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Welsh Borderland Geological Framework Project: The geology and applied geological issues of the region around Knighton, Powys: a scoping study

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Welsh Borderland Geological Framework Project: The geology and applied geological issues of the region around Knighton, Powys: a scoping study

CW Thomas and R Kendall

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Foreword

There are no modern geological survey data for the area around Knighton, Powys, in central eastern Wales, and the adjacent area in western-most central England, nor is there a modern published map and accompanying text describing the geology. This is despite the classic geology of the region that has been important in advancing the development of the science through the 19th and early 20th centuries. The BGS has therefore undertaken a small scoping project to assess the state of knowledge of the geology of this region of the Welsh Borderlands.

The region includes significant sections, most particularly in Silurian rocks. Shallow water facies in the Ludlow area, deposited on the edge of the Midlands Microcraton platform, pass westwards into basinal facies across the Welsh Borderland Fault Zone. The fault zone is a critically important structural system that has controlled the geometry and depositional setting of Ordovician and Silurian strata, and has subsequently acted as a focus for deformation during late Caledonian tectonism. Some elements of the fault zone are still active today.

A very rural region with great landscape value, the Welsh Borderland host important N-S trunk routes between NW England and N Wales and S Wales and the West Country, and certain key W-E routes. In addition, reservoirs and other water resources in the eastern Wales river catchments are important with regard to water supply in the West Midlands, especially the Birmingham conurbation and its satellite towns and cities. The economy is largely based on agriculture and forestry, but tourism is also important because of the great natural beauty of the area. Mineral resources are limited, although the Knighton district is peppered with small quarries and pits; mostly disused, these largely supplied very locally sourced building materials. The only active quarries are located on the southern margins of the district, supplying crushed rock aggregates. Dolyhir Quarry is notable for secondary minerals hosted in Silurian and Precambrian rocks. There is only limited information on sand and gravel resources, but consideration of the available data on Quaternary superficial deposits suggests locally significant reserves.

This report documents broadly the current understanding of the bedrock and superficial deposit geology. It highlights the contrasts in state and nature of geological knowledge between this region and the wider Welsh Basin, where there has been a significant focus on understanding the sedimentary architecture of the Lower Palaeozoic sedimentary rocks. It also highlights the lack of a modern understanding of the Quaternary geology of the region.

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FIGURES

No table of figures entries found.

Summary

The region between Knighton, Powys, and Ludlow, Shropshire, hosts some of the finest Palaeozoic geology to be found in the UK. Early classical studies of the Silurian and Ordovician strata were critical in the development of the science of geology, particularly with regard to the application of biostratigraphy. The internationally important sections in the Silurian Period have, for decades, been an important training ground in classical geology. However, despite the classical character of the geology, there are no modern geological survey data, and no modern published map or accompanying explanatory text. Indeed, no map of the Knighton area (Geological 1:50 000 sheet 180) has been published since the very first edition at 1:63360 scale in the 1860s. Furthermore, the map of the adjacent, equally classic Ludlow District (Geological 1:50 000 sheet 181) only exists as a Provisional edition, published by the BGS in 2000, again, without an explanatory text. The district had been subject to piecemeal partial revision in the 1930s, 1950s and 1980s, with some very limited fieldwork undertaken in the late 1990s, prior to publication of the provisional edition.

In order to assess the current state of knowledge of the geology of the region that includes the Knighton district and part of the Ludlow district, the BGS has reviewed the existing literature published on the region, and data held by the BGS and other bodies. This review provides information that can be used to plan a revision of the geology in the coming years, bringing understanding into line with surrounding areas. The recently completed study of Palaeozoic rocks in the wider Welsh Basin by the BGS, to the west of the Knighton – Ludlow region, provides a modern, lithostratigraphically and sedimentologically consistent framework, within which a modern revision of the geology of the ground around Knighton and to Ludlow, can be undertaken.

The region is dominated by Silurian strata and includes lithostraigraphical units representative of all the Silurian series, from the Llandovery through to the Pridoli. In the west, the older strata reflect slope to basinal depositional environments with various levels of oxygenation. To the east, the strata are characteristic of deposition in shallower waters, reflecting the shoaling on to the platform of the Midlands Microcraton. Although eustatic controls on deposition are important, tectonic control on deposition is apparent across the Welsh Borderland Fault Zone, the structurally complex domain that controls basin architecture and the transition from platform to basin environments. The activity of the fault zone during sedimentation results in second-order controls on base level, over and above those imposed by global eustatic control. This complex interaction between eustacy and tectonics results in complex sedimentation across a relatively small region.

The Quaternary geology of the region is only moderately well-understood, with little modern work having been undertaken. The Devensian limit is recorded in the extreme east of the area and there exist complex assemblages of landforms and deposits in the vicinity of this limit. These include a pro-glacial lake complex with associated spillways and deltas. Evidence for strongly active glaciation is limited, with some evidence for local, cold-based ice caps on the Clun and Radnor Forest massifs. A modern revision of the Quaternary geology will elucidate not only the evolution of the landforms and deposits, but also the extent of resources or reserves of sand and gravel, etc. Older, pre-Devensian Quaternary deposits also occur in the Hereford basin in the south.

Palaeozoic rocks in the region have been exploited as building stone and crushed aggregates, but there are only a handful of currently active quarries. The hydrogeology and hydrology of the region is important because the rivers lie in a catchment that is part of the wider Wye and Severn regional catchments. Water resources are important because they form part of the supply to the large West Midlands conurbations.

1 Introduction

This presents a review of the extent of geological knowledge and available analogue and digital data for the region around Knighton, Powys (Figure 1). Although a key consideration underlying this report is the lack of modern geological mapping for the greater part of 1:50 000 Geological Sheet 180 (Knighton), the wider context of new BGS and NERC strategies requires that it considers the geology of the region and the resulting issues more broadly. Thus, the scoping study considers the geology within relevant parts of the upper catchments of the rivers Severn and Wye, as broadly delimited in Figure 1. Although *relatively* limited in age range, the geology is complex both lithostratigraphically and structurally. Because of this and time constraints, this report only discusses the geology at a level of detail sufficient to highlight the most important geological issues, rather than aiming to present a fully comprehensive account.

The region studied includes the Knighton district, but also includes the western part of the Ludlow district (181; provisional edition), with specific regard to the Silurian and lower parts of the Devonian succession. The region also overlaps with parts of the other 8 adjacent 1:50 000 geological maps (Figure 1). Matters in this regard are simplified because of the recent, high quality geological data and mapping available for Llanidloes (164), Montgomery (165), Rhayader (179) and Builth Wells (196). The map for the Hay-on-Wye (197) district is provisional and is known to have problems with the geology as currently defined. Finally, the region has minor overlaps onto Church Stretton (166), published in the 1960's and Hereford (198).

The report provides a compilation of existing data, considers the scientific and applied issues arising from the review of the geology and databases, and proposes strategies for updating the geological database for the region.

2 Overview of the geology of the Knighton area

The Knighton district lies in eastern central Wales, overlapping into western Shropshire (Figure 1). The geology is dominated by Lower Palaeozoic rocks of Silurian age, but includes some Ordovician strata in the west and in the Builth Inlier. The region is important geologically because it includes the transition, in the Lower Palaeozoic, from shelf and platform strata in the east to deep basinal lithologies in the Welsh Basin to the west. There are no strata younger than Pridoli or possibly earliest Devonian known in the area.

The region is transected by dominantly NE-SW trending fault zones, including the complex and long-lived Welsh Borderland Fault Zone (WBFZ) that effectively bisects the area. The WBFZ is the fundamental boundary between the Midland Microcraton platform to the east and the Welsh Basin to the west. The system was active during Lower Palaeozoic sedimentation and subsequently during Acadian and Variscan deformational events.

With regard to the Quaternary deposits and landforms, all bar the extreme east of the area (and off the Knighton Sheet) lies is thought to lie within the defined Devensian Limit of Brandon (1989). Ice-marginal landforms and depositional facies lie in the eastern part of the area and the Knighton Sheet.

The only published maps available that present the geology of all of the Knighton Sheet (180) are those published at 1:250 000 and 1:625 000 scales; there is no 1:50 000 map (digital or paper) and only a few hand-coloured copies of the original 1:63 360 scale map from the 1860s. Because of this, there is no modern, published lithostratigraphical or lithodemical representation of the strata and igneous rocks, and the maps represent the geology chronostratigraphically at Series level at best. There is a similar lack of published modern and comprehensive Quaternary data for the region. The bedrock geology and large-scale fault arrays are shown in Figure 2.

Physiography Much of the Knighton area comprises rolling upland dissected by tributaries of the rivers Severn and Wye in their upper catchments (Figure 3). Most of the upland lies between a maximum of 350 and 450 m O.D., although elevations of up to 660 m (Great Rhos; [SO 182 639]) occur in the heart of the Radnor Forest massif. Elevations between 500 and 550 m occur in the Beacon Hill [SO 177 768] – Pool Hill area in the north. The upland ground forms a very roughly y-shaped massif in the centre of the area, which, though dissected, runs into the Ludlow Anticline in the east (Figure 3). Upland ground also lies to the north of the Teme and Knighton. The Ludlow Anticline shows up clearly on the NextMap imagery, as does the gentle complimentary syncline to the north that leads round to the classic NE-SW aligned escarpment of Wenlock Edge.

Although the underlying structural grain in the bedrock is NE-SW, as evident from some of the landscape features (Figure 3), the principal drainage courses cut almost orthogonally across this grain. However, the tributaries to the main courses are commonly at least roughly aligned NE-SW, suggesting a structural control on these third-order streams. Figure 3 also reveals elements of the Welsh Borderland Fault Zone, particularly the Pontesford and Church Stretton lineaments and the Titterstone Clee fault, all three of which form marked linear features in the NextMap imagery.

The key Severn tributaries are the Teme, the Lugg and the Arrow, flowing eastwards from the central high ground. In the west, the River Ithon and its tributaries, such as the River Aran, drain upland southwards, past Llandrindod Wells, to the Wye. The watershed between the two catchments lies in the Black Mountain – Pool Hill – Becaon Hill massif in the NW of the area, through Llanbister Road Station, to the Radnor Forest massif in the SW. The river valleys broaden markedly east of Kington, Presteigne and Bucknell as the land decreases in elevation across the Welsh Borderland Fault Zone and onto the Midlands Platform.

3 Bedrock geology

3.1 HISTORY OF GEOLOGICAL RESEARCH

The now much better-established sedimentological, litho-, chrono- and biostratigraphical frameworks for the latest Ordovician through Silurian strata are founded largely on the geology of the Welsh Basin (Wilson & Davies, in prep). However, Wilson and Davies (*op. cit.*) highlight key general problems that have hampered elucidation of the geology of the Welsh Basin which pertain on a smaller but still significant scale with regard to the geology of the Knighton area. These include:

a) locally developed lithostratigraphical nomenclature

b) difficulties in correlating successions across the area because of the transition from shelf to basin facies and

c) concomitant facies effects on indicative zonal faunas, so that even graptolites may be subject to strong facies control .

Thus, within the Knighton area, the lithostratigraphical architecture is incompletely understood. Although a significant amount of research has been undertaken by a number of workers over the years (see below), each study is generally restricted in extent, either geographically or stratigraphically and much of the work in 50s and 60s has a very strong palaeontological bias. Whilst a key tool in correlation, biostratigraphy has been over-emphasised (e.g. see Holland (1958), to the detriment of the lithostratigraphy and sedimentology. Furthermore, the Knighton sheet has remained unmapped since the early primary survey by the BGS, despite the fact that the geology underlying the district critically links the basinal and distal shelf facies to the west and the proximal shelf facies to the east, particularly around the Ludlow Anticline.

The following briefly summarises the extent of published and unpublished work.

In his paper on the 'higher Silurian' strata of Montgomeryshire (part of the Montgomery sheet), Earp (1938b) provides a brief history of research in much of the general area up to the 1930s, but points out that very little was undertaken and published after the work of Murchison (1839) and the publication of the old series 1" geological maps of the region in the 1850s. Elles and Slater (1906) published on the strata in the Ludlow anticline and Stamp (1919) published on the strata in the Bucknell area, north of Knighton. A significant proportion of this work, including that of Earp (1938a, 1938b) appears to have focussed on the transition into the 'Downtownian' strata and have been particularly directed towards using the palaeontology to differentiate and correlate units, rather than using lithostratigraphy coupled with sedimentology and supported by biostratigraphy to define the geological architecture. More recent work (in the 1980s particularly) has endeavoured to take the latter approach, at least in the central and western parts of the area.

Nancy Kirk undertook PhD work along the Church Stretton fault zone in the mid 1940s (Kirk, 1947), before mapping more extensively in the west of the Knighton sheet, where she covered a significant area, overlapping in part with area mapped by Holland (1958). The latter work has only really come to light in the research for this report as it was never published beyond two abstracts (Kirk, 1951a, Kirk, 1951b).

Holland (1958) and Cummins (1958a, 1958b) were amongst the first to take a more systematical approach to the description and subdivision of the strata in the area. Both used thin sections to detail the petrology and Holland even used the Munsell scheme to define rock colour. Holland also defined bed thickness terms, although his terms 'shaly', 'flaggy' and 'massive' are not used in the modern sense. However, some of their descriptions may be of sufficient detail to allow, for example, the identification of bioturbated units or hemipelagite in the finer grained lithologies, so these are of some value in the review of the geology.

Holland's work in the Knighton area, between the Teme and the Lugg, (Holland, 1958, see Plate XXI) appears to be the most up to date mapping survey of this middle ground, illustrating the distribution of his subdivisions of the geology. Essentially, his stratigraphy extends from his 'Lower Ludlow Graptolitic Shales' (probably Nantglyn Flags Formation, (**NGF**), of Wilson & Davies, *in prep*) through to the 'Red Downtonian', so includes the transition from the basin facies of the Llangollen Group into the shelf facies of the Epynt Group and then into the marginal/terrestrial facies of the ORS (Raglan Mudstone). Within this interval, several important formations are defined and have been studied.

Woodcock (1990) aimed to bring some wider coherence and order to Welsh Lower Palaeozoic stratigraphy by applying sequence stratigraphical principles to divide the Lower Palaeozoic and Lower Devonian sedimentary rocks of Wales into three lithostratigraphical Supergroups, each bounded by unconformities.

Subsequently Woodcock et al. (1996) critically examined the application of sequence stratigraphical principles to the Lower Palaeozoic strata of the Welsh Basin, highlighting difficulties with this approach where both eustatic and tectonic factors markedly influence absolute and relative base levels. Most recently, and building on Woodcock's original work, Wilson and Davies (in prep) have reviewed the lithostratigraphy of the region and propose a new stratigraphical framework and nomenclature to formation level. Their approach represents the culmination of over two decades of work in the Welsh Basin by BGS. The new lithostratigraphy is sophisticated in that it reflects the key events with regard to changes in base level, and so places large-scale (regional and global) processes at its core.

In their critique of Woodcock's original supergroup framework, Wilson and Davies point out that the supergroups do not reflect the major and important eustatic events that occur, nor the resulting marked facies changes. They propose two post-Tremadoc supergroups, each representing a major eustatic transgressive-regressive cycle. This approach allows correlation with sequences beyond the Welsh Basin and adjacent shelves. Thus their Eryri and Hafren supergroups include the Gwynedd and Powys supergroups of Woodcock, but their boundaries are not generally coincident, except for the base of the Gwynedd and Eryri supergroups at the base of the Arenig. With regard to the Knighton area, the strata lie within the Hafren Supergroup.

The new BGS lithostratigraphy for the basin and outer shelf has major consequences for the mid and inner shelf deposits across the Knighton area into the Ludlow Anticline. The biostratigraphically orientated stratigraphy, with its now classic nomenclature cannot be readily accommodated within the event-based lithostratigraphy and thus needs revision. This will necessarily represent a major change in the classification of strata in an area of classical geology. As Wilson and Davies point out, this is likely to be met with resistance from the largely academic community that has been at the heart of the research in the Ludlow area for many decades.

The Quaternary in the Knighton area has received only limited attention, the key paper being by Dwerryhouse and Miller (1930). Subsequently, Cross and Hodgson (1975) published on glacial diversion of the River Teme. However, there has been no modern systematic investigation of the Quaternary landforms, deposits and history in an area that includes the Devensian Limit in the east and which, on cursory examination of the geomorphology, looks to contain much that reflects the behaviour of a dynamic ice margin. Most deposits are presumed to be Late Devensian, but Mid Pleistocene deposits are known just to the southeast of the area (Richards, 1999) and it may be that pre-Devensian deposits are preserved in the Knighton area as well.

3.2 SUMMARY OF THE GEOLOGY

Neoproterozoic

The oldest rocks within the region are confined to fault-bound inliers along the Church Stretton Fault Zone. Those in the small Stanner-Hanter Complex, exposed on the south-central edge of the area about 10 km west of Kington (Figure 2), comprise mid-Neoproterozoic basic to acid intrusive igneous rocks. Recent new dating work shows this complex to be at least 710 Ma old (Schofield *et al.*, 2010). The complex lies within the Church Stretton segment of the Welsh Borderland Fault Zone. The contact is faulted on its northern margin, but Silurian strata are interpreted to overstep the complex on its southern side (Schofield, *et al*., *op. cit.*). Although generally regarded as ‘Avalonian’ in character (e.g. Woodcock *et al.*, 1996), isotopic evidence indicates a different and older crustal source to the magmas in the complex, suggesting a different peri-Gondwanan provenance (possibly Cadomian) to the N America Avalonian terranes. This has implications for much of the rest of the basement to southern Britain.

Rocks assigned to the Brampton Formation (‘Longmyndian’) crop out in the Pedwardine Inlier (Boynton & Holland, 1997, Cox, 1912) (see also below). These comprise conglomeratic and gritty arenaceous lithologies with shaly intercalations, and have been quarried for building stone. Clasts include vein quartz and rhyolitic volcanics, with lesser amounts of schistose lithologies and deformed vein quartz. Cox (1912) assigned these rocks to the ‘Longmyndian’ on the basis of lithological comparison. Whatever their strict correlation, these rocks are yet another small outcrop of Neoproterozoic strata caught up in fault-bound slivers within the Church Stretton Fault Zone.

Lower Palaeozoic strata

Lower Palaeozoic strata in the Knighton area range in age from Tremadoc to Lower Devonian (Emsian) and comprise silicilastic to carbonate sedimentary rocks deposited in deep to shallow marine and ultimately terrestrial environments. Units assigned to the Eryri Supergroup are represented only in limited outcrop of Llanvirn to Caradoc age rocks in the Builth Inlier and anticlinal Twyi Lineament. Volcanic rocks in the Builth Inlier are interpreted to reflect subduction along the southern margin of Iapetus in intra- to back-arc extensional settings (Woodcock *et al.*, 1996, p.197).

Ordovician strata Within the broader Knighton area, Ordovican rocks crop out in the northeastern end of the Builth Inlier in the southwest (southeast of Llandrindod Wells), in the Twyi Lineament in the west of the area and in the small Pedwardine Inlier (Boynton & Holland, 1997). A very small outcrop of Ordovician (Sandbian to Katian, formerly known as Caradoc) sandstone, siltstone and mudstone with thin limestone lies on the northern margin of the area adjacent to the Church Stretton Fault between Clunbury and Clungunford; this outcrop does not extend onto the Knighton sheet as far as is known.

The **Builth Volcanic Inlier** extends into the Knighton sheet (s.s.). The rocks range in age from Darrwillian to Katian (formerly Llanvirn to early Caradoc) and comprise mainly basaltic volcanic and dominantly fine-grained siliciclastic rocks, such as those within the Llanfawr Mudstones Formation (LrM), in the younger parts. The Ordovician rocks are generally overlain unconformably by Silurian rocks of Wenlock age, except to the NE of Llandrindod Wells, where rocks of Llandovery age lie to the NW of Ordovician strata.

Strata of Sandbian and Katian (formerly Caradoc and Ashgill) age crop out in the core of the **Twyi Lineamen**t, NW of Llandrindod Wells, where they are unconformably overlain by strata of Llandovery (Telychian) age (Cerig Fmn). The area also includes the intra-Ashgill (now known as Katian to Hirnantin) unconformity arising from the Shelvian deformation phase, inferred to result from the soft docking of Avalonia with Baltica in the late Ordovician (e.g. Cherns *et al.*, 2006, p.80, Toghill, 1992).

In addition to the Neoproterozoic strata discussed above, the **Pedwardine Inlier** [SO 36 70 – SO 37 72], also includes rocks assigned to the Tremadocian (Formerly Tremadoc) (Shineton Shale Fmn) and the Llandovery (Letton Fmn and *Pentamerus* Beds – see below in the section on Silurian strata) (Boynton & Holland, 1997, Figure 1, Cox, 1912). Cox (*op. cit.*) referred to the shales assigned to the Tremadoc as the *Dictyonema* Shales, as they bear the graptolite *Rhabdinopora (syn. Dictyonema) flabelliformis*; they were therefore correlated with the Shineton Shales. Lithological description is limited: Boynton and Holland (*op. cit.*) refer merely to ‘rather soft, yellowish grey, shaly and flaggy micaceous siltstones’.

Silurian strata The larger part of the area is underlain by Silurian strata, the bulk of these being Wenlock and Ludlow in age and belonging to the Hafren Supergroup. Rocks of Llandovery age (Myddfai and Plynlimon groups) crop out in the west of the area. However, unlike equivalent successions on Builth Wells, Rhayader, Llanidloes and Montgomery (and, to a degree on Ludlow), the Silurian strata are undivided beyond Series level in any BGS map and there is currently no published formal lithostratigraphy within the area of the Knighton sheet. The same is true for the Hay-on-Wye sheet to the south, of which the area outlined in this report overlaps the northern margin. As discussed above, strata in the Ludlow Anticline are subdivided largely on faunal grounds, thus making it difficult to correlate sensibly between these shelf successions and the outer shelf and basinal successions to the west.

The latest Ordovician (Hirnantian) to Wenlock depositional system of the Hafren Supergroup in the Welsh Basin and outer platform comprises two distinct components arising from different controls on base level, one eustatic, the other tectonic. In the early phase, through to the early Telychian, easterly-derived slope-apron facies dominate and reflect (and can be correlated with) eustatically-controlled (global) changes in base level. Sediments include mudstones and turbidites, and very locally derived debrites in the eastern margin of the basin. Tectonic controls become more influential in the later Llandovery, and eustatic controls on sedimentation were regarded as more difficult to recognise in succeeding Wenlock strata (Cherns *et al.*, 2006, Woodcock *et al.*, 1996). However, the work reported by Wilson and Davies (in prep) shows that eustatically influenced sedimentation continued on into the Wenlock.

Nevertheless, from the Telychian onwards, southerly-derived turbidite systems become important, reflecting a relative and regional change in base level and rejuvenation of southern source resulting from tectonism. Subsidence analysis shows that very rapid subsidence occurred in the basin during the latest Llandovery and early Wenlock, matched by rather smaller, but synchronous subsidence on the platform (Prigmore *et al.*, 1997). Geophysical evidence indicates that crustal-scale extension must have occurred and was probably characterised dominantly by strike slip along major faults within the basin, including, with specific regard to the Knighton area, the Twyi Lineament (Woodcock *et al.*, 1996).

Within the **Pedwardine Inlier**, lithologies assigned to the Llandovery (Letton Fmn) include coarse sandstones and conglomerates comprising well-rounded clasts predominantly of quartzite (Cox, 1912). They are generally very poorly exposed and the outcrop appears to extend over just a few hundred square metres. The key exposure is in the stream section SE of Upper Pedwardine Farm [SO 365 708].The rocks rest on a planed off surface of the Shineton Shales with strongly angular unconformity. Palaeontological evidence indicates a late Telychian age.

Silurian lithostratigraphy – further detail

Basinal deposits of the Plynlimon, Llangollen and Fynyddog Grit groups The western part of the Knighton area is underlain by basinal deposits assigned to the mainly **Llandovery Plynlimon Group** and the Wenlock to Ludlow **Llangollen** and **Fynyddog Grits groups**. These are fully described by Davies et al (1997) in the memoir to the Rhayader and Llanilar districts.

The oldest of the basinal units is the late Telychian **Dolgau Mudstone Formation**. This comprises mainly sand-free, pale green, largely oxic mudstone. Within the western Knighton area the Dolgau Mudstone is succeeded sharply by the **Nant-ysgollen Mudstones Formation**, dominated by hemipelagite with minor mudstone turbidite beds. Medium to thick bedded siltstone and sandstone turbidites become more abundant upwards and eastwards, and are vertically and laterally transitional into the **Penstrowed Grits Formation** (equivalent in the region to the *Castle Vale Formation* of Dimberline & Woodcock (1987) and references therein). This unit represents a southerly-sourced, turbidite sand lobe that is limited laterally to the east by faults contiguous with the Garth Fault to the south; it thus has limited presence on the Knighton sheet (s.s.). The Penstrowed Grits Formation is interpreted to result from extensional events in the early Wenlock, but its deposition also coincides with early Wenlock glaciation and consequent eustatic changes in base level (Wilson & Davies, in prep). The Siltstone and sandstone turbidites and structureless, medium to thick bedded, high-matrix turbidite sandstones are interbedded with hemipelagite. Slumped units are also present in places. Dimberline & Woodcock (1987) have discussed the sedimentology in some detail.

The Penstrowed Grits are succeeded laterally and upwards by the **Nantglyn Flags Formation**, a largely turbiditic unit with interbedded hemipelagite and with the distinctive burrowed **Mottled Mudstone Member** (MMM).

The Wenlock basinal strata were deposited under largely anoxic conditions (except for the MMM), but this can't be equated with simple eustatic control on base level (Davies et al., 1997).

Shelf deposits of the Epynt Group: The **Epynt Group** comprises latest Llandovery, Wenlock and Ludlow shelf deposits on the southeastern margins of the Welsh Basin (Wilson & Davies, in prep). This group is diachronously overlain by westward prograding red-bed deposits of the Old Red Sandstone. In the Knighton area, these deposits are nominally of Pridoli to Lower Devonian age.

The base of the Epynt Group marks a return to flooded conditions across the shelf, following the Ireviken event. Anoxic bottom conditions were established and largely persisted until late Ludlow times. A brief oxic period is represented by the **Aston Mudstone Formation** in the Homerian, before the Gorstian transgression re-established anoxic conditions at the base of the

Ludlow. Much shallower depositional systems were established late in the Ludlow, as indicated by the presence first of oxic medium grey, commonly calcareous siltstones of the **Knucklas Castle Formation** and then shoreface and beach deposits of the increasingly sandy **Cefn Einion Formation**. These units correlate with the uppermost Ludlow **Fibua Formation** and the transgressively overlying **Cae'r Mynach Formation** in the Builth district, but the latter two formations are interpreted as representing an initial early Ludfordian deepening event (**Fibua Formation**), followed shallowing and progradation, as represented by the **Cae'r Mynach Formation**.

Shelf to outermost shelf The classical and variably carbonate-bearing shelf successions of the Ludlow area pass west into outer shelf and proximal basin facies in the ground between Ludlow and Knighton. Lithological names, such as the Elton Beds/Group, Bringewood Beds/Group and Wenlock Limestone are well-known and classical in the literature and history of geological research of the region. Whilst the importance of faunas in characterising these successions cannot be underestimated, it is equally true that a sound lithostratigraphical framework for the ground across the Ludlow-Knighton area that is consistent with that in the Welsh Basin is required to complete the understanding of the depositional history of the Welsh Basin and its eastern shelf on to the platform of the Midlands Microcraton.

Attempts have been made to correlate the lithostratigraphy from the inner to outer shelf and basin margin (e.g. Holland & Lawson, 1963, Woodcock & Tyler, 1993, and references therein). Both Holland & Lawson (*op. cit.*) and Woodcock and Tyler (*op. cit.*) figure cross-sections of the generalised interpreted relationships. Holland's (1958) mapping between the Teme and the Lugg still represents the most complete mapping of the Ludlow and Pridoli rocks in the area, as discussed further below.

Llandovery: Burrow-mottled mudstones of the (Telychian) **Cerig Formation** extend from the Rhayader district into the Knighton area and lie between the northeasterly extensions of Garth and Rock Park faults on the SE side of the Twyi Lineament (Davies *et al.*, 1997, fig. 42). The Garth Fault juxtaposes the Cerig Formation against now westerly-younging basinal Telychian deposits that unconformably overlie the **Ashgill Pentre Formation**. The Cerig Formation comprises largely oxic green or grey mudstones, in which colour banding, burrow mottling and diffuse lamination are variably developed. Disturbed beds are developed in places. Lacking folds, exotic clasts and re-worked fauna, the disturbed beds are characterised by destratification and listric surfaces.

Wenlock: South of the Rock Park – Goytre Fault extension, the **Builth Mudstone Formation** extends eastwards into the Knighton area around the NE end of the Builth Inlier, widening its outcrop at the expense of the Cerig Formation because of faulting (Davies *et al.*, 1997, fig. 42). The extension of these structural and stratigraphical complexities into the Knighton district (s.s.) is currently poorly understood.

The Builth Mudstones are dominated by variably calcareous, graptolite-bearing, fine-laminated mudstone. This anoxic facies reflects a marked deepening in the late Llandovery – early Wenlock. However, the abundance of fragmented shelly detritus indicates relative proximity to shelly, shelf communities, and probable redistribution of this material by storms. Davies et al (1997) regard the Builth Mudstones as distal shelf/ramp facies, contemporaneous with the basinal Wenlock turbidite deposits in the Nant-ysgollen Mudstones, Penstrowed Grits and Nantglyn Mudstones. Finally, the Builth Mudstones are separated abruptly from the basinal facies by the Garth Fault. The abrupt change may reflect syn- or post-depositional movement, but it is clear that there was a steep, west-facing slope in the area, as indicated by the presence of significant slump sheets in the Builth Mudstones, and that the latter accumulated on the leading edge of this slope. The northeasterly extension of this Wenlock ramp system into the Knighton area, northeast of the Builth Inlier will require some attention to elucidate the relationship between sedimentology and structure and the degree to which their relationship extends up into the overlying Ludlow successions.

Ludlow slump facies: A key feature of the depositional processes active during the early to middle Ludlow, around the Gorstian-Ludfordian boundary, is the slumping/mass wasting of fine-grained deposits on the shelf margin and proximal basin. The **Bailey Hill Formation** (Llangollen Group) contains abundant slumps in its outcrop fringing the western and southern sides of Clun Forest and western and northern sides of Radnor Forest (Tyler & Woodcock, 1987, Woodcock, 1976a, Woodcock, 1976b). Similarly, in the ground around Leintwardine, southwards to the Wigmore Rolls area, there is evidence for major erosion and/or mass wastage and slumping during the Ludfordian. Around Leintwardine, Whitaker (1962) described the channels previously identified by earlier workers (e.g. Alexander, 1936, Lightbody, 1863) in a broader context. These channels cut down through Gorstian to Homerian (Wenlock) strata. In addition, over some 30 km^2 in the Wigmore Rolls area southwest of Leintwardine, Whitaker (1994) records an unconformable surface that cuts down from Gorstian strata (his Elton Group) down into Sheinwoodian strata (Coalbrookdale Formation). The **Bailey Hill Formation** is equivalent in age to the largely Gorstian to earliest Ludfordian **Irfon Formation** of the Builth district, which also is characterised over much of its outcrop by mass slumping facies.

According to Whitaker, up to 275 m of succession is missing, including over much of the area, the **Bringewood Group**. Boulder beds are developed above the unconformity at or close to the base of the '*Lower Leintwardine Group*' (LLG). Whitaker (1994) recognises two types:

a) a single, thick boulder bed generally c. 1.5 – 2.5 m (but up to 7 m) thick with angular to rounded clasts between 30 – 50 cm across
b) boulder beds up to 10 m thick confined to pronounced channels; imbrication of tabular clasts indicates an easterly derivation

Elsewhere, scattered clasts of calcilutite up to boulder size are common in the LLG. Whitaker remarks that the clast lithologies are similar to the underlying Wigmore Rolls Formation and so presumes that they are derived from it.

The sedimentology is complex and would benefit from modern observation and interpretation. Elements of the lithologies described, such as phosphatic pebbles and abraded fossils, together with hardgrounds at the base of Ludfordian strata on the shelf (Cherns, 1980), indicate higher energy environments with limited deposition or current-winnowed surfaces during a low-stand.

Whitaker (1962) described the channels at Leintwardine as 'canyon heads' and compared them to similar features known from modern shelves. Whatever, in modern terms, the channels at Leintwardine appear to be ravinements on the shelf and so reflect erosion resulting from sea level fall. The implication is that, in sequence stratigraphic terms, they probably reflect a Type I sequence boundary developed at a low-stand.

Given the extent of slumped units in the Bailey Hill Fmn eastwards into the Ludfordian strata, questions perhaps remain as to the mechanisms by which the slumps formed: Did the slumps form through local, episodic slumping in response to the deposition of a high sediment load and the development of an unstable sediment wedge, or did the slumping result from an early Ludfordian regional olistotromic event that happened simultaneously across the shelf – slope apron to the basin margin as the sea level dropped? Was slumping triggered solely by absolute (eustatic) sea level fall, or was there a tectonic driver (either regional uplift or seismic)? Could 'disturbed beds' be developed within sections of the stratigraphy due to massive, possibly seismically-driven slope failure? These hypotheses would need testing by careful observation of field relationships and the sedimentology.

Marine to terrestrial transition: late Ludlow – Pridoli (Downtonian) The late Silurian evolution of the Welsh Basin is marked by a reduction in accommodation space and the westwards progradation of shallow marine and then terrestrial facies, assigned to the Epynt Group by Wilson and Davies (in prep). More generally, the units in this group have a complex relationship with those of the Old Red Sandstone (ORS). In southwest Wales, ORS deposition is interpreted to begin in the mid Wenlock, much earlier than that seen in the Welsh Borderland, where marine deposition continued through to the end of the Ludfordian.

The main outcrop of Pridoli strata fringes the eastern margin of the area (Figure 2), with three main outliers to the west: two extending over Clun Forest to the north of Knighton (extending onto the Montgomery sheet) and one east of Knighton, between Presteigne and Bucknall and limited to the east by the SSW continuation of the Church Stretton Fault system.

The most complete mapping of the Ludlow-Pridoli transition in the Knighton area is that by Holland (1958, see plate XXI). He divided the late Silurian stratigraphy into several units west and south of Knighton (Table 1). The rocks through this succession are predominantly fine-grained, but become coarser upwards and include pebbly sandstone in the ‘Red Downtonian’ (Raglan Mudstone Formation). The rocks are also increasingly calcareous up to the base of the ‘Red Downtonian’, indicating an increasingly proximal carbonate source in the hinterland.

The base of the Pridoli in the central area was placed by Holland at the base of the *Platyschisma helicites* Beds, deemed stratigraphically equivalent to the Ludlow Bone Bed.

The current evidence, although weak in terms of good, modern lithological and sedimentological description, indicates a gradual transition from open marine to nearshore and then terrestrial conditions. Thus a modern field review of the sedimentology would be advantageous, both with regard to correlation and understanding the last phase of sedimentation in the Welsh Basin. In addition, uppermost Ludlow rocks are not well known south of the Lugg over Radnor Forest, based on current published data (collaboration with Dick Waters and Rob Hillier will be advantageous, given their current research interest in the late Silurian – Devonian).

Quaternary geology

The Quaternary geology of the Knighton area is not well-known within a modern context. Most texts discussing the Quaternary geology of Wales and the West Midlands avoid the Knighton area, despite the fact that estimates of the Devensian Limit pass through it (Figure 4). However, Dwerryhouse and Miller (1930) describe in some detail the geomorphology and glaciation between Clun and Radnor forests and beyond, and include much field evidence in terms of the distribution of drainage and overflow channels and moraines, which are plentiful. More recently, Cross and Hodgson (1975) describe the glacial diversion of the Teme south of Ludlow, in the extreme east of the area.

In the south of the area, Wye ice reached Orleton, producing a lowland piedmont lobe that left the well-defined, arcuate terminal Orleton moraine that is well-documented (e.g. Cross & Hodgson, 1975). This ice lobe dammed waters to form lakes Woofferton and Wigmore, and Broad Heath, immediately west of Presteigne and north of the ridge from Aymestry to Kington. The southern part of Lake Wigmore contains a gravel delta in which deposits are recorded as being at least 10m thick. The complex of spillways and drainage channels that connects the ponded areas and the major rivers in the area (Clun, Teme, Lugg and tributaries) indicates a complex history to be elucidated beyond that described by Dwerryhouse and Miller (*op. cit.*). Perhaps the most impressive of the spillways is the 200’ deep Downton Gorge that connects Lake Wigmore with Lake Woofferton, and which now carries the Teme northeastwards to Ludlow; before this capture, the Teme clearly must have flowed south past Wigmore to a confluence with the Lugg at Aymestry.

Thus active ice margins and related retreat features are indicated by the evidence available to date. Dwerryhouse and Miller (1930) generally treat everything as a single progression-regression of ice, but, viewed in a modern context and in light of similar margins elsewhere in the UK, it is probable that ice advance and retreat were complex and episodic. In addition, the Hereford Basin is known to contain older, pre-Devensian deposits of Middle Pleistocene (probably Anglian) age that represent drainage from the north including a precursor to the modern River Lugg (Richards, 1999, 2005). It is probably an open question as to whether similar pre-Devensian deposits and landforms exist in the Knighton area, or not.

Major sources of Devensian ice are not obvious. The presumption is that ice was sourced in the west and over-rode much of the upland areas around Knighton. However, Jansson and Glasser (2005, see fig. 3) infer predominantly northeasterly ice flow across central and north Wales, and just into the northwest of the Knighton area. Furthermore, in the NextMap imagery, the massifs of Clun and Radnor forests look effectively unglaciated and Dwerryhouse and Miller (1930) came to the same conclusion from their observations. Indeed, the form of these massifs is similar to that of the eastern Cairngorms, which is known to have been little affected by glacial erosion. It seems likely that these massifs were covered by cold-based ice, rather than being over-ridden by an active ice-sheet sourced in the west and thus may have acted as local sources. Jansson and Glasser (2005, fig. 1a) indicate a N-S trending core to the Welsh ice cap that would include the Knighton area at its southern limit.

Clearly, there is much to learn about the glaciation and deglaciation history. Use of modern technology and datasets (Geovisionary, SocetSet, NextMap, GetMapping) will be essential in any work on the Quaternary, prior to field work. There is potential for new, significant publications. On the applied side, a much better knowledge of the superficial deposits and landforms will accrue which will help in any assessment of sand, gravel and other mineral resources won from superficial deposits.

3.3 IGNEOUS ROCKS

Igneous rocks within the area are confined to the Builth Inlier (Ordovician) and to the Stanner-Hanter Complex (Neoproterozoic). Both have been well-studied, particularly those in the Builth Inlier, which was re-mapped during the revision of the Builth Wells sheet. Thus, these units will not require much attention in the revision of the geology of the Knighton area.

3.4 BIOSTRATIGRAPHY

Biostratigraphy has been at the core of much of the work in the area, most particularly in the Silurian of the Ludlow Anticline – as discussed above, much of the current understanding of the stratigraphy is founded on the biostratigraphy. Biostratigraphy is critically important to the development of a modern understanding of the bedrock of the region. However, the palaeontology is complicated because of the facies control on faunas resulting from the transition from inner shelf to outer slope and basin across the area. This means that lithostratigraphy can be informed by the palaeontology, but cannot be dependent upon it. Furthermore, the chronostratigraphical value of the palaeontology is limited because none of the faunas will be ubiquitous at any point in time. This issue has particular implications for the lithostratigraphy of the strata in the Ludlow Anticline – a classic area of British Silurian geology with a long-established stratigraphy based on the faunas. A particular problem for BGS is the lack of a modern skills base in macropalaeontology within the organisation. Unless new macropalaeontology staff and skills are acquired, BGS will have to look to contract out palaeontology work, probably to the university community, assuming the skills exists in the academic sector as well.

3.5 STRUCTURE

Although structure is extremely important in the Knighton area, it is only commented on in outline here, as there is a wealth of relatively recent literature, much of it by Nigel Woodcock and colleagues, which will guide possible future fieldwork in the area. Dr Woodcock has made his fieldslips available to BGS and these have been scanned and registered as part of the data capture work undertaken this year (09-10).

The structure of the Knighton area is complex. The area is transected by the Welsh Borderland Fault Zone (WBFZ), the very long-lived anastomosing complex of faults and related folds that broadly define the boundary between the Midlands Microcraton and the Welsh Basin. The fault system has a history extending back to the Precambrian, although large-scale Precambrian displacements are not evident. The faults were important during Lower Palaeozoic sedimentation, controlling the disposition of facies, the development of the shelf to basin topography, the partitioning of turbidite flow directions, the generation of accommodation space and the generation of slumped facies, the latter so common in the Silurian. Thus the sedimentary history cannot properly be considered without integrating the structural history.

The WBFZ comprises several components, chief amongst which are (from east to west) the Church Stretton Fault, the Pontesford Lineament and the Twyi Lineamant/Clun Disturbance/Severn Valley Faults. The Swansea Valley Disturbance, Neath Disturbance and Titterstone Clee Fault are related structures lying to the SE of the main group of lineaments.

Reactivation of the faults during the Lower Palaeozoic deformed the sedimentary rocks, resulting in structural highs, erosion and the development of unconformities, folds and, ultimately, basin inversion during late Caledonian Acadian tectonic events.

Woodcock, particularly, has reported on detailed and wider aspects of the structural history with regard to the significance and effects of the WBFZ (Woodcock, 1976a, Woodcock, 1976b, Woodcock, 1984a, Woodcock, 1984b, Woodcock, 1988, Woodcock & Gibbons, 1988, Woodcock *et al.*, 2007). The overall history of the system is discussed in Woodcock & Gibbons (Woodcock & Gibbons, 1988, and references therein), from which much of the following brief summary is drawn.

Much of the faulting has a significant strike-slip history, but thrust, normal and strike-slip displacements are all known, for example, from the Church Stretton Fault, first defined by Ramsey & Aveline (1848).

The evidence for significant late Precambrian movements on faults within the WBFZ is not strong. As detailed by Woodcock & Gibbons (1988), the Pontesford-Linley Lineament (PLL) probably marks the margin of the Midland Microcraton in Ordovician time. The PLL separates thin Caradoc sequences sitting unconformably on Tremadoc or older rocks on the platform from a more complete Ordovician sequence in the Shelve area. The PLL also appears to have been significantly active during Ashgill times, with lateral displacements of up to 40 km possible, if, for example, the Ordovician rocks of the Builth and Shelve areas were once part of the same volcano-sedimentary centre.

Although connectivity from shelf to basin was maintained during the Silurian, component faults of the WBFZ were active, as indicated, for example, by the widespread slumping in Wenlock and Ludlow deposits. Subsequently, the fault system was reactivated during the mid-Devonian. Acadian deformation was manifest in different ways on the three major components, although timing is not well constrained (Woodcock and Gibbons, 1988). The Church Stretton Lineament was dominated by faulting, with little development of marginal folds and no major strike-slip displacement. Tight folding along the Pontesford Lineament resulted in the Clun Forest Disturbance, which displays flower-like geometry consistent with limited strike-slip displacement. The SE-facing Myddfai Steep Belt may also result from movement on deeper faults in the Pontesford Lineament. The Twyi Lineament underwent strong reverse movement and folding and marks the SE limit of strong Acadian cleavage development in the Welsh Basin.

Despite their significance in the Welsh Borderland, the discrete northeastwards continuation of these structures is unclear because of the late Palaeozoic and Mesozoic cover in the Staffordshire and Cheshire basins. However, Variscan movements are indicated by the strike-slip displacement of U. Carboniferous rocks NE of the Church Stretton area. Permo-Triassic rocks are also affected, suggesting that movement on extensions of the WBFZ influenced the development of the Cheshire and Staffs Permo-Trias basins. Furthermore, there is some circumstantial evidence from the pattern of faults in Staffordshire and Cheshire on the BGS Tectonic Map of Britain, Ireland and Adjacent Areas (British Geological Survey, 1996) to suggest that the WBFZ swings northwards and then northwestwards, north of the inferred apex of the Midlands Microcraton.

4 Summary of the key geological knowledge and data issues

The Knighton area, and specifically the Knighton 1:50 000 Geological Sheet, has been neglected by the BGS since the original survey in the mid 1800s. Current and future budget limitations and the orientation of the BGS programme are very likely to preclude a full, detailed 1:10 000-scale survey of the sort similar to those undertaken in recent years on adjacent sheets across the Welsh Basin. Coverage of the area by academic mapping is extensive (see below), but is inconsistent in terms of standardisation, information and quality, and is of widely different vintages. A focussed survey programme is required to fill gaps in data and knowledge for the Knighton area and to clarify and integrate academic work, in order to develop a consistent understanding of the geology. Thus, an early phase of a Knighton-Ludlow project would necessarily include a more detailed assessment of the geological data currently available to establish the critical geological problems to be addressed. The use of GeoVisionary, SocetSet and other digital techniques will be particularly important with regard to landform mapping as a basis for mapping the Quaternary, and for bedrock mapping where featuring is sufficiently strong.

The key issues are:

- Lack of a systematic, well-founded lithostratigraphy consistent with adjacent areas, across the Knighton area, including the Ludlow Anticline, where the current stratigraphy is strongly influenced by the palaeontology
- Limited understanding of the sedimentology, related depositional processes and the controls thereon
- Lack across most of the ground of a modern survey of the Quaternary landforms and their deposits in the vicinity of the Devensian Limit
- Lack of a modern understanding of the Quaternary history of the area, particularly compared to better known areas to the north
- Complete absence of digital geological data at formation level or better for the Knighton area, with concomitant lack of knowledge of lithological variation and properties.

The key benefits of a modern geological survey & interpretation

- Aquisition of geological data in the Welsh Borderlands, through which run the main N-S trunk routes connecting N Wales and Cheshire with South Wales, noting that the nearest N-S motorway is the M6, many miles further east.
- Though smaller, there are also key E-W routes connecting the Midlands to central West Wales, particularly Aberystwyth.
- An opportunity to understand more completely the geological linkages between the classic shelf geology of the Ludlow area with the Welsh Basin to the west.
- Opportunity to markedly improve upon the understanding of the Quaternary history of the region, coupled to modern understanding of Quaternary history elsewhere in the southern UK.
- Effective completion of a modern survey of the Welsh Basin (compatibility with surrounding modern mapping and interpretation to the north and west.

- Challenging opportunities for training and development in field geology skills in a complex terrain where structure, sedimentology and stratigraphy are intimately connected.
- Completion of the DigMap data set for England and Wales

Proposed solutions:

- Compilation of existing published map data, georeferenced in the project GIS
    - *Maps scanned and referenced as part of the work for this scoping report*

- Assessment of lithostratigraphy, based on compiled maps and published data, supported by knowledge of the lithostratigraphy developed for several of the surrounding sheets
    - Identify areas poorly covered by published work
    - Identify areas for targeted, problem-orientated fieldwork

- Key scientific publications, e.g.
    - A Lower Palaeozoic inner shelf to basin transition: the Silurian of the Eastern Welsh Basin
    - The tectonic versus eustatic controls on sedimentation in the Silurian of the Eastern Welsh Borderland
    - Tectonic history of the Welsh Borderland Fault Zone and related structures within the context of the Palaeozoic evolution of the crust of Southern Britain (Avalonia)
    - Character of Variscan deformation in the foreland
    - The Late Devensian glaciation and deglaciation of the Eastern Welsh Borderland
    - Biostratigraphy vs lithofacies models – to what degree are they related?
    - Reinterpretation of the stratigraphy and sedimentology of the classic Ludlow shelf system

- Training opportunities:
    - Opportunities for less experienced colleagues to develop skills in field observation and interpretation in an area of complex, challenging geology
    - Training in the sedimentology of shelf to basin sedimentary rocks, and the controls thereon
    - Training in structural geology

- Current holdings: mapping, geochemistry, geophysics, hydrogeology,etc
    - Mapping
        - Kirk (fieldslips), Holland (published map), Woodcock (fieldslips), Whitaker (published map), Earp,
    - Regional geophysical data (magnetic, gravity)
    - G-BASE geochemical data
    - Data listings in appendices

- Quaternary data
    - Good, modern Quaternary data are lacking

    - Opportunities to develop Quaternary science in areas marginal to the Devensian limit
    - Digital imaging techniques using Geovisionary and the like will provide rapid means of assessing and mapping Quaternary landforms and deposits

- Hydrogeology
    - The tributary rivers of the River Severn in the east (Teme, Clunn, Lugg and Arrow) are important as part of Severn-Trent Water's water supply network

5 Applied and Economic Geology

Elan Valley Resevoirs Aqueduct - Dolau-Bledfa Tunnel

Severn-Trent Water has proposed the construction of a new water supply aqueduct in the Dolau – Bledfa area, to replace an existing brick-lined tunnel built in Victorian times. This tunnel would transect the Welsh Borderland Fault Zone, so engagement with Severn-Trent would provide opportunities to study the WBFZ internally. BGS has already been approached to cost an extensive ground mapping survey along the tunnel route, although there is no indication that a contract will result at present.

Working Quarries in Knighton Area

All of the working quarries described below are close to the southern boundary of the Knighton area within the Hay-on-Wye sheet. Their economic interest and summaries of the geology are summarised below. For a more detailed discussion, see Woodcock (1988).

Dolyhir Quarry SO 243 584 Walton. Operated by Tarmac Ltd – Western

This quarry works both Precambrian greywackes sandstones of the Yat Wood Formation and Silurian limestones of the Dolyhir Formation. The Precambrian Rocks are sold as crushed rock aggregate, roadstone and coated roadstone and the Silurian limestones as roadstone and coated roadstone.

Precambrian, Yat Wood Formation

These comprise pale green laminated or massive siltstones, thinly laminated mudstones and fine-grained, generally massive, sandstones. They are are interpreted as having been deposited on "an alluvial flood plain or subaqueous delta environment." (Woodcock, 1993).

Limestone, Silurian, Dolyhir Limestone Formation

"Massive crystalline limestone, rich in algae and bryozoa and containing brachiopods, trilobites and conodonts microfauna. They represent a shallow turbulent environment, possibly local submarine topographic high due to already partly uplifted basement in the Church Stretton Fault Zone or possibly part of a more extensive carbonate shelf continuous with the Woolhope Limestone in the inliers of the Southern Borderland" (Woodcock, 1993).

Minerals at Dolyhir

Dolyhir is also well known for its many mineral species and has been an important site for mineral collectors since 1995, being one of the most diverse mineral locations in the British Isles. Over 70 different species have been identified and several "assemblages" recorded, each relating to different geological events.

It is thought that the mineralisation is related to the various local igneous intrusions, alteration of which has resulted in the release of rare element mineral species that have subsequently recrystallised within the fractures of the Silurian and Precambrian Rocks. Supergene weathering of mineral veins has also produces suites of rare secondary minerals. Recent research has identified "Alpine-type" fissures, more commonly found in Snowdonia.

National Museum of Wales Website: Mineralization at Dolyhir Quarry (http://www.museumwales.ac.uk/en/1656/)

Gore Quarry

Walton [SO257 592]. Operated by Tarmac Ltd – Western
This quarry works Precambrian sandstones of the Strinds Formation, Wentnor Group for use as roadstone, crushed roadstone and crushed rock aggregate

The Strinds Formation comprises pale greenish grey, purple and brown, fine- to medium-grained, massive, micaceous sandstones, with beds of conglomerate containing clasts of vein quartz, rhyolite and mica schist. These clastic rocks are interpreted to have been deposited in a braided alluvial environment.

Strinds Quarry
Walton [SO242 578]. Operated by Tarmac Ltd – Western

Strinds Quarry works the Strinds Formation for roadstone and the Dolyhir Limestone Formation for building stone, coated roadstone and crushed rock aggregate

Responsive Surveys Projects

Wilby P. 2010 ***A geological investigation of the Quaternary of the upper Lugg Valley, Wales British Geological Survey Comissioned Report CR/09/174***

The British Geological Survey – Responsive Surveys Wales was commissioned by the Environment Agency Wales to conduct a desk study and geological survey of the buried valley between Pilleth and Llangunllo and Monaughty and Bleddfa, along an un-named tributary of the Lugg, to determine the thickness and characteristics of the Quaternary Valley fill. This supported the EA in their modelling of the Quaternary aquifer within the upper Lugg Valley and its tributary.

6 Geohazards

Enhanced rainfall, slope stability, surface drainage and groundwater If climate changes in the region develop in line with predicted global warming, there are likely to be increases in rainfall, with concomitant enhanced risk for slope failures of various types, enhanced flooding risk (the Teme has flooded significantly in recent years) and enhanced risk of groundwater contamination. Understanding the distribution of potential landslide risk along key transport corridors will be important – especially because the road network is largely rural, commonly confined by the topography and situated away from the main N-S road network. Alternative readily accessible routes, capable of carrying significant traffic during possible road closures due to landslides, etc, are likely to be very limited, causing sever disruption.

Seismicity An assessment of the seismicity across Wales was undertaken by Musson (2005), from which this discussion is drawn and information summarised.

Despite the concentration of major fault structures in the Welsh Borderland Fault Zone (WBFZ), the wider Knighton area is less seismically active than other areas of Wales, notably the Lleyn Peninsula and the South Wales Coalfield. Nevertheless, there are a small number of records of earthquakes up to ML 4 and 5 (local magnitude = to Richter Scale; Musson, *op. cit.*, p.90) in the area with epicentres lying within the domain of the WBFZ. It is important to note, however, that the epicentres cannot be tied to current fault traces at surface, even when they coincide. Indeed, given the likely depth of the foci at > 10 km, any direct causal link between a currently visible fault and an earthquake at depth is very likely to be tenuous and Musson cautions strongly against drawing any conclusions about movement on current faults linked to recent earthquakes. In doing so, he counters more assertive claims of links between faults and earthquakes made by Blenkinsop et al (1986).

In terms of hazard, Musson determined that the Knighton area overlaps two broadly defined domains in which there is a 10% likelihood of a 5 or 6 European Macroseismic Scale (EMS) earthquake occurring in the next 50 years. EMS 6 earthquakes are widely felt and cause general alarm, but only minor damage (cracked plaster, damaged chimneys). The boundary between the EMS 5 and 6 domains lies within the WBFZ. Thus, while it is difficult to point to particular faults as discrete hazards, it nevertheless remains that the WBFZ as a whole is associated historically with seismicity whereas the wider region of central Wales is seismically very quiet.

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Appendix 1

LITERATURE REVIEW

In addition to the complete list of references given above, this Appendix categorises the bibliography according to subject.

Biostratigraphy

Biostratigraphical control on the ages of the rock units within the region are discussed in a number of papers, the Knighton – Ludlow region being classic for the application of conventional macro- and micropalaeontological biostratigraphy. These include conodonts, in a paper in which Aldridge describes conodont taxa and their usefulness to for dating, including references to the Welsh Borderlands. Palynomorphs, have been used to date rocks from the Upper Whitcliffe and lower Downton Castle Sandstone Formation (Ludlow and Pridoli) within the Knighton District in a paper by Richardson and Rasal. They recognise a change in taxa within the Downtown Castle Sandstone formation.

Graptolites also have a role to play in the biostratigraphy of the region. A paper by Zalasiewicz illustrates how Silurian graptolites zones have a short duration, averaging 0.8Ma, and may be subdivided still further.

The Late Ordovician of the Welsh Basin, between basin and shelf successions, has been dated using chitinozoa by Challands, who devised a biostratigraphic scheme for the Welsh Basin.

Ziegler, Cocks and McKerrow described the evolution of a number of brachiopod fauna which enabled them to make correlations between the Silurian shelf sequences of the Welsh Borderland and the type area of Llandovery and the existing graptolite zones. This work tracks the transgression across the borderland which took place at the beginning of the Llandovery.

Holland examined Cephalopods from a borehole in the type Wenlock area of the Welsh Borderland. The bore hole intersects Wenlock Shales, as described in the paper. He also identified a biostratigraphical division based on relative abundances of various species and its correlation with the *Cyrtograptus lundgreni* biozone.

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- Zalasiewicz, J. and Williams, M. 1999. Graptolite biozonation of the Wenlock Series (Silurian) of the Builth Wells district, Central Wales. Geological Magazine, **136** (3): 263-283.

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- Miller, C. G., Sutherland, S. J. E. and Dorning, K. 1997. Late Silurian (Ludlow-Přídolí) microfossils and sedimentation in the Welsh Basin near Clun, Shropshire." Geological Journal **32**: 69-83.

Palaeontology

There are number of palaeontological studies which have been carried out within the Knighton area and the wider region. These include a study by Cherns, which describes how faunal data can be matched to facies to interpret benthic palaeoecology and palaeogeographical evolution in the Anglo-Welsh Basin with particular reference to the Lower Leintwardine Formation. Of particular interest here is the correlation of stratigraphy from the offshore environments to the west of the district to the shallower shelf environments to the east. Similarly, Brett and others studied associations of fossil genera, which display repeated, predictable patterns of change across stratigraphic sections.

Turner and Salter both discuss the occurrence of particular fossil groups in the region. Turner describes a succession of theodonts, identified through scales and ascribed to four assemblages in the Welsh Borderland. These successions are compared with similar occurrences in Scotland, Europe, Russia and Canada, suggesting distinct faunal assemblages, influenced by palaeogeography. Salter has written about Pteraspis trackways within Upper Ludlow Sandstones.

- Brett, C. E., Hendy, A. J. W., Bartholomew, A. J., Bonelli, J. R. J. & McLaughlin, P. I. 2007. Response of shallow marine biotas to sea-level fluctuations: a review of faunal replacement and the process of habitat tracking. Palaios. **22**, 228-244.

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- Green, H. M. 1955. The calcareous algae of Woolhope and Wenlock limestones from certian localities in the Welsh Borderland. Unpublished PhD, University of Manchester.

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- Salter, J. W. 1867. On some Tracks of Pteraspis (?) in the Upper Ludlow Sandstone. Quarterly Journal of the Geological Society. **23**: 33-339.

- Turner, S. 1973. Siluro-Devonian thelodonts from the Welsh Borderland. Journal of the Geological Society. **129** (6): 557-582.

Quaternary geology

Only a small number of publications exist on the Quaternary geology of the region. Dwerryhouse and Miller studied glaciation around Clun and Radnor Forests, the two principal upland areas in the district. They concluded that the area was glaciated by ice originating in the highlands of Central Wales. The related glacial outflows gathered in the valleys of the Ithon and Irfon. Ice flows escaped via the valley of the Upper Severn, Mule, Clun and Teme in the North and the Wye to the south. Dwerryhouse and Miller proposed that ice eventually rose an altitude that permitted non-topographically constrained flow over the higher ground of Clun Forest and to heights of at least 1700 feet on Radnor Fforest, overtopping the escarpment of Gilwern Hill and Aberedw Hill. The Radnor Forest massif is considered to have obstructed ice flow eastward. Many streams were deflected from their courses. Cross and Hodgson (1975) building on the earlier work, presented new field evidence for the Teme’s diversion towards the Wye and the former existence of a large proglacial lake – Lake Wooferton.

Discussion about the Quaternary in a wider geographical area is provided by Richards (1990) which looks at Middle Pleistocene Glaciations in Herfordshire and Richards (2005). Jansson and Glasser (2005) looked at palaeoglaciology of the Welsh part of the British Ice Sheet, concluding that ice flow was directed towards the south and southwest, rather than eastwards, as inferred by Dwerry and Miller.

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Structure and tectonics

The current understanding of the tectonics and structure of the region comes from a range of papers, with a number concentrating on the Welsh Borderlands.

The Welsh Borderland Fault Zone includes the Pontesford Lineament and the Church Stretton Lineament. The Pontesford Lineament is discussed in detail in Woodcock (1984) and Lunas et al (1985). The latter was intermittently active from the mid Ordovician through to the Triassic with both strike slip and dip slip displacement.

The Church Stretton Lineament is discussed by Woodcock (1988). The paper focuses on the Old Radnor Inlier, where there is evidence for strike slip displacement along the length of the limeament. In the Knighton area this displacement is interpreted to have been sinistral along the main strand of the lineament after the Wenlock.

Kirk (1947) discussed anticlinal disturbance of Breconshire and Radnorshire described by and the influence of tectonics on sedimentation in the region are discussed by Woodcock and Gibbons as well as Cherns and Cocks.

Many of the papers have a broader focus such as seismicity in Wales, regional variation in cleavage and fold development, extensional tectonics and rifting.

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Stratigraphy

No attempt has been made in this review of literature to translate the stratigraphic terminology used by each author to modern nomenclature. The terms are as stated by the authors. The references have been organised by the stratigraphy to which they refer.

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Townsend Tuff

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Uppermost Silurian

Temeside Bone Bed

Antia, D. D. J. 1981. The Temeside Bone-Bed and associated sediments from Wales and the Welsh Borderland. Mercian Geologist. **8** (3): 163-215.

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Bassett, M. G., Lawson, J. D. and White, D. E. 1982. The Downton Series as the fourth Series of the Silurian System. Lethaia. **15**: 1-24.

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Ludlow

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General

Ziegler, A. M. and McKerrow, W. S. 1975. Silurian marine red beds. American Journal of Science. **275** (1): 31-56.

Dimberline, A. J., Bell, A., and Woodcock, N. H. 1990. A laminated hemipelagic facies from the Wenlock and Ludlow of the Welsh Basin. Journal of the Geological Society. **147** (4): 693-701.

Wilson, D. and J. R. Davies (in prep). Stratigraphical framework report for the post-Tremadoc Ordovician and Silurian strata of Wales and the Welsh Borderland. British Geological Survey Research Report.

Regional overviews

There are a number of papers and PhD’s that take a regional perspective of areas in and around the Knighton district as well as more generally on Wales and the borders.

Parts of the Knighton district its-self is covered by Holland and Kirk whilst in the north of the district, Earp looked at the Clun Forest. The old county of Radnorshire, covers the area on the Welsh side of the border on the Knighton sheet. A notable paper on this region is by Roberts on The Abby-cwmhir area to the south west of Knighton.

The county of Shropshire which lies to the to the north and east of the area, occupies the eastern margin of the Knighton sheet area, has papers by Cox, Whittard, Watts and Lapworth. Also the east of the district, the geology at Pedwardine has been examined by Boynton and Holland as well as Cox who look at the Longmyndian inlier, whilst the Leintwardine area is covered by Whitaker.

The Geologists’ Association have published a number of detailed field reports and guides, these include the Ludlow area, Shropshire and Central Wales as well as Powys. The “Geology of Powys In Outcrop” also describes a number of sites in the region.

Knighton

Holland, C. H. 1957. The Stratigraphy and Structure of the Knighton District. PhD, University of

London.

Kirk, N. H. 1951. The Upper Llandovery and Lower Wenlock rocks of the area between Dolyhir and Presteigne, Radnorshire. Abstracts of the Geological Society, London. **1471**: 56-58.

Kirk, N. H. 1951. The Silurian and Downtonian rocks of the anticlinal disturbance of Breconshire and Radnorshire; Pontfaen to Presteigne. Abstracts Geological Society, London. **1474**: 72-74.

CLUN FOREST

Earp, J. R. 1938. The Geology of the South-Western Part of Clun Forest. Quarterly Journal of the Geological Society. **96**: 1-11.

Pedwardine

Boynton, H. E. and Holland, C. H. 1997. Geology of the Pedwardine district, Herefordshire and Powys. Geological Journal. **32** (3): 279-292.

Cox, A. H. 1912. On an Inlier of Longmyndian and Cambrian Rocks at Pedwardine (Herefordshire). Quarterly Journal of the Geological Society. **68** (1-4): 364-373.

LEINTWARDINE

Whitaker, J. H. M. 1962. The Geology of the area around Leintwardine, Herefordshire. Journal of the Geological Society**. 118** (3): 319-351.

LUDLOW

Woodward, H. B. and Dixon, E 1904. Long Excursion to the Ludlow District. Proceedings of the Geologists' Association. **18**: 487-491.

SHROPSHIRE

Cocks, L. R. M. 1989. The geology of South Shropshire. Proceedings of the Geologists' Association. **100** (4): 505-519.

Whittard, W. F. 1952. An Account of the Geology of South Shropshire. Proceeding of the Geologists' Association **63** (2): 143-197.

Watts, W. W. 1925. The Geology of South Shropshire. Proceedings of the Geologists' Association **36** (4): 321-363.

Lapworth, C. and Watts, W. W. 1894. The geology of South Shropshire: With special reference to the district to be visited during the long excursion. Proceedings of the Geologists' Association **13** (9): 297-355.

Radnorshire

Davies, L. 1912. Radnorshire. Cambridge University Press.

Roberts, R. O. 1929. The Geology of the District around Abbey-Cwmhir, Radnorshire. Quarterly Journal of the Geological Society. **85** (1-4): 651-676.

Rhyayder

Davies, J. R., Fletcher, C. J. N., Waters, R. A., Wilson, D., Woodhall, D. G. and Zalasiewicz, J. 1997. Geology of the country around Llanilar and Rhayader; Memoir for 1:50 000 Geological sheets 178 & 179 (England & Wales). London, The Stationery Office.

Powys

Woodcock, N. H. and Bassett, M. G. 1993. Geological Excursions in Powys Central Wales, National Museum of Wales on behalf of South Wales Geologists' Association.

Davies, J. H., Holroyd, J., Lumley, R. G. and Owen-Roberts, D. 1983. Geology of Powys in Outcrop. A field guide to the geology of Powys, Merioneth Press.

Welsh Borders

Bridges, P. H. 1975. The transgression of a hard substrate shelf: the Llandovery (Lower Silurian) of the Welsh Borderland. Journal of Sedimentary Petrology. **45** (1): 79-94.

Whitaker, J. H. M. 1994. Silurian basin slope sedimentation and mass movement in the Wigmore Rolls area, central Welsh Borderland. Journal of the Geological Society. **151**: 27-40.

Mid-Wales

Dimberline, A. J. and Woodcock, N. H. 1987. The southeast margin of the Wenlock turbidite system, Mid-Wales. Geological Journal. **22** (Thematic Issue: Sedimentation and Tectonics in the Welsh Basin): 61-71.

Bailey, R. J. and Woodcock, N. H. 1976. Field meeting: the Ludlow Series slumps of east central Wales. Proceeding of the Geologists' Association. **87** (2): 183-190.

Baker, J. W., Hughes, C. P., Bassett, M. G., Bates, D. E. B. and Rickards, R. B. 1979. Summer (1973) field meeting in central Wales, 31 August to 7 September 1973. Proceedings of the Geologists' Association. **90** (1-2): 65-79.

Wales

Bassett, M. G. (ed). 1984. Focus on Wales. Proceedings of the Geologists' Association. **95** (4): 289-398

Miscellaneous

Allender, R., Holland, C. H., Lawson, J. D., Walmsley, V. G. and Whitaker, J. H. McD. 1960. Summer Field Meeting at Ludlow. Proceedings of the Geologists' Association **71** (2): 209-232.

Azmy, K., Veizer, J. Wenzel, B., Bassett, M. G. and Cooper, P. 1999. Silurian strontium isotope stratigraphy. Geological Society of America Bulletin**. 111** (4): 475-483.

Ball, T. K., Davies, J. R., Waters, R. A. and Zalasiewicz, J. 1992. Geochemical discrimination of Silurian mudstones according to depositional process and provenance within the southern Welsh Basin. Geological Magazine. **129** (5): 567-572.

Schofield, D. I., Millar, I. L., Wilby, P. R. and Evans, J. R. 2010. A new, high precision U–Pb date from the oldest known rocks in southern Britain. Geological Magazine**. 147** (1): 145-150.

Murchison, R. I. 1839. The Silurian System. London.

Cocks, L. R. M., Holland, C. H. and Rickards, R. B. 1992. A revised correlation of Silurian rocks in the British Isles. Geological Society Special Report. **21**. London. 32pp.

Kaljo, D., Martma, T., Mannik, P and Viira, V. 2003. Implications of Gondwana glaciations in the Baltic late Ordovician and Silurian and a carbon isotopic test of environmental cyclicity.

Bulletin de la Societe Geologique de France **174** (1): 59-66.

Cook, A. H and Thirlaway, H. I. S. 1954. The Geological Results of Measurements of Gravity in the Welsh Borders. Quarterly Journal of the Geological Society. **111**: 47-70.

De-La-Beche, H. 1830. Sections and Views Illustrative of Geological Phenomina.

Cantrill, T. 1917. On a boring for Coal at Presteign, Radnorshire. Geological Magazine. **4**: 481-492.

Cantrill, T. C. 1918. Boring for coal at Presteign. Geological Magazine. **55**: 47-48.

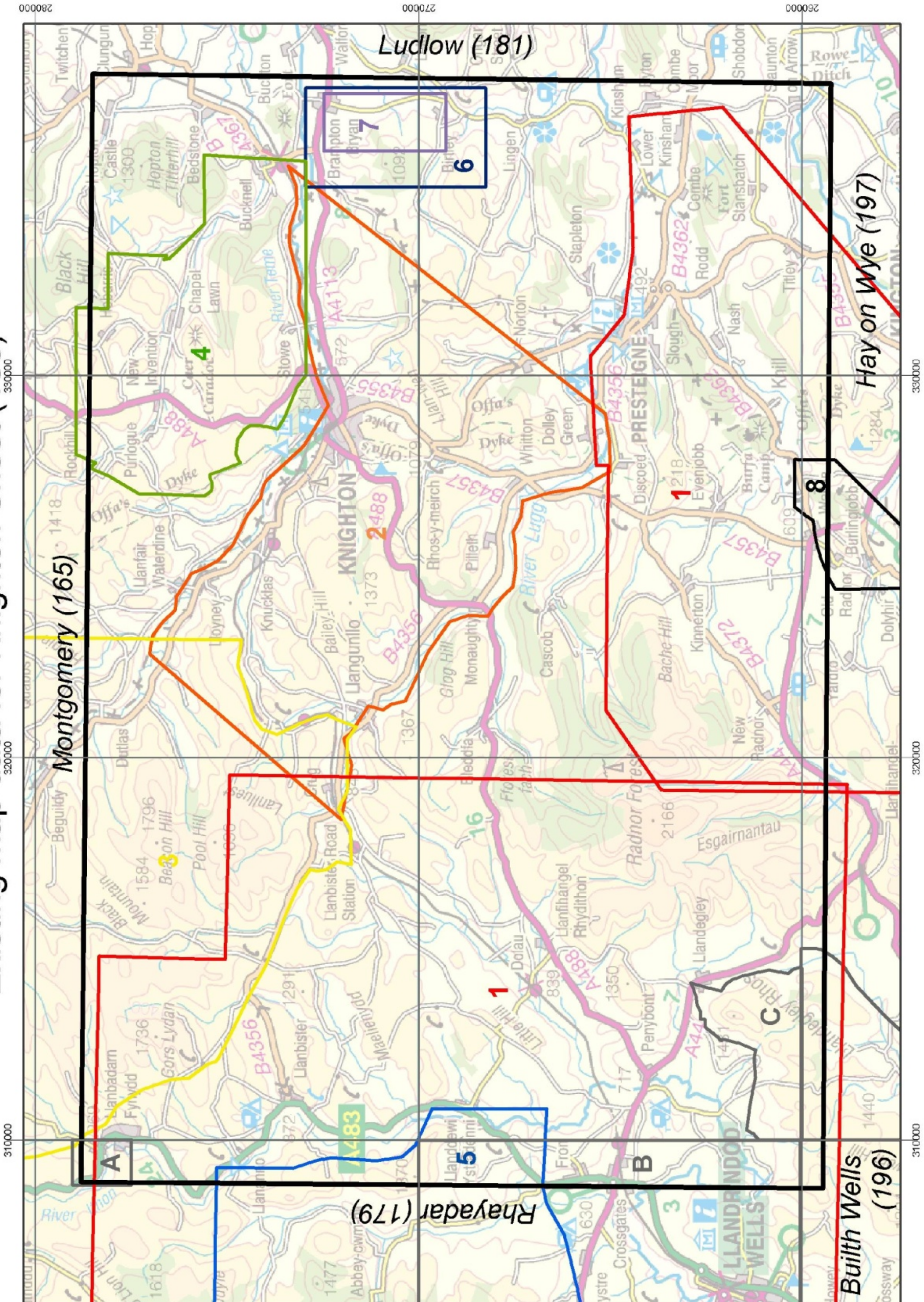
Watts, W. W. 1917. Coal in the Silurian at Presteign. Geological Magazine **4**: 552-553.

Mata, S. A. and Bottjer, D. J. 2009. The paleoenvironmental distribution of Phanerozoic wrinkle structures. Earth-Science Reviews. **96** (3): 181-195.

Appendix 2

EXISTING MAPS

Published papers that present mapping data which would inform a field mapping programme are identified below. The areas covered by each publication are illustrated below. The numbered areas are referenced in the accompanying text.



Existing map data for Knighton Sheet (180)

Overlapping BGS mapping data

A number of BGS field maps that cover marginal areas of the Knighton district (180) are available in scanned form on the BGS Geoscience Data Index. The overlaps result from mapping undertaken in adjacent districts of Montgomery (A) and Rhayadar (B). Also included is detailed mapping of the Builth Inlier (C), in the south west corner of the sheet.

Other published and unpublished maps

In 1962, Hains, Boulton, and Williams produced a map at 1:10560 of an area of Radnor Forest. Their results are published in: "Geological Investigations for Hydraulics Research Station of catchment areas in Wales and the Welsh Borderland". This is an internal report of the Institute of Geological Sciences, although a copy of this report has not yet been located by the Library.

1 Dr N Kirk

Dr Nancy Kirk mapped widely in the district. Her field slips have been made available to the BGS and have been scanned and geo-rectified. They provide some very detailed observations of the geology of the Knighton district, especially in the west. There is also a montage of field slips within this collection. Although mainly falling within the Hay-on-Wye district, this collection also covers parts of the south east corner of the Knighton district.

2 C H Holland

Holland's (1958) work on the uppermost Silurian succession covered an extensive area south of Knighton.

3 J R Earp

Earp (1940) mapped the south western part of the Clun Forest, in the North Western corner of the Knighton district, extending into the Montgomery district. He worked on the "highly contorted strata" using stratigraphical subdivisions adopted in the Kerry District.

4 L D Stamp 1918

Stamp (1918) mapped and described the sequence and distribution of uppermost Silurian strata in the Knighton area. He recognised the transitional nature of the rocks, being, because they are, "of particular interest as they are intermediate between the Shropshire (Ludlow) district with its calcareous type of cement to the east and the Welsh area, where the corresponding rocks are of an argillaceous character".

5 Roberts 1929

The area covered by this map extends into western edge of the Knighton district from the adjacent Rhayadar district. The map includes the 'Bala', 'Valentian' and Wenlock Series but Roberts (1929) concentrated primarily on the Wenlock strata.

6 Boynton and Holland 1997

This mapping covers a small area in the east of the Knighton sheet, including the Pedwardine inlier. This area includes Precambrian, Tremadic and Llandovery rocks. The work also reports on the distal record of mass movement deposits seen more fully at Wigmore Rolls. The inlier lies within the Church Stretton fault zone. This work builds on earlier work of Cox (1912).

8 Schofield et al 2010

This work records a U-Pb zircon age for the granophyric rocks of the Stanner Hanter Complex of 710.8 +/- 1.5Ma and includes a geological map of the complex after Holgate and Hallowes, 1941 and Woodcock 1988.

9 Structural mapping by Woodcock

Figure 2 in Woodcock (1984) highlights the major lineaments in Wales and the Borderland with the Pontesford Lineament shaded. This data covers the whole of the Knighton sheet.

10 Woodcock Field Slips

Dr Nigel Woodcock (Cambridge) has provided his fieldslips of the the region in which he has mapped extensively. These have been scanned, georeferenced and included in the project GIS.

Appendix 3

REGIONALLY IMPORTANT GEOMORPHOLOGICAL SITES (RIGS)

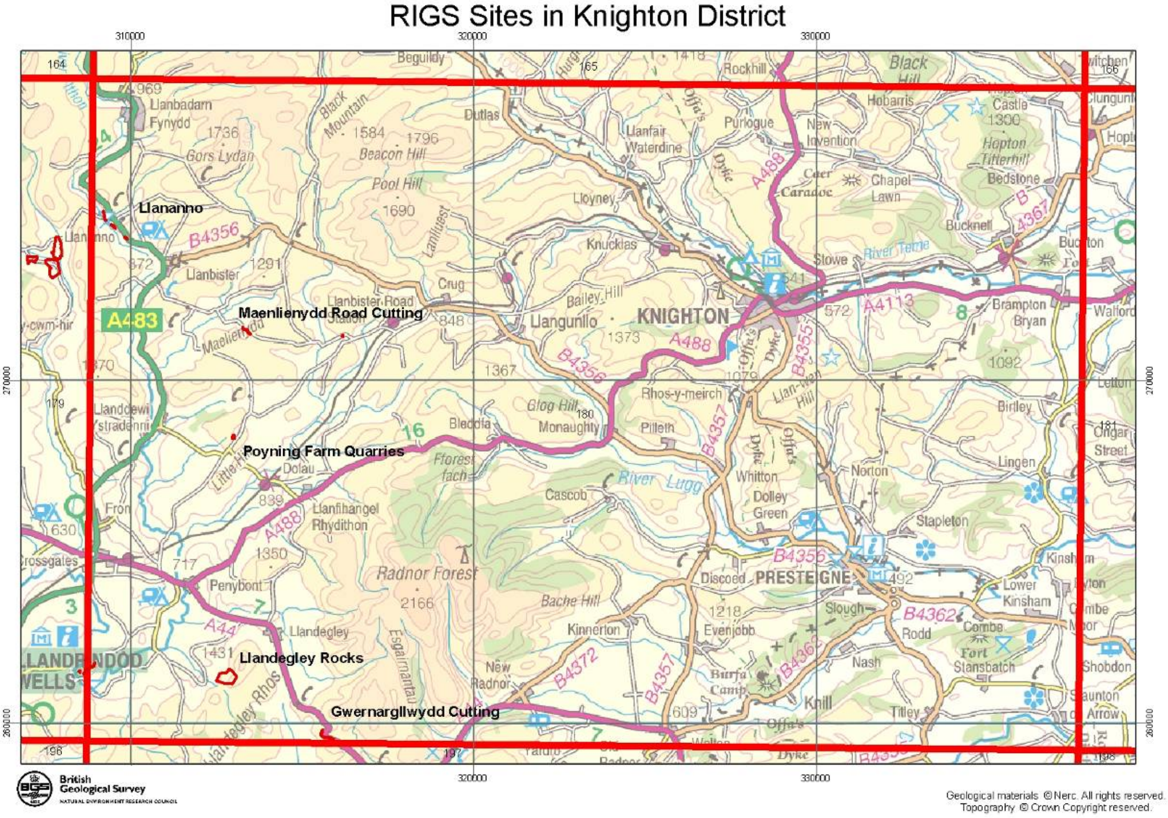
What are RIGS?

Protected through local authority planning system, RIGS are selected for their scientific, educational, historical and aesthetic values:

- **Scientific** sites are important for ongoing research in the Earth sciences
- **Educational** sites provide and outdoor geological classroom for all ages and abilities
- **Historical** sites demonstrate the importance of geology in archaeological and historical constructions, the development of geology as a science and commemorate the outstanding contributions of important geologists.
- **Aesthetic** sites demonstrate the importance of geology to understanding and appreciating some of our cherished landscapes and scenery

The following sites have been identified as RIGS within the Knighton District by the Central Wales RIGS group, lead by Bill Fitches and the extracts are from the Central Wales RIGS Group Website (http://www.geologywales.co.uk/central-wales-rigs/cwales.htm).

RIGS Sites in Knighton District



Site Name: Llananno Central Grid Reference: SO 095746
RIGS Category: Educational & Scientific
Earth Science Category: Silurian (Wenlock) Stratigraphy and Structure
Geology 1:50,000: BGS Sheet Newtown
RIGS Statement of Interest:
This road-cutting is one of three RIGS in the Llananno area that collectively provide an important section through the middle Silurian strata that were deposited near the southeastern margin of the Welsh Basin. Again collectively, the three RIGS reveal a profile through a major, southeastward overturned fold that may mark a step at the basin margin, the Tywi Lineament, which became reversed during regional compression. This structure, here referred to as the Llananno Monocline, may be the SW continuation of the huge fold inferred near the Tan Y Foel Quarry RIGS.

This RIGS is distinguished from the other two near Llananno mainly because the beds here are inverted in the common limb of the Llananno Monocline whereas they retain their original orientation at the other sites. The rocks exposed here, belonging to the Penstrowed Grits Formation, are mostly turbidites which have been the subject of recent investigations by researchers at Cambridge University, and are described in a well-known geological field guide (location 5, Dimberline & Woodcock, 1993). A major attraction of the cutting is that the bases of the sand turbidites, showing flute casts and other signs of current scouring, are easily seen and well-exposed because they are inverted.
Surveyed by: W.R. Fitches

Site Name: Llananno Northwest Grid Reference: SO 092748
RIGS Category: Educational & Scientific
Earth Science Category: Silurian (Wenlock) Stratigraphy and Structure
Geology 1:50,000: BGS Sheet 180, Knighton (not yet mapped)
RIGS Statement of Interest:
This road-cutting is one of three RIGS in the Llananno area that collectively provide an important section through the middle Silurian strata that were deposited near the southeastern margin of the Welsh Basin. Again collectively, the three RIGS reveal a profile through a major, southeastward overturned fold that may mark a step at the basin margin, the Tywi Lineament, which became reversed during regional compression. This structure, here referred to as the Llananno Monocline, may be the SW continuation of the huge fold inferred near the Tan Y Foel Quarry RIGS.

This RIGS is distinguished from the other two near Llananno because it contains a spectacular slumped unit that reveals down-slope movement into the Welsh Basin, exposes small tectonic folds, and there are calcite veins that offer information about deformation processes. Moreover, the rocks here are not inverted as they are at the Llananno Central RIGS a short distance to SE. The rocks exposed here, belonging to the Penstrowed Grits Formation, have been the subject of recent investigations by researchers at Cambridge University, and are described in a well-known geological field guide (location 6, Dimberline & Woodcock, 1993).

Most of the section comprises beds of sandstone, reaching 0.5 m in thickness, interlayered with thinner bedded siltstone and mudstone. Using current-indicators exposed in the quarry and elsewhere, it has been shown that the sandstones were carried by submarine density currents from southern parts of the Welsh Basin whilst some of the finer sediments were transported in from the basin margin to the east. Statistical data have been obtained from the quarry section to study rates of sedimentation.
Surveyed by: W.R. Fitches

Site Name: Llananno Southeast Grid Reference: SO 098742
RIGS Category: Educational & Scientific
Earth Science Category: Silurian (Wenlock) Stratigraphy
Geology 1:50,000: BGS Sheet 180, Knighton (not yet mapped)
RIGS Statement of Interest:
The rocks at this site, part of the Nantglyn Flags Formation, appear to be rather monotonous and uninteresting, and are degrading quickly because of weathering. However, they provide information essential for demonstrating the presence of the major Llananno Monocline fold and determining the stratigraphic evolution of this area. This information needs to be integrated with observations made at the two other Llananno RIGS. This site is different from the other two as it comprises slightly younger Silurian strata, the rocks are generally finer grained, without sandstones, and they are situated in the SE limb of the Llananno Monocline.
The condition of the site is not as good as the other two. These rocks have recently been studied by researchers at Cambridge University and are briefly described in a well-known field guide (location 4, Dimberline & Woodcock, 1993).
Surveyed by: W.R. Fitches

Site Name: Llandegley Rocks Grid Reference: SO 1275 6135
RIGS Category: Educational & Scientific
Earth Science Category: Ordovician (Llanvirn) Stratigraphy, Igneous Geology
Geology 1:50,000: BGS Sheet 180, Knighton (not yet mapped)
RIGS Statement of Interest:
This RIGS consists of a number of individual outcrops that combine to show a good sequence through the Llandegley Tuffs and the lower part of the Builth Volcanic Group, including several fossiliferous localities. There are good viewpoints showing the structure of the sequence across Llandegley Rocks, and the effects of underlying geology on topography. It is a remarkable set of exposures, including good outcrops of the Llandrindod Tuff Formation with pyroclastic (explosive volcanic) textures and secondary hydrothermal metamorphism (alteration by hot water circulation), keratophyric lavas) with flow banding, coarse ashes of the Llandegley Tuffs, a problematic reworked volcaniclastic unit known informally as the laminated ashes, and fossiliferous sandstones at two levels. The upper of these fossiliferous sites (SW ridge), in the lower part of the Gilwern Volcanic Formation, is of substantial international interest. This site preserves a diverse fauna of articulated echinoderms and sponges, a unique occurrence from a nearshore, coarse sand environment of Early Palaeozoic age. The contrast between the two completely different shelly faunas either side of the Llandrindod Tuff Formation suggests the eradication of the earlier fauna and immigration of the later, revealing an unusually interesting ecological history.
Surveyed by: J. P. Botting & W.R. Fitches

Site Name: Llandegley Rocks Grid Reference: SO 1275 6135
RIGS Category: Educational & Scientific
Earth Science Category: Ordovician (Llanvirn) Stratigraphy, Igneous Geology
Geology 1:50,000: BGS Sheet 180, Knighton (not yet mapped)
RIGS Statement of Interest:
This RIGS consists of a number of individual outcrops that combine to show a good sequence through the Llandegley Tuffs and the lower part of the Builth Volcanic Group, including several fossiliferous localities. There are good viewpoints showing the structure of the sequence across Llandegley Rocks, and the effects of underlying geology on topography. It is a remarkable set of exposures, including good outcrops of the Llandrindod Tuff Formation with pyroclastic (explosive volcanic) textures and secondary hydrothermal metamorphism (alteration by hot

water circulation), keratophyric lavas) with flow banding, coarse ashes of the Llandegley Tuffs, a problematic reworked volcaniclastic unit known informally as the laminated ashes, and fossiliferous sandstones at two levels. The upper of these fossiliferous sites (SW ridge), in the lower part of the Gilwern Volcanic Formation, is of substantial international interest. This site preserves a diverse fauna of articulated echinoderms and sponges, a unique occurrence from a nearshore, coarse sand environment of Early Palaeozoic age. The contrast between the two completely different shelly faunas either side of the Llandrindod Tuff Formation suggests the eradication of the earlier fauna and immigration of the later, revealing an unusually interesting ecological history.
Surveyed by: J. P. Botting & W.R. Fitches

Site Name: Neuadd Farm track Grid Reference: SO 0875 6150
RIGS Category: Educational & Scientific
Earth Science Category: Ordovician (Llanvirn) Stratigraphy, Igneous Geology
Geology 1:50,000: BGS 1:50,000 Sheet 179 Rhayader
RIGS Statement of Interest:
This RIGS consists of a long track cutting that exposes the only complete section through the upper part of the Builth Volcanic Group in the northern part of the Builth Inlier. The rocks include a variety of igneous and reworked explosive volcanic deposits, including very good volcanic bombs, and a range of volcano-sedimentary structures. It is the only complete section through the upper part of the Builth Volcanic Group to the north of Gelli Hill, and records a strikingly different lithological sequence, with a higher proportion of original igneous rocks. The beds grade upwards into weathered ashy shales overlying the sequence, containing a sparse fauna of inarticulate brachiopods and graptolites. It is among the best locations in the inlier for studying the interval covering the subsidence of the main volcanic phase, and in combination with the Llandegley Rocks RIGS provides an excellent and nearcomplete succession through most of the igneous sequence in the area.
Surveyed by: J. P. Botting & W.R. Fitches

Site Name: Poyning Farm Quarries Grid Reference: SO 130683
RIGS Category: Educational & Scientific
Earth Science Category: Silurian (Ludlow) Stratigraphy
Geology 1:50,000: BGS Sheet 180, Knighton (not yet mapped)
RIGS Statement of Interest:
This site comprises two small quarries, almost adjacent to each other, in which Silurian marine sedimentary rocks are exposed. The age of the rocks is early Ludlow. In the NE quarry, the lower few metres of strata are simply and gently inclined to NW but higher beds have been severely contorted by spectacular slumping of the sediment before it was lithified. A10 cm thick layer of volcanic clay (bentonite) near the boundary between intact and disturbed beds may have acted as a slip surface at the base of the slumped unit. Fossils in this quarry included graptolites, broken crinoid stems and brachiopod shells. During our RIGS survey, a well-preserved coiled cyrtocone, 10 cm diameter, was found in a concretion in the slumped unit; the fossil is of museum quality. The less easily accessible SW quarry is cut entirely within the slumped unit. These sedimentary, fossil and volcanic features are of considerable interest to researchers and educational groups, and they may be included in public awareness material aimed at drawing attention to the local and regional geology.
Surveyed by: R. Cave & W.R. Fitches

Appendix 4

GEOLOGICAL EXCURSION GUIDES PROVIDING DETAILED INFORMATION ABOUT SPECIFIC SITES

There are two notable excursion guides which include itineraries for the Knighton area and the rest of Powys. These are:

Geological Excursions in Powys Central Wales
Edited by Woodcock and Bassett
Published 1993 by the National Museum of Wales for the South Wales Geologists' Association

This publication, along with excursions across the Powys area, includes detailed itineraries covering "The Ludlow and Pridoli of the Radnor Forest to Knighton Area" and "The Precambrian and Silurian of the Old Radnor to Presteigne area".

Geology of Powys in Outcrop. A Field Guide to the Geology of Powys.
By Davies. JH, Holroyd. J, Lumley. RG, Owen-Roberts. D
1983
Merioneth Press

Geology of Powys in Outcrop is also an itinerary based work which contains tours and detailed interpretations on the features seen in Gore Quarry, and the Dolyhir and Yatt Quarry Complex as they were in 1983.

Appendix 5

LOCAL GEOLOGY INTEREST GROUPS

At the time of writing, the following groups are local to the Knighton area.

Shropshire Geological Society
The Shropshire Geological Society has been in existence from 1979 and its stated objectives are "to advance the education of the public and to promote research in geology and allied sciences, more specifically in Shropshire and adjacent areas, in particular but not exclusively by: a) organising lectures, discussions, field excursions, exhibits and displays, b) promoting the recording and conservation of sites of geological interest." The group holds regular meetings, lectures and field trips and produce a regular newsletter and articles in their proceedings. They also have a RIGS group. www.shropshiregeology.org.uk

Herefordshire and Worcestershire Earth Heritage Trust
The trust has a programme to identify, survey and protect the "Earth Heritage" within the Counties of Herford and Worcester the former of which makes up part of the Knighton area. They have identified RIGS and SSSI's within the two counties and aim to raise public awareness or the geological heritage by means of trail guides, information leaflets, holding open days and organising fun days for schools and families. www.earthheritagetrust.org

Central Wales RIGS Group
"The Central Wales RIGS group (Regionally Important Geodiversity Sites) was formed in May 2005 and is co-ordinated by Bill Fitches from Aberystwyth. We are the third and most recent RIGS group to be set up in Wales, and join the Gwynedd & Mon group working in the NW of the country and the NEWRIGS group in the NE, in the Association of Welsh RIGS groups (AWRIGS). This association belongs to UKRIGS, the national organisation.

Like the other Welsh RIGS groups we are financed by the Aggregates Levy Sustainability Fund for Wales, administered by the Welsh Assembly Government. We receive substantial support from the Countryside Council for Wales (CCW), notably in the provision of maps, airphotos, library and meetings facilities, and especially opportunities to exchange information and ideas on Geodiversity."

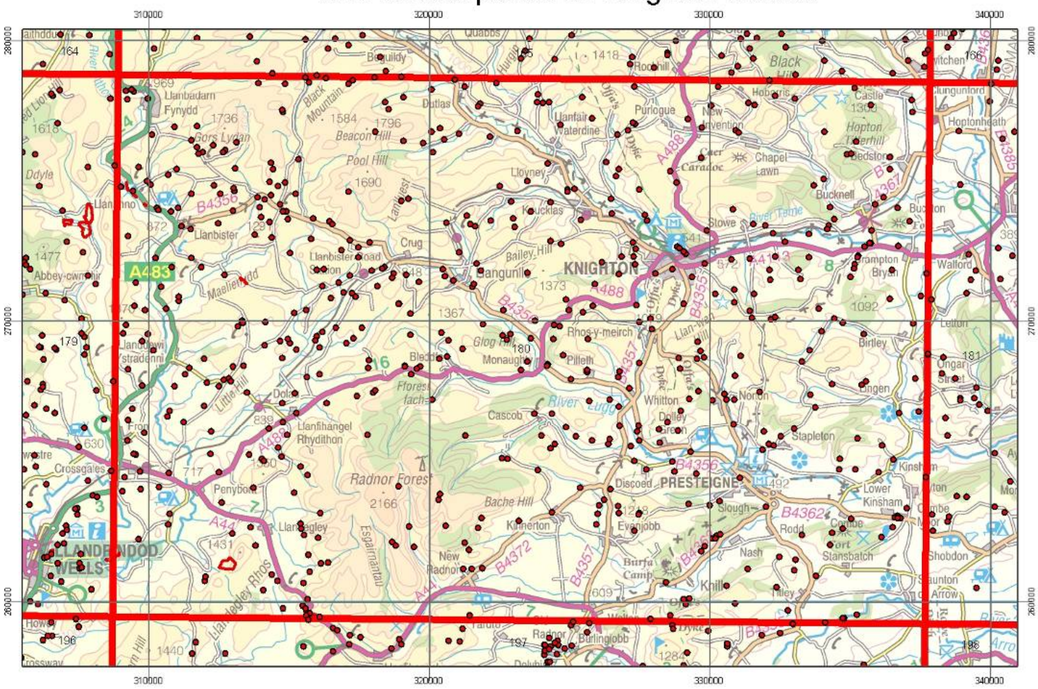
www.geologywales.co.uk

Appendix 6

BRITPITS

The BritPits project collects mineral resource data on producing mines and quarries. Originally only details of active or temporarily inactive sites were included but because of the importance of former workings information is also collected on inactive and closed operations. Data is gathered from BGS records, Mineral Planning Authorites, central government departments and agencies. The attached map shows the distribution of information from the Britpits dataset.

BritPit Data points for Knighton District



British Geological Survey

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