axis has been active from a very early date. In Mesozoic times the Bath axis played an important part, not only in its northern section, but even where it lies beneath the later Armoricanoid folds south of the Mendips. The Bath axis' most striking effect is to be seen in the Upper Lias strata, which show that the seas shallowed in a belt extending to the Dorset coast. The winnowing action of the currents prevented the accumulation of the finer sediments, which were deposited in the form of clays and silts in the less disturbed waters flanking the sand banks on the axis. The extraordinary lithological variations of the Great Oolite rocks may also be related to movements along the Bath axis.

The present author has outlined above many of the interesting facts that are associated with a line of disturbances stretching

1. Welch, F.B.A. and Crookall R, 1948. Brit.Reg.Geol. "Bristol and Gloucester District".

from north Worcestershire to the coast of Dorset, a distance of 120 miles. Whether the disturbances south of Gloucestershire are synonymous with the Malvern uplift is a debatable point, but there is that significant fact that this line appears to act as a hinge down this central portion of England, separating the older fold systems in the west from the much younger S.E. dipping beds to the S.E. of this line. This axis appears to have been active from earliest times and according to Davison[1] may be still active.

Past authors such as Strahan[2] and Rastall[3] have pointed out the radial pattern of the axes of the structures in the South Midlands and the convergence of these axes on the Pennine axis. The Malvern line, however, spoils this symmetry and the present writer reiterates the conclusions reached by Blyth[4] and Whitworth[5], that the Malvern belt of folds is probably related in origin to movement in the pre-Cambrian basement.

1. Davison, C. 1924. "A History of British Earthquakes" Cambridge Press.
2. Strahan, A. "Discrimination of periods of Earth Movements in the British Isles".
3. Rastall, R.H. 1925. Geol.Mag. Vol.LXII p.193 - 222
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THE AGE OF THE MAJOR TECTONIC MOVEMENTS.

Within this chapter, the present author discusses the main period of tectonic movement found in the Malvern and Abberley districts. It is quite possible that all the main tectonic periods in the geological history of the British Isles have affected this district, but the discussions outlined below strive to date the principal folding movement.

Examining first the succession of rocks found within the district mapped, we see a conformable sequence of beds from the Llandovery up to the end of Lower Old Red Sandstone age. Within this range of time there are probably several non-sequences, which might be due to uplift, but no angular discordance could be found. Immediately to the west of the area in the county of Herefordshire the Upper Old Red rests unconformably upon the Lower Old Red Sandstone. According to some (Pringle and George[1]) this was the main period of Caledonian folding in South Wales.

Elsewhere such as in the Forest of Dean Coalfield there is a complete upward transition from Upper Old Red Sandstone to the Carboniferous Limestone Series, but within the area mapped by the present author, the lowest beds of Carboniferous age found were the Coal Measures. These Measures occupy the axial region of the Kingswood Syncline immediately to the west of the Woodbury district. These beds have been described both by Groom and the Geological

1. Pringle, J. and T.H. George 1948. Brit.Reg.Geol. South Wales p.44.

Survey as being equivalent to the Upper Coal Measures of the Mamble Coalfield, which form the lowest portion of the Halesowen Group[1] or the Etruria Marl of South Staffordshire. Trueman[2], however, thought that these beds may belong to the Middle Coal Measures, but recently Mykura[3] has verified that these beds are Upper Coal Measure in age. As these Measures appear to be folded with the underlying Downtonian, it follows that the main folding movement was at least after these Coal Measures and can be attributed to a late - or post - Morganian age. Mykura suggests that the movement could possibly belong to the Asturic phase of the Variscan Orogeny.

Falcon[4], however, considered that the Upper Coal Measures were not involved in the folding and suggested movement between Middle and Upper Coal Measures. Reference is made elsewhere in this work (p. 85) to this erroneous claim.

Former workers have suggested that the Coal Measures of Woodbury Hill are not folded with the Silurian and lie unconformably upon the eroded structures of the folded Silurian. The present author has already suggested on p. 101of this thesis that there is no proof of this major unconformity and proposes that these measures are part of the same series of beds found in the Kingswood Syncline, which they resemble lithologically. Of course, this would necessitate some sort of unconformity between the Woodbury

4. Falcon, N.L. 1947. Geol.Mag. Vol.LXXXIV p.229.
3. Mykura, W. 1951. Geol.Mag. Vol.LXXXVIII p.389.
2. Trueman, A.E. 1947. Q.J.G.S. Vol. Ciii p.LXV-CIV.
1. Kidston, R, Cantrill, T.C. and Dixon, E.E.L. 1917
   Trans.Roy.Soc.Edin. Vol.LI pt. IV p.1019.

Coal Measures and the underlying beds. Such an unconformity has been found by Mykura[1] and verified by the present author in Ellbatch Wood, where Coal Measures, stratigraphically equivalent to those found in the Kingswood Syncline, rest with an angular unconformity of 30° upon Downtonian. The reader is referred to the diagram on p.235 .

Haffield Breccia is deposited upon practically all horizons of the Silurian and the Coal Measures. It is apparently unfolded and the present author, therefore, concludes that the main folding movement was prior to this formation.

Falcon[2] has suggested that some of the folding may be attributed to post-Triassic movements possibly Tertiary in age. The contrasting dips on either side of the Malvern Boundary Fault would presumably be explained as being due to basement control. As many of the folds axes' abut against the Triassic without the New Red Beds showing any sign of folding, the present author does not seriously consider a Post-Triassic major movement. The present writer therefore concludes that the evidence within the Malvern-Abberley range of hills shows that the main folding occurred in late- or post-Morganian times, but prior to the deposition of the Haffield Breccia. Minor folding did take place before the deposition of the Coal Measures of the Kingswood District

1. Mykura, W. 1951. op.cit. p.391.
2. Falcon, N.L. 1952. Geol.Mag. Vol.89 p.304.

and this might be attributed to Trueman's "Malvernian" Phase[1] of early Morganian age.

Considering next evidence from neighbouring districts, we find in general that major folding movements occurred during or after Upper Coal Measure deposition.

Whitehead and Pocock[2] writing in the "Dudley and Bridgnorth" Survey memoir attributed the folding of the Trimpley Anticline to post-Staffordian movements, but prior to the base of the Clent Beds (possibly equivalent to the Haffield Breccia). These authors go on to say that they believe that this was the main period of folding along the Malvern and Abberley axis, and that the Trimpley structure retains a "Caledonoid" trend probably impressed by earlier movements. They also conclude that, at this time, movement was localised in the neighbourhood of pre-existing axes, such as those of Malvern, Trimpley, the Lickey Hills and the now buried "Mercian Highlands".

Writing on the Coalbrookdale coalfield, Whitehead, Robertson, Pocock and Dixon[3]: Edmunds and Oakley[4] show that the Coalport Beds of Morganian age, rest with strong unconformity upon folded Coal Measures and Silurian. They continue to say that later movements, between Upper Coal Measures and Triassic beds also took place.

1. Trueman, A.E. 1947. Q.J.G.S. Vol.CIII p.LXV.
2. Whitehead, T.H. and Pocock, R.N. 1947. Geol.Surv. of Grt. Brit. p.121-22.
3. Whitehead, T.H., Robertson, T., Pocock, R.W., and Dixon, E.E.L. 1928. Mem.Geol.Surv.
4. Edmunds, F.H. and Oakley, K.P. 1947. Brit.Reg. Geol. "Central England".

Immediately to the south of the Malverns there is the small Newent coalfield. Murchison[1], Phillips[2] and Richardson[3] all conclude that the coal series rest unconformably on Old Red Sandstone and this series is itself overlain unconformably by New Red Sandstone. Aber[4] provisionally assigned the coal series to the Upper Transition Series or the Lower part of the Upper Coal Measures. Wills[5] infers that they may be equivalent to the Halesowen Group which are of Morganian age. These two unconformities therefore suggest early or pre-Morganian and post- but pre-Triassic movements.

The Batsford boring near Moreton in the Marsh about 30 miles E.S.E. of Malvern shows Upper Coal Measures dipping at 6-7° resting on Silurian beds with a dip of 20-25°[6].

Trotter[7] in his survey memoir of the Forest of Dean district, shows that most of the main folds affect the Coal Measures and Moore[8] shows that there are two periods of movement (intra-Morganian and post Upper Coal Series) in the East Crop of the South Wales Coalfield. These considerations show a similarity to those movements outlined above in the Woodbury-Kingswood districts of the Abberley Hills.

8. Moore. 1948. Q.J.G.S. Vol.CIII p.287.
7. Trotter, F.M. 1942. "Geology of the Forest of Dean Coal & Iron - ore Field" p.3.
6. Strahan, A. 1913. "Discrimination of Periods of Earth Movement in the British Isles".
5. Wills, L.J. 1948. "The Palaeogeography of the Midlands".
4. Arber, E.A.N. 1910. Geol.Mag. Vol.VII p.241-4.
3. Richardson, 1930. "Wells and Springs of Gloucestershire" Mem.Geol.Surv.
2. Phillips, 1848 op.cit. p.109
1. Murchison, Sir R. 1839. op.cit. p.154-155.

In the Bristol area, Kellaway and Welch[1] showed that there was important pre-Pennant folding in the Bristol Coalfield. Moore and Trueman[2] called these movements "Malvernian". Trueman[3] later suggested that these Morganian movements had more important effects in Britain than the pre-Stephanian Asturian folding.

We see therefore that the neighbouring districts to the Malvern-Abberley range show earth movements which could be correlated with those found in Kingswood Syncline. The present writer therefore concludes that there were two periods of folding.

1) pre- or early Morganian - minor folding.

2) late- or post-Morganian and pre-Haffield Breccia - major folding.

From this we see that Trueman's "Malvernian" folding of early Morganian age could correspond with the minor folding (1 above), but does not successfully correlate with the major earth movement proposed for the Malvern-Abberley Hills.

3. Trueman. 1947. Q.J.G.S. Vol.CII. p.xcix.
2. Moore and Trueman, 1939. P.G.A. Vol.L. p.63.
1. Kellaway and Welch, 1948. Brit.Reg.Geol. "Bristol and Gloucester" p.30.

GEOLOGICAL HISTORY.

This chapter is concerned with describing the geological history of the Malvern-Abberley Hills district.

The oldest rocks found in the area are the Malvernian gneisses and schists, and the volcanic rocks of the Warren House Series, the latter is comparable with the Uriconian of Shropshire. No sedimentary rocks have been detected among the Warren House Series and there is no proof of the establishment in the district of the terrestrial conditions of the Torridonian period.

At the close of the pre-Cambrian period the Malvern area, together with much of the English Midlands, sank beneath the sea-level, and the Cambrian Quartzite was deposited, probably upon the denuded edges of the older series. The fairly large size of many of the pebbles of the Cambrian Quartzite points to the proximity of a shore line. Towards the end of Middle Cambrian times the water presumably became deeper, as is indicated by the prevailing argillaceous character of the sediments.

At the close of the Cambrian period, a shallowing of the sea took place which seems to have brought much of Shropshire and the Midlands above sea-level, where the Cambrian and pre-Cambrian rocks suffered erosion.

The Malvern district is completely devoid of Ordovician sediments, and it is suggested that this indicates that the area formed part of another land surface lying eastward of the Ordovician

Sea that covered Wales and latterly, parts of Shropshire.

When subsidence again brought the sea over this land, Upper Llandovery sediments were laid down unconformably upon all the sub-divisions of the Cambrian and pre-Cambrian rocks. The coarse conglomeratic nature of the lowest member (Cowleigh Park Beds), suggests the near-by presence of a land surface, and it is quite possible that isolated peaks of eroded older beds formed islands in this Silurian sea.

Throughout Upper Llandovery, Wenlock and Ludlow times, deposition appears to have been continuous. The sea possibly shallowed at certain periods, such as during the formation of the Wenlock Limestone, as indicated by the abundance of coral colonies.

The great Caledonian earth movement is not evident at the close of Silurian times, since sedimentation went on continuously from the Silurian to the end of Lower Old Red Sandstone times. The conditions of sedimentation, however, changed considerably at the end of the period of deposition of the Ludlow Beds. The shelly limestones and shales of definitely marine type gave place to the red marls and sandstones of the Downtonian and the Lower Old Red Sandstone, which appear to have been deposited under shallow water or deltaic conditions at no great distance from the land areas which emerged as the result of the earth movements mentioned above.

There was some elevation of the land during the middle Old Red Sandstone period and rocks of this age were not deposited. At the close of the Devonian, when the continental areas had been worn to sea level, subsidence again took place and deposits of Carboniferous age were laid down.

The first detectable sign of folding in the Silurian and Downtonian strata is to be found in Ellbatch Wood (see page 103). Here there is an angular unconformity of 30° between the Downtonian and basal members of the Coal Measures. From this observation it is uncertain at what time the earth movement took place, it might be as early as the Mid Devonian movement or immediately prior to the deposition of the Ellbatch Wood measures (see page 202).

The present author suggests that the Coal Measures of the Kingswood - Ellbatch district were deposited on a folded and eroded surface. It is true that Coal Measures appear to be conformable with the Downtonian at Kingswood Common, but this is believed to be of only local significance.

The regression of the Upper Carboniferous sea marked the beginning of another terrestrial period during which the folding and overthrusting took place. The whole series of rocks prior to the Permo-Triassic were subjected to E. - W. compressive stresses which resulted in the folding and finally, under bigger stresses, they yielded and were overthrust in the form of a nappe and also overturned the rocks beneath it.

During this terrestrial period, but after the folding and thrusting, the area was under tangential tensile stress which produced a series of normal step faults, downdropping east. This movement deliminated the axial region of the Malvern Hills, and several other areas to the north, by downdropping portions of the overthrust nappe. The major movement on the Malvern Boundary Fault occurred during this earth movement.

The land surface after these movements must have been one with large topographical features. An extensive period of denudation, especially of the still uplifted western region and widespread removal of the thrust mass from it, left a land surface which possibly did not differ greatly from that seen today. Gradually the basin to the east of the Malverns was infilled with Permo-Triassic deposits, the land to the west lowered and the sea transgressed and covered the whole region with Triassic, Jurassic and Cretaceous strata.

Post-Cretaceous elevation and uplifting to the west initiated the removal of the formations covering the region.

At some date after the Triassic deposition, there was another period of tangential tensile stress which resulted in the renewed movement down to the east on the Malvern Eastern Boundary Fault, and possibly faulted other regions adjacent to this fracture. The exact dating of this movement is impossible, but it has been suggested that it might be tertiary in age, and Raw[1] has given it to be a Late Eocene disturbance.

Continued denudation under Tertiary and Quartenary conditions produced the land surface as we see it today.

1. Raw, F. 1952. Proc.Geol.Assoc. Vol.LXIII p.238.

SUMMARY OF GEOLOGICAL HISTORY.

Superficial Deposits (Alluvium and Drift)		Late Tertiary and Quarternary.
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv Possible normal faulting in Late Eocene.		
Keuper Marl		Permo/Triassic
Keuper Sandstone		
vvvvvvvvvvvvvvvvvvvvvv Probable unconformity.		
Bunter Sandstones		
vvvvvvvvvvvvvvvvvvvvvv Probable unconformity.		
Haffield Breccia		
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv Major earth movement of E.-W. compression, followed by normal faulting.		
Coal Measures		Carboniferous.
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv Minor earth movements.		
Upper Old Red Sandstone		Devonian.
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv		
Dittonian		
Downtonian		
Upper Ludlow	Ludlovian.	Silurian.
Aymestry Limestone		
Lower Ludlow Shales		
Wenlock Limestone	Wenlockian.	
Wenlock Shale		
Woolhope Limestone		
Woolhope Shales	Valentian.	
Wyche Beds		
Cowleigh Park Beds		
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv		

Malvern Quartzite	Cambrian.
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv	
Warren House Series - possibly Uriconian in age vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv Malvernian.	Pre-Cambrian.

CONCLUSIONS.

The following geological facts have emerged as the result of research carried out in the Malvern and Abberley Hills:

1)The stratigraphical succession of the Silurian and Downtonian rocks does not differ to any extent from the successions accepted for the Welsh borderland district. Minor points of interest concerning these rocks include:-

a) The presence of a coarse conglomerate within the Cowleigh Park Beds (Llandovery) known as the "Miss Phillips' Conglomerate".

b) The absence of ball stones within the Wenlock Limestone.

c) The presence of a microscopic sedimentary rhythm of silt and calcium carbonate within the Wenlock Limestone.

d) In most places there are two, sometimes three periods of massive limestone development within the Wenlock Limestone.

e) The recognition of two varieties of Strophonella euglypha, one typical of the Wenlock, and the other of the Ludlow.

f) The Aymestry Limestone is not so well developed in the south as in the north.

g) The presence of a representative of the bone-bed in practically all exposures of the Silurian-Downtonian boundary.

h) In all formations except the Upper Ludlow and Llandovery, a white bentonitic-type clay was found.

2)The folds have N.- S. axes and appeared in some places to be overfolded towards the west.

3) Thrusting is a common feature along the eastern margin of the folded Silurian rocks. In all cases the fault plane of these thrust masses dips at between 10 and 20° in a general easterly direction. In every case except one (Birchwood Overthrust) the beds immediately to the west of the thrust mass are overturned.

4) The principal strike directions of faults are:

a) N. - S. These faults are generally major fractures and are the direct result of the compressional and tensional stresses.

b) N.E. - S.W. and N.W. - S.E. These fractures allow minor relief to the E. - W. stresses.

5) The tear faults only affect those formations along the eastern margins of the folded Silurian rocks. In consequence, tear faults diminish in importance westwards. Thus the Aymestry Limestone is rarely, if ever, fractured by a transcurrent fault. It appears that the incompetency of the shaley formations, especially the Lower Ludlow Shale absorbs the stresses which would fracture any harder rock.

6) In considering the Mesozoic-Palaeozoic boundary, the present author concludes that it is definitely a fault. Surface information suggests that the fault is of relatively small throw, but geophysical observations show that it is a major fracture, possibly with several feet of displacement. It has been suggested by F. Raw and accepted by the present author, that the Malvern Boundary Fault may be of two movements.

a) Pre-Triassic - major throw.

b) Post-Triassic, possibly Tertiary - minor throw.

7) The age of the principal folding was post the Coal Measures of Woodbury Hill, but prior to the deposition of the Haffield Breccia. The present author, unlike previous workers, accepts that the Woodbury Hill measures might be folded with the Silurian formation and appear as unconformable masses primarily due to the cover of Haffield Breccia.

8) The Malvern axis is an old and persistent line which is probably influenced by the configuration of the pre-Cambrian basement.

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A P P E N D I X.

APPLICATION OF GEOPHYSICS.

In the vicinity of Walsgrove Hill, the mapping of the Aymestry Limestone eastern outcrop was made difficult by the scarcity of outcrops and the masking of the feature it usually creates by the presence of the main Aymestry ridge nearby. It was decided to experiment with resitivity traverses.

A control was made over the floor of Woodbury Quarry where the overburden was no more than one foot and the resitivity phenomena could be easily associated with particular rock types on the quarry face. Four equally separated electrodes were placed in the line of the traverse and potentials recorded on a megger between the inner pair. After each observation each electrode was moved on 10 feet. The results are recorded in the diagram on page 269.

A trial traverse was made over the Aymestry eastern outcrop where the boundaries of the limestone were known with fair accuracy from surface mapping. The faulted Aymestry Limestone was represented by a resitivity high.

Ten other traverses were made using 20 foot separations and their results plotted as histograms on the accompanying map. Some of the results are inconclusive, but in conjunction with the scanty field evidence they enabled the "eastcrop" to be mapped. S.E. of Walsgrove Hill the resitivity "highs" and the topographical feature suggest the limestone is tear faulted with a left hand displacement. Evidence for this transverse faulting within the main Aymestry Limestone ridge showed the presence of minor displacements, it is, therefore, inferred that this anomalous region of the "eastcrop" might be represented by closely set tear faults.

Inspection of the resitivity profiles suggests that the strike fault along the western boundary of the eastern Aymestry outcrop might be associated with a steeply decreasing resitivity slope. This resitivity feature could be found on most profiles.

Immediately N.E. of Walsgrove Farm two traverses confirmed the presence of a band of Aymestry Limestone (see page 96).

Further to the south, resitivity traverses were made over outcrops of shallow dipping Woolhope Limestone. The topographical feature produced by the limestone was broad and insufficient for accurate mapping. The same procedure was adopted as for the Aymestry Limestone described above and as before, the limestone formed a resitivity high.

VARIETIES OF STROPHONELLA EUGLYPHA.

A difference between the Strophonella euglypha found in the Ludlow Shale and Aymestry Limestone and those found in the Wenlock Shale is made in the diagrams on page 271. These drawings have been made from several specimens collected from the two formations. Summarising, the main differences are:-

1) The Ludlow variety has a semi-elliptical dorsal valve, whereas the Wenlock form is semi-circular in outline.

2) The Ludlow's dorsal valve is more convex or higher than the same valve from the Wenlock Shale.

3) In general, but now always true, the Wenlock variety is slightly smaller than its representative from the Ludlow.

A SEDIMENTARY RHYTHM WITHIN THE WENLOCK LIMESTONE.

A microscopic rhythm of calcium carbonate and silt in parts of the Wenlock Limestone has been used to determine top and bottom criterion. This alternation does not appear to be restricted to one stratigraphical horizon since the rhythm has been found in many places within the Limestone, from just above the base to near the top. On a weathered surface in a quarry this rhythm shows the calcareous portion as fine, hair thick ridges standing in relief above the rock matrix.

A large collection (30 approximately) of samples were made from:

a) Wallhouse Plantation (32/751636)

b) Quarry west of Wallhouse Plantation (32/750638)

c) Quarries south of Fetterlocks Farm (32/752632)

d) Dundridge Coppice (32/754627)

e) North of Basten Hall, Alfrick (32/733537)

f) Cother Wood, West Malvern (32/754472)

This represents a collection over a distance of approximately 10 miles.

Each sample was ground smooth across the bedding surface and etched in 5% Hydrochloric acid for about 5 minutes. This had the effect of dissolving away the calcium carbonate and leaving the silty matter as high ridges. Microscopic examination of the etched surface revealed:

a) Alternate bands of calcium carbonate and silt with dimensions of the order of 2 mm. for a complete cycle, although some of the bands were much thicker.

b) The silt particles' size remained comparatively constant throughout any particular cycle.

c) In considering a specimen the right way up, the number of silt particles gradually increases until they nearly exclude the presence of all lime, after which they suddenly disappear. An idea of this rhythm is seen in the photograph (see p. 285). In two cases the orientation of the rock sample was known from current bedding and a worm caste displayed on the same surface as this rhythm. Other orientations were known from the field mapping.

There are three ways of considering the formation of this mixture of sediments:

i) Consider a sea in which lime is being deposited in a constant quantity and the silt fraction varies.

ii) A sea in which the silt is constant and the lime content varies.

iii) Combination of i) and ii).. This means cannot seriously be considered since some of the cycles would most likely be reversed.

The problem is to visualise some physcial or chemical means whereby silt suddenly fails to be deposited (i) above) or lime suddenly appears (ii) above). No account has been found in literature whereby a detrital sediment suddenly ceases to be deposited without causing grading above it, this dispenses with theory i). Therefore, some process has to be throught of to suddenly precipitate lime in a sea where silt sedimentation is constant.

Conditions of sudden precipitation of lime could be obtained in a sea where the water is saturated or even super-saturated with lime, with an alteration of one of the physical constants governing the saturation of the water, such as a) temperature or b) pH value of the water. W.W. Rubey[1] writing on a similar alteration of sediments attributes the cycle to seasonal conditions. Probably this Wenlock cycle has similar causes since seasonal variations include temperature and rainfall, changes which have their associated effect on food supplies for sea creatures and shifts in marine currents (warm and cold) both these effects would influence the precipitation conditions.

1. W.W. Rubey, 1932. U.S. Geological Survey Professional Paper 165.