South Wales RIGS Audit
Volume 1 - Overview

Geology and Landscape Wales
Commercial Report CR/12/033

BRITISH GEOLOGICAL SURVEY

Geology and Landscape Wales

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Foreword

The South Wales region has a rich and varied geological history. It is a geology that shapes not only the landscape but its people.

South Wales has a huge wealth of geological and geomorphological treasures providing resources, opportunity for education and extraordinary scenery. At the heart of the region is the South Wales coalfield; its geology formed the focus of the industrial revolution, powering industrialisation of both the UK and beyond. The impact on the landscape, buildings and people cannot be underestimated. The rich variety of geology provides for a varied landscape; from the high mountains of the Brecon Beacons, to the rocky, dramatic coastlines. In the rocks and landscapes of South Wales there are stories of ancient mountains, shifting continents and glaciers gouging their paths through the landscape. There is mineral wealth and fossil interest as well as continued exciting research in the area which includes novel use of the coalfield to continue to produce energy into the future.

This study has provided a set of sites to designate as Regionally Important Geodiversity Sites (RIGS) and Sites of Importance for Nature Conservation (SINC)'s in which this rich diversity can be researched, explored, appreciated, learned from and conserved for future generations.

The Welsh Government's commitment to conservation of the geodiversity of Wales has ensured that Wales is the first nation in the UK to complete its national audit. This commitment has manifested itself not only via funding for these audits through the Aggregate Levy Sustainability Fund for Wales but also through recent changes in policy which endeavour to give geodiversity sites protection through the planning system.

Acknowledgements

A large number of individuals have contributed to this project. These have included staff from BGS, the National Museum of Wales, Cardiff University, University of Glamorgan, and Fforest Fawr Geopark. There have been many volunteers from the South Wales Geologists' Association, The Russell Society, Open University Geological Society, Brecon Beacons Park Society, Blaenavon World Heritage Site - Forgotten Landscape Project and the Monmouthshire Volunteers, Cambrian Cave Registry, Environment Agency amongst others. This assistance has been gratefully received at all stages of the study. In addition to the collection of data and field work to evaluate sites, many individuals have freely given their advice, and provided the local knowledge. As in other parts of Wales, the success of the project has depended largely on contributions made by specialists with close experience of the geodiversity and volunteers who have provided valuable local knowledge.

There have been many individuals who have contributed to this project, mainly from the organisations mentioned above. We would particularly like to thank the following:

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Planning is a devolved Welsh Government responsibility for which the Welsh Government has produced a planning policy. This document (Planning Policy Wales 2011) and its supplements sets out the ambition to conserve and improve the natural history of Wales. Natural heritage is defined in these documents as including geology and landforms. Conservation designations for geology and landscape are not as common as those already in place to cover biodiversity, being mainly restricted to Sites of Special Scientific Interest. The RIGS designation provides for a secondary tier of sites for geological conservation which are considered on a local basis, through the planning process.

The South Wales (Regionally Important Geodiversity Sites) RIGS Audit extended the systematic audit of Geodiversity sites into South Wales, following the approach taken in the rest of Wales. The South Wales RIGS Audit therefore, completes the audit for Wales, making Wales the first nation to achieve a national coverage of RIGS.

This document discusses geoconservation and RIGS and their place in the planning system. It also sets out the aims of the project and the methods used to chose sites. Finally, this document summarises the geology of the region and places each chosen site in its context.

It is envisaged that documentation for each RIGS chosen by this audit will be given to each planning authority in its region. This document should accompany those sets of RIGS reports to give wider geological context and explain the methods involved in the site selection process.

1 Introduction

This report is the published product of a study by the British Geological Survey (BGS), on behalf of the Welsh Government. The project was funded by the Aggregate Levy Sustainability Fund for Wales. The aim of the study was to establish a suite of sites to become RIGS, to describe the geology and landscape of the South East Wales region. The project ran from April 2008 until March 2012.

1.1 GEOCONSERVATION

The importance of conserving sites which reflect the geodiversity of the UK landscape and natural environment is now recognized as being of major importance in the context of sustainable land-use planning and development. Such sites can provide access to key bedrock, superficial deposits and soil units which contain instructive evidence of previous periods of environmental change, including climate and land-use change; many chart the history of local mineral extraction and associated industrial development; others were, and remain, the only source for building stones that contribute to our architectural heritage.

Increasing environmental awareness within the population and an appreciation of where the raw materials which drive our economy are derived from, is leading to increased consideration of local geology, the need for high quality, consistent record keeping and the necessity of protecting vulnerable sites. This interest is also reflected in increasing numbers attending field trips organized by local geological organisations and is further exemplified by the achieving of European and Global Geopark status for Fforest Fawr which lies within the project area (*UK RIGS 2000)*

The Welsh Government “Technical Advice Note 5” *Nature Conservation and Planning* (discussed later in this document) lists the many the conservation designations that should be considered during the planning process of which RIGS is just one component. Many of these can include geological interest. These are divided into International, National and Local designations. Listed below are many that may include geological interest:

Internationally Important Sites: Special Protected Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar sites. These are in the main related to bird or other flora and fauna species.

Nationally Important Sites: National Nature Reserves (NNR’s), Sites of Special Scientific Interest (SSSI)* and Marine Nature Reserves (MNR’s).

Regionally or Locally Important Sites: Local Nature Reserves (LNR), Sites of Importance for Nature Conservation (SINC), Regionally Important Geological Sites (RIGS), Limestone Pavements, Coastal waters, lakes, rivers, streams or other wetlands (*Welsh Assembly Government, 2009).*

National Parks: National Parks are “protected areas” because of the beauty of their countryside, their wildlife and cultural heritage. They are designated under the Countryside Act 1949 (*anon 2012)*

Areas of Outstanding Natural Beauty (AONB): These are areas which are “precious landscapes whose distinctive character and natural beauty are so outstanding that it is in the nations interest to safeguard them”. They are created under the Countryside Act of 1949. The Gower is an AONB within the South Wales RIGS area. (*anon 2010*)

***Geological Conservation Review (GCR)** Is a project intended to provide a record of all of the sites of geological interest in the UK. Many of these sites are of international importance and are either already notified as SSSI's or are being considered for notification. (*Ellis NV et al 1996*)

1.2 WHAT ARE RIGS?

Regionally Important Geodiversity Sites – RIGS - are currently the most important places for Earth Science conservation outside statutorily protected land such as Sites of Special Scientific Interest (SSSI). RIGS form a network within a county or region of geological sites that are considered worthy of protection for their Earth Science importance. They are identified by locally developed criteria which may emphasise the local educational, historical and recreational resource rather than its national scientific significance which is the remit of SSSI status. RIGS form a network of second tier sites that supports the SSSI sites but which do not have statutory protection. However, the designation of RIGS is one way of recognising and therefore protecting important Earth science and landscape features through the local authority planning system for the future (*UK RIGS, 2000)*.

The RIGS initiative was established as there was an identifiable need to:

- Conserve local geological and geomorphological sites for educational purposes.
- Involve people in Earth heritage conservation.
- Build on existing resources and good practice.
- Build a network of locally important sites to underpin the SSSI network and protect locally important sites.
- Facilitate consultation between existing local groups already involved in local Earth heritage conservation.
  (*UK RIGS, 2000)*

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

Sites may be designated under one or more of the above categories.

(AWRG Leaflet)

1.2.1 RIGS and SINC's

It is recognized that not all sites identified will achieve RIGS status, although the site may be of local significance. For the purposes of this report, SSSI sites are considered the primary conservation status with RIGS being secondary. As a consequence, this study has identified a third tier of sites which should be considered by local authorities for inclusion within the Sites Important for Nature Conservation (SINC) network.

These tertiary sites may be more accessible or provide additional supporting scientific or educational resources to those recommended for RIGS. For example, the RIGS selection process may highlight a site quoted in literature or which may be the "type locality" of a particular geological unit. This means that that particular site is the place where this particular feature was first described in scientific literature and where the typical nature of a formation or fossil or mineral can be studied. Often these sites were identified decades ago, the sites have subsequently degraded or are less accessible, and whilst the site remains scientifically significant, other locations today may highlight the same features, be more accessible or are more easily utilised by the local community. It is these sites which are recommended for SINC status and may in time be raised to RIGS status if the original locality is lost.

A good example within Cardiff Council is the type locality for the Llanishen Conglomerate. Today this important locality is restricted to a very small outcrop in Llanishen Railway Station yard and the remainder of the outcrop is largely hidden by retaining walls. This study recommends this site as a RIGS for its historical importance as the place that this formation was first described. However, at Transh-y-Hebog, North of Cefn Onn there is a larger outcrop of the same formation which is much more easily accessible and so it has been recommended as a SINC. Together, both sites provide important information of this particular geological feature.

Although the designation of a RIGS is primarily about conservation of an identified feature, a site with a seemingly destructive process such as a quarry could also be identified as a RIGS. The features for which a site has been chosen may be improved by further excavation in active quarries. There may be scope within the restoration phase of quarrying operations to preserve a face which then may have subsequent scientific or community amenity value. Consultation with the operator or owner prior to closure may result in quarry faces being graded to make them safe or accessible once extraction has come to an end.

1.3 RIGS GROUPS IN WALES

The South Wales RIGS Audit, was the fifth RIGS audit undertaken in Wales, carried out under the standards established by the Association of Welsh RIGS Groups (AWRG) to ensure consistency of approach and data recording, so that results contribute to a pan-Wales dataset. The project follows on from evaluations undertaken in NE Wales by NEW RIGS, Gwynedd and Anglesey by Gwynedd and Mon RIGS, Central Wales by The Central Wales RIGS Group and South West Wales by the South West Wales RIGS Group. This project completes the initial audit of sites for the Principality. Wales becomes the first of the UK nations to complete its audit of geological sites.

Figure 1 RIGS Groups in Wales including boundaries and RIGS defined to date illustrates the distribution of RIGS and SINC's, designated by these groups, in Wales, to date.

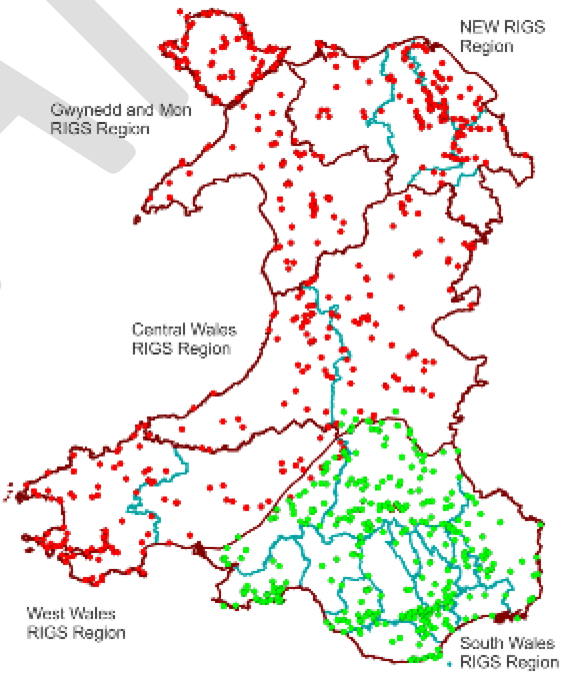


Figure 1 RIGS Groups in Wales including boundaries and RIGS defined to date

1.4 PROTECTION OF GEOLOGICAL SITES AND WELSH PLANNING SYSTEM

RIGS do not enjoy statutory protection under law as is the case for Sites of Special Scientific Interest (SSSI). The protection of RIGS is achieved most effectively through the planning system through local experts recommending sites to the appropriate planning authority. Most local planning authorities regard RIGS as equivalent to non-statutory wildlife sites and thus list them in their local plans. One of the key aims of the initiative is to conserve a series of locally important geological sites as many geological localities are threatened by irreversible damage.

Some geological sites, within the South Wales Region are of international importance and are protected as SSSI's. These have often been identified by the Geological Conservation Review (GCR). Where possible, these sites are referred to in the geological discussion section of this report as they form a significant part of our geological heritage and part of the network of sites of geological interest of which RIGS forms a part.

Planning is a devolved Welsh Government responsibility and so The Welsh Government has published, in 2011, a "Planning Policy Wales Edition 4 (PPW)" document which sets out the land use planning policies of the Welsh Government. This document is further supplemented by "Technical Advice Notes (TANs)". The PPW, TANs and circulars together comprise the national planning policy which should be taken into account by local planning authorities in Wales in the preparation of unitary development plans (UDP). They may also be used to make decisions on individual planning applications.

Chapter 5 of the PPW deals with "Conserving and Improving Natural Heritage and the Coast" and is most relevant to RIGS. The document sets out its policy objectives as being to:

- promote the conservation of landscape and biodiversity, in particular the conservation of native wildlife and habitats;
- ensuring that action in Wales contributes to meeting international responsibilities and obligations for the natural environment;
- ensure that statutory designated sites are properly protected and managed;
- safeguard protected species and to
- Promote the functions and benefits of soils, and in particular their function as a carbon store.

Natural heritage in Wales is defined as including its geology, landforms, biodiversity and its natural beauty and amenity *(Welsh Assembly Government, 2011).*

In 2009, the Welsh Assembly Government issued Technical Advice Note 5 (TAN 5) to provide advice on how local authorities address nature conservation issues in planning documentation, and so supplement the information in Planning Policy Wales (2002). TAN 5 makes specific reference to how "*….the land use planning system should contribute to protecting and enhancing biodiversity and geological conservation*." (Paragraph 1.2.1.). Paragraph 3.2.4. goes on to highlight that under Section 11 of the Countryside Act (1968) all public bodies are "..*to have regard to the desirability of conserving the natural beauty and amenity of the countryside*." Whilst Section 49(4) of the Act provides that the "…*conservation of natural beauty are to be construed as including reference to the conservation of its flora, fauna and geological and physiographical features*."

The following extracts illustrate the importance given to geology and geodiversity within this document:

"'Geodiversity' is the variety of geological environments, phenomena and active processes that make landscapes, rocks, minerals, fossils, soils and other superficial deposits that provide the framework for life on earth. Geodiversity is important because it underpins biodiversity with soils being the link between them."

"The geology of Wales, including its landforms, minerals and fossils, is diverse, visually impressive and of great scientific importance."

RIGS are defined in this document as "local Sites", meaning that they are of local rather than national interest. Local sites are defined as having "important role to play in meeting biodiversity targets and contributing to the quality of life and well-being of the community. Paragraph 5.3.11 of PPW explains the policy in respect of such sites. Policies in Unitary Development Plans (UDP's) and Local Development Plans (LDP's) provide for their protection."

The nature conservation interests for which they have been designated are a material consideration in planning decisions." Paragraph 5.3.11 as mentioned above, explains that "non-statutory designations should apply to areas of substantive conservation value where there is good reason to believe that normal planning policies cannot provide the necessary protection."

TAN 5 specifically refers to RIGS as a "Nature Conservation Interest" in Table 4.1. that should be considered when an application for any proposed development is submitted, and that appropriate regard should be made to the relevant body at any early stage in the pre-application discussion.

The designation of RIGS and geological SINC's allows local authorities to discharge their duties under this legislation and the relevant Welsh Government policies, usually via the mechanism of the Local and Unitary Development Plan (LDP/UDP) process.

TAN 5 also states that "Locally designated sites should be subject to the application of rigorous criteria to ensure their designation is justified on biological or geological grounds. The process of designating and maintaining the sites should be transparent with records and assessments publicly available, unless information about particular species is sensitive in terms of their protection. Developers should be able to identify how their proposals may affect the interests for which the sites are designated (either positively or negatively) and where relevant, how the sites contribute to wider ecological networks or mosaics" *(Welsh Assembly Government, 2009).*

This last paragraph underlines the need for a robust selection methodology, thorough scientific investigation and detailed documentation of sites proposed as RIGS so that the validity of chosen sites is clearly demonstrated.

1.5 RIGS AND PLANNING APPLICATIONS

Each RIGS has a report that describes the importance of the site (Appendix 1), its geological setting and may also provide guidance on how the site could be used. The report will also provide enough information for a geologist to understand the importance of the site and what kinds of development would harm or potentially improve the site.

In contrast to the development of many biological conservation sites, a planning application that involves a RIGS does not necessarily completely preclude the site's development. Many RIGS will be destroyed by development but many can be improved. For example; a quarry development may expose more of the rocks that are of interest and may improve the interest of the site. In situations such as these, discussion with developers to consider, for example, leaving a face intact at the end of the life span of extraction works, would be helpful.

If there are questions in regard to potentially damaging operations at a RIGS, queries can be made to the British Geological Survey Cardiff, The Countryside Council for Wales or Association of Welsh RIGS Groups who will be able to provide guidance as to specifics of each site and the appropriateness of specific applications.

1.6 SENSITIVE SITES

Some of the RIGS are considered to be sensitive and their details should not be routinely distributed. This may be because a landowner objects to access (RIGS status DOES NOT confer a right of access) or may be because the site is vulnerable to over collecting or vandalism and so attention should not be drawn to these sites. If a site is considered to be of this nature, only a summary of the site will be published. This will include contact details of a relevant geological institution who will be able to help with any queries that may arise regarding the site.

2 South Wales RIGS Audit

2.1 INTRODUCTION

This three-year, South Wales RIGS Audit project, commenced in April 2008 and has audited geologically significant sites within the region. The project was managed and coordinated by the British Geological Survey's Cardiff Office working with a consortium of organizations including local geological groups, universities and institutions. A detailed list is given in Table 1 Organisations involved in the audit.

The South Wales RIGS evaluation was the fifth audit of its kind, carried out under the standards established by the Association of Welsh RIGS Groups (*Wood, 2007)* to ensure consistency of approach and data recording, so that results contribute to a pan-Wales dataset. The project follows on from evaluations undertaken in North East Wales, Gwynedd and Mon, Central Wales and South West Wales.

Figure 2 Map of the South Wales RIGS Region

The South Wales RIGS region extends from Kidwelly in the west to the border with England in the east and extends as far as Builth Wells and Hay-on-Wye in the north.

Included in this area are the counties of southern Powys (Brecknockshire) and eastern Carmarthenshire and the unitary authorities of Swansea, Neath Port Talbot, Bridgend, Vale of Glamorgan, Rhondda Cynon Taff, Merthyr Tydfil, Cardiff, Newport, Caerphilly, Blaenau Gwent, Torfaen and Monmouthshire.

The areas encompasses some of the most densely populated areas of Wales and some of its largest cities with a rich history of coal and iron extraction and steel production, adding to the geological interest of the area. Also within its boundaries are the Brecon Beacons National Park and its associated Fforest Fawr Geopark, Gower AONB and the Severn Estuary, all nationally and internationally important areas. It also includes many sites of significance for the understanding of geology in an international context.

2.2 DETAILED AIMS AND OBJECTIVES OF THE SOUTH WALES RIGS AUDIT

The South Wales RIGS Audit has three broad aims. These are to conserve a series of locally important sites for educational reasons, to involve local people in Earth heritage conservation and to raise public awareness and appreciation of Earth heritage.

The project has also sought to achieve the following aims and objectives during its three year duration.

1. to undertake a desk study of previous work to identify potential RIGS sites within the project area.
2. to examine and document all known sites of potential RIGS value within South Wales
3. to select sites on the basis of their aesthetic, educational, historical and scientific importance.
4. to register the catalogue of sites with relevant authorities and statutory bodies as appropriate, providing them with hard copies and digital versions of reports, site boundary maps, aerial photographs and site photographs to show key points of interest, these data being consistent with site audits already undertaken elsewhere in Wales.
5. to liaise with Local Records offices regarding the archiving and dissemination of RIGS documentation
6. to create a website to highlight progress of the project and will develop on-line resources for educational purposes as the project progresses. It is anticipated such resources will be available for free download
7. to develop a comprehensive library of references and skilled people is a byproduct of this process and would be a valuable resource to people in the future wishing to build on geological knowledge of the region.
8. To involve local people in site recording

South Wales RIGS
Geoconservation

Figure 3 South Wales RIGS Logo

Some functions such as a website of the results will continue to be maintained past the end of the initial project and with the involvement of local groups. It is hoped that one or more groups will be started to continue the work of RIGS in the audit area perhaps looking after sites and producing walks leaflets and display boards.

The figure opposite shows a logo that was designed for this new group. The design elements are drawn from the logo for the Association of Welsh RIGS Groups which uses the red and green triangles depicting the colours of the Welsh flag and a fossil trilobite which is found in Wales. The dinosaur footprint motif was chosen as it represents a fossil which occurs in the South Wales RIGS region and nowhere else in Wales.

2.3 METHODOLOGY

The methods of site selection employed by the project follow on from similar audits that have previously taken place in Wales and are based on the guidance laid out in by the Association of Welsh RIGS Groups (AWRG) (*Wood, 2007)*. The methods (discussed below) are also comparable to those used to identify sites for the GCR networks (*Ellis, 1996*). The methods of identifying sites is divided into stages and is described below.

STAGE 1 - LITERATURE REVIEW

The starting point of this study was a review of available literature, relying heavily on BGS memoirs and maps and other published papers and guides about the region. Data from previous geodiversity audits have also been incorporated. These include preliminary surveys by Cardiff University for; Cardiff Council, Rhondda Cynon Taff County Borough Council, Neath Port Talbot County Borough Council and the Vale of Glamorgan Council. This study has also utilised a database of underground sites from the Cambrian Cave Registry (www. http://cambriancavingcouncil.org.uk/cave_registry.html).

This phase of the project included consultation with specialist workers in the region, to gather opinion on sites that should be reviewed. Specialists have detailed knowledge of features that make sites important and are familiar with the latest research that may be relevant.

Volunteers have also been invaluable at this stage with local knowledge of sites which could be dismissed or highlighted as interesting based on experience of areas in which they live. All of the data collected has been entered into a database (please see Data Management) for ease of data management and review.

Based on the literature review and consultation with specialists and project coordinator, many sites were highlighted at this stage as potential RIGS and SINC's.

STAGE 2 - INITIAL SITE VISIT

The review of the literature search data and specialists engagement produced a wealth of sites of potential interest across the region. At this stage, BGS ran a series of workshops for local volunteers and according to individual confidence and interests, sites were allocated to volunteer field workers (See Table 1 Organisations involved in the audit), as well as to BGS staff.

The aim of these visits was to establish if the sites still exist, if the features identified in the desk study are still extant and to assess the condition of the sites. Estimates of the extents of the site were also drawn on base-maps of appropriate scale which were provided.

This phase of the work has resulted in a set of site visit reports and photographs which provide a good review of the state of many of the sites, revealing new sites and showing some, once important sites to have degraded beyond usefulness. The data is collected on forms designed by this project to ensure consistent data recording (Appendix 2). Review of this data by specialists, field workers and coordinator has highlighted the appropriateness of some of the sites as RIGS and SINC's

STAGE 3 - RIGS ASSESSMENT AND DOCUMENTATION

Sites chosen as RIGS required a detailed write up. The format of these write-ups is based on recommendations by the AWRG (*Wood, 2007)*. The RIGS reports include:

- A site boundary marked on a map enclosing the important features
- A concise statement of scientific interest
- Full documentation on other attributes such as site safety, access, ownership and suitability for interpretation as well as photographs on the site highlighting features of interest or hazards.

See section on RIGS Documentation

At the end of the project, data should be made available to each local authority and to The Countryside Council for Wales (CCW). This includes information about the RIGS initiative, the site documentation, GIS maps showing site boundaries, aerial photographs and site photographs.

At each stage, data was reviewed by the project coordinator, specialists and field workers and Members of these review teams change according to geographical region and geological specialty and so a project coordinator has been involved throughout this process to ensure consistency across the South Wales RIGS region.

2.4 DATA MANAGEMENT

Effective management of the data involved in the RIGS project was crucial. Desk studies generated thousands of potential sites with their associated data which in turn resulted in hundreds of site visits generating more text and image data. With such large quantities of data and many groups of people working in the area, good data management was important. In excess of 5500 sites have identified by literature searches.

Data has been entered in to a Microsoft Access 2007 database. This application has been chosen because it supports a relational database design, SQL and has extensive export options facilitating output of data to a range of applications. Microsoft Access allows for the creation of input forms, facilitating consistent data recording. A number of reports have also been created based on the data. These have included, presentation of collected data, progress reports and charts, partial population of reports in preparation for fieldwork and presentation of completed RIGS documentation at each stage of the project (See Methodology).

Integration of data with a Geographical Information System (GIS) application has been critical in this project. The British Geological Survey uses ArcGIS as its GIS and so this application has been used for special analysis of data. The position of sites, identified by the audit, have been imported into ArcGIS from MSAccess and this has been used to identify duplicate sites, recorded in the desk study phase of investigation. It has also been used to identify those sites which correspond to existing SSSI's GCR's or other designated land. Another use is to illustrate the distribution of sites as part of reviews of data.

The British Geological Survey uses ArcGIS to display much of its data archive which is known as "GDI" Geoscience Data Index. The use of the GDI has been critical in the selection of sites as it allows for data such as BGS mapping (published at a range of scales down to 1:10000 and field notes), boreholes, and aerial photography to be viewed alongside point data from the RIGS Audit.

Local authorities, Countryside Council for Wales and Welsh Government all use MapInfo and so MapInfo will be used to produce GIS layers.

2.5 PROJECT STAFFING

2.5.1 Project Coordination

The project was managed and coordinated by the British Geological Survey's Cardiff Office (by Rhian Kendall), working with a consortium of organisations. Although much of the work has been undertaken by BGS staff, volunteers have played a vital role at all stages of the project. The coordinator at BGS has supported volunteers by producing maps and site visit forms and distributed them to individuals or groups who have undertaken the work. The data generated has then been collated and added into the project database. The coordinator has also arranged work, health and safety insurance and training to support the fieldworkers. Training has included the use of map and compass (plus clinometer) standard methods for describing sites, samples, how to fill in the forms, organize payment of expenses, safety issues, any other kit required.

The coordinator has organised reviews of data at each stage, inviting experts and field workers to discuss results. The coordinator has also provided advice from a consistency point-of-view, with an overall view of all the sites.

A team of geologists at BGS have produced the final recommendations and paperwork to be supplied to local authorities and CCW.

2.5.2 Specialists

The identification of a framework of individuals early on in the project was very important. Their help was imperative to ensure that sites are identified based on latest specialist research. Specialists have advised, been involved in reviews of identified sites, undertaken site surveys and RIGS write-ups and even coordinated groups of volunteers.

2.5.3 Volunteers

Volunteers were essential to help with a range of activities associated with the South Wales RIGS project. These activities include:

- Literature Searches
- Initial Site Visits
- RIGS write-ups
- Ad hoc geological and local advice

Volunteers have played an integral part of the RIGS audit of site and their involvement was a part of the original project plan. Volunteers were drawn from local groups, predominantly the South Wales Geologists' Association but also include the the Severnside branch of the Open University Geological Society and the Russell Society and many others (**see table below).** The volunteers have had a range of field experience and one of the aims of this project are to encourage people to learn more about geology so their training and encouragement is of utmost importance and leaves a legacy for the future.

2.5.4 Supporting organisations and their involvement

- **The British Geological Survey**
  - Long experience of working in Wales
  - Extensive data holdings
  - Co-ordinate RIGS work in South Wales
- **The South Wales Geologists Association**
  - Local organisation with much local knowledge
  - Develop and maintain website
  - Provide training
  - Volunteers on the ground
- **The Open University Geological Society – Severnside Branch**
  - Local organisation with much local knowledge
  - Volunteers on the ground
- **The Russell Society**
  - Local organisation with much local knowledge
  - Volunteers on the ground
- **The South Wales Regional Group of the Geological Society**
  - Strong industry links
  - Much industrial site knowledge
- **The Department of Geology at the National Museum of Wales**

  - Extensive data holdings
  - Undertaken some site auditing already
- **The Department of Earth, Ocean and Planetary Sciences at Cardiff University**
  - Major educational and research centre
  - Already undertaken some site auditing
  - Students to assist with project
- **Fforest Fawr Geopark**
  - Internationally Recognised Area
  - Some potential sites already identified
- **Countryside Council for Wales**
  - Statutory Body
  - Supporting RIGS activities throughout Wales
  - Will hold index level data on GIS

Table 1 Organisations involved in the audit

2.6 RIGS DOCUMENTATION

The RIGS description form, (Appendix 1), is the final, full record of any site that will be proposed as a RIGS, following the review procedure. It is divided into two sections: Section A contains public domain information and Section B contains data restricted by the Data Protection Act.

The RIGS Description form contains many kinds of information that can identify the site on the ground and within national databases of RIGS. It also contains detailed descriptions of the geology as well as a short description of the sites importance “RIGS Statement of Interest” that can be understood by a non-specialist. Accessibility and Safety as well as land ownership details are also included as well as photographs of the site and outlines of the features on a map.

The following section, describes, in detail, the RIGS description form.

2.6.1 Description of the sections of the RIGS Description Form.

SECTION A

Site Name: The name given to the site

RIGS Number: The RIGS Number is the unique, number allocated to the site by CCW and identifies it within the national network of Welsh RIGS.

Grid Reference: An Ordinance Survey National Grid Reference (NGR) has been be chosen to represent the site. This could be a single point in the centre of a site or a pair of grid references marking opposite ends of a feature.

RIGS Category: RIGS are selected for their scientific, educational, historical and aesthetic values or a combination of these.

Earth Science Category: The Earth Science category is similar to the “interest” section of the Site Visit form (see appendix), used to collect data in the field and describes the types of features present that make this site special. These will include one or more of the following:

Stratigraphical / palaeontological / mineralogical / petrological / geomorphological / industrial / historical / Educational / Social / Soils / Structural / Sedimentological / Other:

Site Nature: This is the type of site such as “road cutting”, “quarry”, “stream section” etc

Unitary Authority: The Unitary Authority in which the site is located.

Details of the various map sheets relevant to the site are summarised in the following boxes:

OS 1:50,000 Land Ranger sheet

OS 1:25,000 Explorer sheet

BGS 1:50,000 Geological sheet

File Number: is the unique site code used by the South Wales RIGS project

Surveyed By: is the name of the person or people who surveyed the site

Date of Visit: the date of the visit or visits is important as it gives context to the condition of the site for the future.

Date Registered: is the date on which the site was registered with the local authority. This section also shows the name of the planning authority relevant to the site or the landowner. This page is intended to be available to the public so it should contain no information that would breach confidentiality.

Documentation prepared: by is the author of the RIGS report.

Documentation last revised: is the date of the last update of the documentation on the site.

Photographic Record: Many sites will have photographs associated with them and are included within the individual RIGS reports.

RIGS Statement of Interest: The RIGS statement of interest is a summary of why this particular site is being recommended as a RIGS. Importantly it provides the context by which the site has been identified. It is succinct and understandable a non-geologist.

Geological setting/context: This section is used to describe the site in detail but also to put it in context with regional geology. This section assumes some geological knowledge.

References: This section is used to record any relevant references used in the report.

SECTION B CONFIDENTIAL

Practical considerations

SECTION B

PRACTICAL CONSIDERATIONS: Please score Accessibility and Safety Red Amber or Green			
Accessibility:			
Comment:			
Safety:			
Comment:			
Conservation status: There are no known conservation designations of this RIGS			

Figure 4 Practical considerations traffic light system

Accessibility and Safety: are considered with regard to good, medium or poor qualities analogous with the red, amber and green of a traffic light system (see Figure 4 Practical considerations traffic light system). This provides a distinct visual indicator of site safety and access. There is also facility to include a qualifying comment if required.

Conservation status: This is where any known SSSI or SINC or National Park status has been recorded.

Ownership/Planning control: Unlike the similar headed section to this on the first page, this area contains contact details for known landowners, where identified and is therefore treated as confidential.

Condition, Use and Management: Any notes on the current use, condition, or potential threats can be added to this section. Some of this information may be sensitive.

Site Development: The site development section is intended to be a section where potential usage in terms of education of more general usage could be described.

Other Comments: If there is additional information, relevant to the site, it can be added to this section.

Photographic Record: Photographs, along with any explanation of the features in them are placed in this section of the report.

Annotated Sketch: This section can contain scans or graphics of features of interest in the site or logs of sections.

Site Plan: This takes the form of an ordinance survey map and an aerial photography version with the extent of the features of interest encircled within a polygon.

3 Geology of the South Wales RIGS Region

The bedrock geology of the South Wales RIGS region is dominated by Palaeozoic rocks, the oldest are strata of Ordovician age exposed in the west of the region. Strata of Silurian age are exposed in the west of the region and also in the Usk inlier of Monmouthshire and around Cardiff. Late Silurian and Devonian strata, collectively known as the Old Red Sandstone form an extensive area of outcrop throughout much of the northern and eastern part of the region, while overlying limestones and coal measure of Carboniferous age are principally exposed in the south. Jurassic and Triassic strata are exposed in the Vale of Glamorgan. Much of the bedrock strata have been influenced by tectonic 'mountain building' processes that have had a strong influence on their present distribution. Superficial deposits of Quaternary age were largely deposited during and immediately following the most recent glaciations that affected the United Kingdom and form a patchy veneer of variable thickness that covers much of the region. A long history of industrial exploitation and human influences means that there are numerous cultural and historical sites which have been included in the evaluation process.

The following table (Table 2 Summary of the geological history of South Wales) summarises the geological history of the South Wales RIGS area. Sequences of rocks which are missing are given in grey. Subsequent chapters elaborate on this summary in order to provide a context for the individual RIGS and SINC's. Many have been written by researchers or experts in those particular areas. Their names are given in each chapter.

Era	System	Age (Millions of years)	Summary of history in Wales
CENOCOIC	**Quaternary**	**0 – 2.6**	Ices ages and milder interglacial periods with evidence, only for the latest of these – The Devensian are preserved. The landscape is scoured by glaciers and glacial drift deposits accumulate. From about 23,000 years ago, the climate warms and coastal areas are drowned by rising sea levels. Alluvium and peats are deposited and modern drainage patterns develop (HOLOCENE).
	Tertiary	2.6 - 65.5	*Rocks of this age are not found in South Wales RIGS area*
MESOZOIC	Cretaceous	65.5 – 145.5	*Rocks of this age are not found in South Wales RIGS area*
	Jurassic	**145.5 – 199.6**	A marine transgression in the Lower Jurassic resulted in a warm shallow sea across the area which laid down the rocks of the Lias Group, preserved in the Vale of Glamorgan.
	Triassic	**199.6 – 251**	Uplift and erosion throughout South Wales in early Triassic. During this time, the British Isles was desert with hills across Wales. Arid and semi-arid conditions with periodic flash flooding. The Dinosaur footprints in the Vale of Glamorgan of this age. Marine transgression at the end of the period.
PALAEOZOIC	Permian	251 – 299	*Rocks of this age are not found in South Wales RIGS area*
	Carboniferous	**299 – 359.2**	Early in the Carboniferous a marine transgression produced a warm, shallow tropical sea, rich in coral and shelly faunas. These sediments now form the Carboniferous Limestone (Pembroke Limestone Group). In the mid part of the Carboniferous, marine regression left extensive deltas and coastal plains which supported forests. By the late Carboniferous accumulations of peat form the coal seams of the Coal Measures. During the Carboniferous and Permian, the

			Variscan Orogeny produced uplift and erosion.
	Devonian	**359.2 - 416**	The mountain building which commenced in the Silurian (Caledonian Orogeny) continued to cause uplift and erosion, producing the sediments of the Old Red Sandstone. The South Wales RIGS area is part of extensive river and floodplain environment. This is the period in which land plants rapidly evolved and diversified.
	Silurian	**416 – 443.7**	Marine conditions deposit muds, silts and sands with some carbonates. Volcanoes to the South West of Wales were responsible for Tuff deposits. There is land with delta in some parts of Wales. Towards the end of the period, there are terrestrial conditions with rivers and floodplains and soil development. Early fish are common and the earliest land plants appear.
	Ordovician	**443.7 – 488.3**	Marine conditions deposit muds, sands, grits and carbonates. Sub-marine and sub-aerial volcanic activity in the north, mid and south-west of Wales.
	Cambrian	**488.3 - 542**	***Rocks of this age are not found in South Wales RIGS area***
PROTERO-ZOIC	**Pre-Cambrian**	**Greater than 542**	***Rocks of this age are not found in South Wales RIGS area***

Table 2 Summary of the geological history of South Wales

(*Waters. 2007, and National Museum of Wales. 2006*)

Simplified Geological Maps of the South Wales RIGS Region

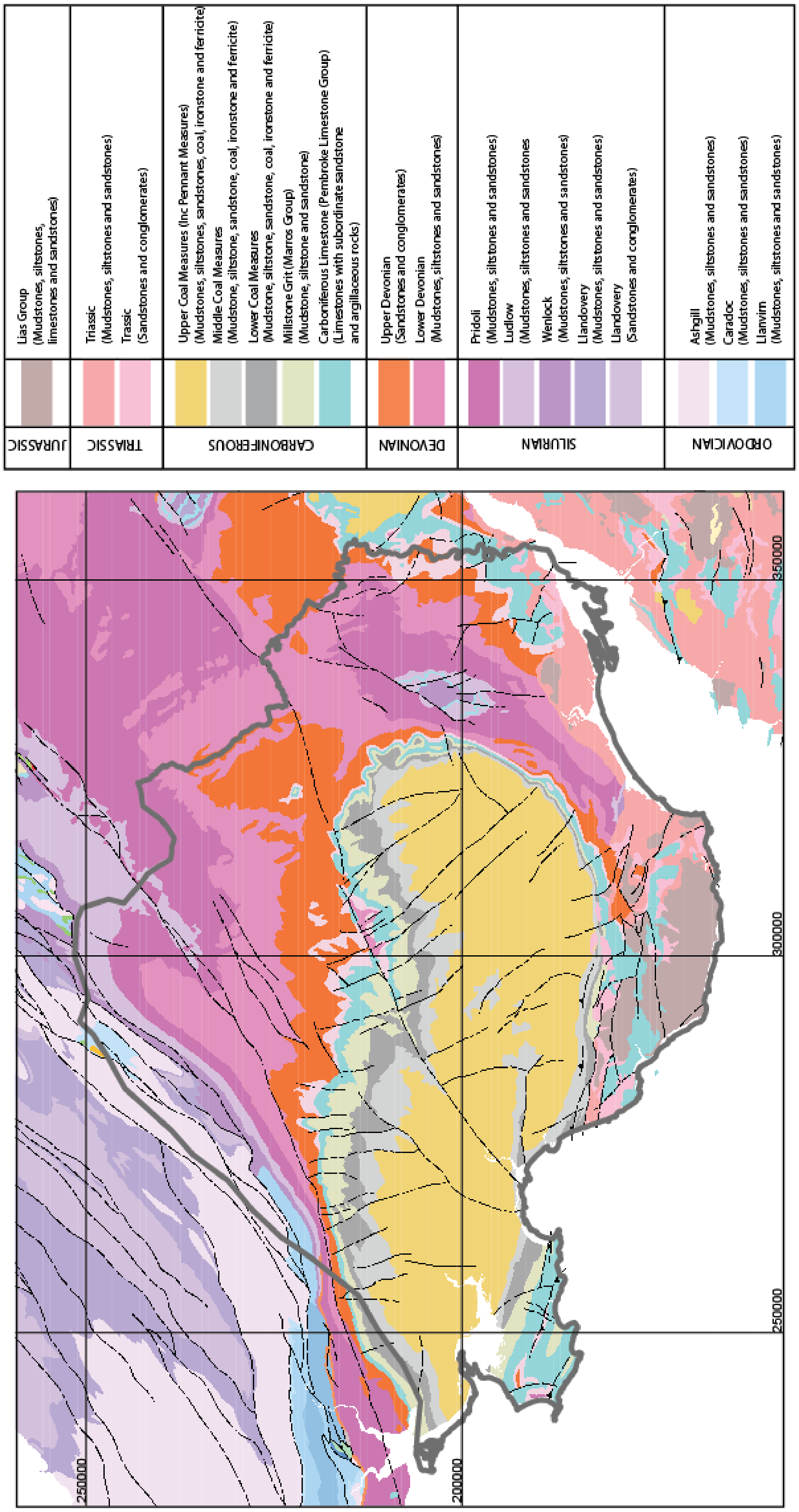


Figure 5 Geology of the South Wales RIGS Region

3.1 ORDOVICIAN

Figure 6 Distribution of Ordovician Rocks

3.1.1 Introduction

Geologists interpret the Ordovician rocks of Wales as having been deposited in an actively subsiding sedimentary basin known as the Lower Palaeozoic Welsh Basin. This formed in response to broader plate tectonic processes including the contraction and consumption of an adjacent ocean called 'Iapetus' and was active as a site of deposition between middle Ordovician and Early Devonian times. The basin is characterised by thick, km's scale, successions of sedimentary deposits preserved towards its centre (largely outside the project area, to the west) compared to thinner sedimentary sequences characterising the adjacent basin margin and shelf area that underlay much of the study region (see review of Brenchley et al., 2006). Isolated inliers of volcanic rocks preserved around the basin margin illustrate the importance of plate tectonic processes at that time.

3.1.2 Llandelian Network Report (DI Schofield)

The middle Ordovician rocks exposed in the vicinity of the town of Llandeilo, Carmarthenshire preserve a unique snapshot of shallow marine sedimentary deposition along the eastern margin of the nascent Lower Palaeozoic Welsh Basin that is not replicated anywhere else. Outcrops in the area are also of great historical significance, originating from early finds of trilobite fossils dating from the 17th Century (*Lhwyd, 1699a, b*). The regional geological significance was first discussed by Murchison in 'The Silurian System' (1839). Subsequent work undertaken during the survey of the Ammanford district to the south by the Geological Survey of England and Wales (*Strahan et al., 1907*) established a stratigraphic framework for the area that was adopted by Williams (1953) in his seminal account of the geology of the Llandeilo area that led to its establishment as a formal type section for the Llandeilo Series against which international geological correlation is established. Although the stratigraphic significance of the type area of the Llandeilo Series is somewhat diminished following it being reunited with the Llanvirn Series (*Fortey et al., 1991*) and subsequently, international stratotypes being adopted (e.g. Gradstein et al., 2004), the Middle Ordovician geology of the district retains its international significance as a historical type section.

For the purposes of the Llandeilian Network, the well known GCR sites of the Ffairfâch railway cutting and Afon Cennen [26307 22142 to 26220 22003], Dynefor Park [SN 26100 22200] and Talar Wen quarry [27012 22660] (*Rushton et al., 1999*) should be considered the principal geological reference localities. However, additional RIGS including the scheduled monument at **Y Garn Goch** [26889 22425], stream section at **Breinant** [26525 22248 to 26581 22236] and crags around **Coed Duon** [27096 22553] are herein proposed in order to provide a more accessible alternative to the railway cuttings as well as an example of rare Middle Ordovician volcanic rocks from the region.

Following from the careful characterisation of the succession by Williams (1953), subsequent academic studies in the area have concentrated on understanding the geological setting of sedimentary deposition as well as palaeoenvironment based on careful analysis of fossil communities preserved within the rocks (e.g. *Wilcox & Lockley, 1981; Williams et al., 1981; Bergström et al., 1987*). Following a new phase of geological mapping undertaklen by the British Geological Survey (*British Geological Survey, 2008*) a new synthesis of the geological uints comprising the Middle Ordovician succession was produced (*Schofield et al., 2008*) which forms the basis of the following brief account.

Following the stratigraphy of BGS (2008) and Schofield et al. (2009) the general succession in the area comprises a lower Abergwilli Formation of anoxic and oxic facies mustones, overlain conformably by massive arkosic sandstone of the Ffairfâch Grit Formation locally containing rhyolite and felsic tuff of the Coed Duon Formation in its upper part, in turn passing up into interbedded sandstone mudstone and limestone of the Llandeilo Flags Formation. The lower part of the succession is not exposed. To the north of the Afon Towi, units pass conformably up into a late Ordovician basinal succession while to the south of the Afon towi, while the upper contact of the succession comprises an unconformity where units of early Silurian age (Llandovery Series) overstep progressively older Middle Ordovician units.

The stratigraphically lower unit, known as Abergwilli Formation was formerly known as the Didymograptus bifidus Beds, named after the abundant tuning fork-shaped graptolite fossils preserved at certain horizons (*Strahan et al., 1909*). At the principal locality for the Didymograptus bifidus Beds in Llanvirn Quarry [SM7980 3076] (included in the Ordovician GCR site for Abereiddi Bay reported in *Rushton et al., 1999*), strata of equivalent age are included within the Aber Mawr Formation. However recognition of significant horizons of burrow mottled, oxic facies horizons within the shales exposed between the **Carn Goch** Anticline and the Meidrim road section to the southwest [SN287 203 to SN289 208] during the recent resurvey of these areas by the BGS (*BGS, 2007; 2008; Wilby et al., 2007; Schofield et al., 2009*) led to them being included in a separate Abergwilli Formation. The relationship between these two lithostratigraphic units has yet to be established. The formation is poorly exposed toward the northern end of the Afon Cennen section [26307 22142 to 26220 22003] but is well exposed in the Breinant stream section [26525 22248 to 26581 22236].

The overlying Ffairfâch Grit Formation comprises pale grey, thin to thick-bedded, medium to coarse-grained arkosic sandstone and pebbly sandstone with local, crude normal grading and poorly developed cross-stratification in some outcrops. The formation also includes massive, structureless, medium to coarse-grained arkosic sandstone with irregular, probably diagenetic ‘pseudobedding’ which has imparted a flaggy appearance to the rock. The grits were probably deposited from hyperconcentrated flows and contain a sparse reworked trilobite and brachiopod fauna of Abereiddian age (Didymograptus murchisoni graptolite Biozone; Williams et al., 1983) that indicate derivation from an adjacent shelf that may also have included feldspar eroded from a locally emergent volcanic source. Schofield et al. (2009) interpreted this, as well as lateral and vertical continuity with shelf facies as indicative of deposition in an intrashelf environment, and possibly confinement in a fault generated topographic hollow. The formation is well exposed in the Ffairfâch railway cuttings [26307 22142 to 26220 22003], as well as in the craggy rampart of **Y Garn Goch** [26889 22425].

The Coed Duon Volcanic Formation intervenes between the Ffairfâch Grit formation and overlying Llandeilo Flags Formation. It comprises approximately 60m of green, fine-grained felspathic tuff with abundant mafic crystal and rhyolitic lithic clasts that is well exposed along the crest of the hill and in a disused quarry on its NE termination. These are overlain by around 15m of white weathering, cryptocrystalline to fine-grained pink rhyolite with a distinctive blocky weathering surface texture that can be seen in crags on the southern flanks of the hill. At this site it can be seen to be a lateral equivalent of the Ffairfâch Grit Formation and represents the products of local volcanic eruptions during the later stages of deposition of that unit, probably of Abereiddian age (*Didymograptus murchisoni graptolite Biozone; Williams et al., 1983*). The formation is only exposed in a craggy ridge at Coed Duon [27096 22553].

The upper unit, The Llandeilo Flags Formation comprises up to 850m of buff-weathering, grey, fine- to medium-grained, hummocky cross-stratified sandstone, with interbedded limestone, and wave rippled and bioturbated silty sandstone and siltstone. These lithologies are interpreted as having been deposited in a storm influenced, shallow marine environment. Towards the eastern part of its crop, the formation comprises diffusely bioturbated, thinly interbedded, calcareous mudstone, siltstone and limestone. In this area, storm event beds are not well recognised in the upper part of the formation, suggesting that deposition took place in a more distal setting. The classic area for sections in the Llandeilo flags formation is in Dynefor Park [SN 26100 22200] and is also seen in structurally simple stratigraphic succession in the Ffairfâch railway cutting and Afon Cennen [26307 22142 to 26220 22003]. An additional GCR site in the formation was proposed at Talar Wen quarry [27012 22660] which has proven a popular site for collecting trilobite fossils (Rushton et al., 1999).

3.1.3 Caradoc to Ashgill - D Schofield, J Davies, RA Waters.

The Late Ordovician rocks preserved along the NW margin of the project area form the margin of broad extent of similar aged rocks that crop out across much of central Wales known to geologist’s as the Lower Palaeozoic Welsh Basin. They comprise largely sedimentary rocks deposited in Late Ordovician and Silurian times and record subsidence and ultimately infilling of a marine basin along the margin of a continental massif that now underlies much of southern Britain. The rocks themselves are mostly interbedded units of sandstone and mudstone that were folded and weakly metamorphosed during collisional plate tectonic processes that culminated at around 400 million years ago. Within the S Wales RIGS project area, and along the margins of the basin itself, deposition during Late Ordovician times was largely controlled and localised by movement along active faults that are collectively known as the Welsh Borderland Fault System.

Although not typical of the Late Ordovician deposits, the two RIGS sites proposed herein preserve evidence for the importance of faults within the area. The sites at **Nant Cwm-du** and **Nant Gwyn Quarries** preserve ancient volcanic rocks of the Llanwrtyd Volcanic Formation. These crop out in a fault bounded ‘volcanic inlier’ that was first studied by Stamp and Wooldridge (1923), but is described in more detail by Schofield et al. (2004) following careful survey of the area (BGS, 2005a). The Llanwrtyd Volcanic Formation comprises basaltic lavas and pyroclastic deposits that mark the site of submarine volcanism that lasted from mid Llanvirn through to mid Caradoc times (around 475 to 455 million years ago) and is mirrored in similar volcanic inliers preserved at Builth Wells and Shelve and is part of a broader rifting event that is also recorded by voluminous volcanic rocks that underlie much of Snowdonia in north Wales. Critically, these fault-bounded units of volcanic rocks record focussing of magmatism within the Welsh Borderland Fault System, while it is apparently largely absent from the more central parts of the basin in central Wales. The base of the Llanwrtyd Volcanic Formation is not exposed. However, it is overlain by mudstones of Caradoc age of the St Cynllo’s Church Formation (seen at **Sugar Loaf road cutting**), that form part of the broad belt of mudstone deposited along the margin of the Welsh Basin. The formation itself comprises more than 600m of acid-ash flow tuffs that are thought to have been deposited in subaqueous conditions and are interlayered with dark grey mudstone, tuffaceous siltsotone, sandstone and conglomerate with units of basalt and microgabbro intrusions. The units themselves were largely deposited from turbidite or debrite flows and are interpreted to reflect unstable, stepp slopes of a nearby submarine volcano or volcanic island.

In contrast the sedimentary rocks exposed at **Llwyn-cus** preserves contorted and destratified silty mudstones that attest to instability along the margin of the Welsh Basin at a time when sea levels were falling rapidly in response to the growth of glaciers in the contemporary polar regions. Rapidly falling sea-levels led to basinward migration of the continental shelf areas across the Welsh Borderland Fault System and exposure and erosion of more landward parts. Rapid growth of shelf areas was accompanied by frequent failure of the pro-grading slope apron giving rise to slumped deposits such as those preserved at Llwyn-cus. Erosion of the contemporary shallow marine reef deposits has provided the source of the diverse and abundant fauna found at this locality in an otherwise poorly fossiliferous Late Ordovician succession (Rushton, 1994; Schofield *et al.,* 2004). Another example of a late Ordovician site is **Tridwr Quarry** which exposes the Tridwr Formation which contains features typical of deposition in muddy shelf conditions and commonly contains fossil shells and worm burrows.

3.2 SILURIAN

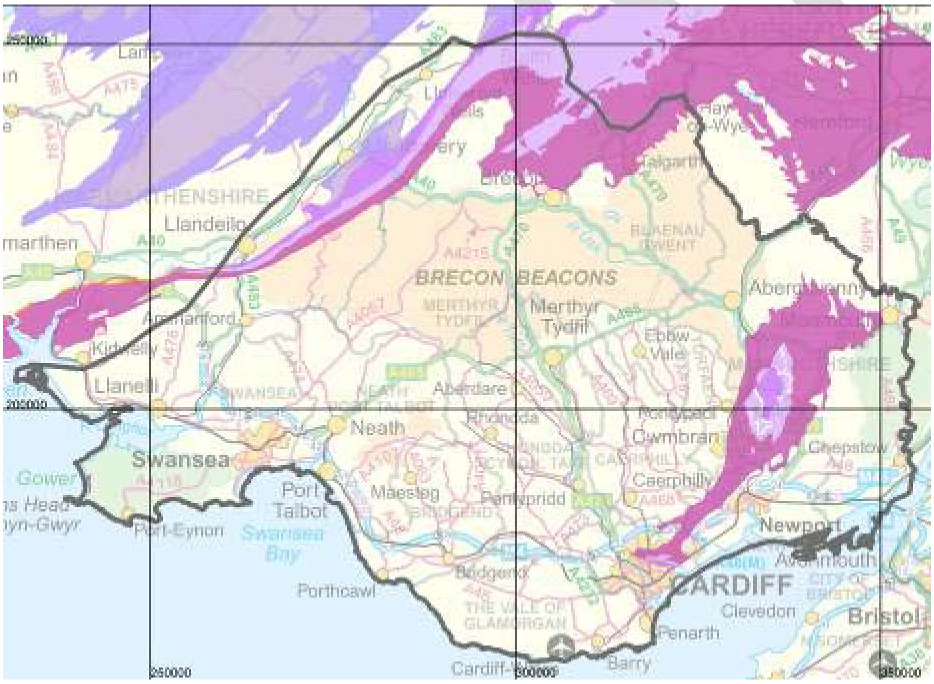


Figure 7 Distribution of Silurian Rocks

3.2.1 Introduction

Sedimentary deposition during Silurian times is characterised by enhanced subsidence in the Lower Palaeozoic Welsh Basin and the development of a thick succession of mudstones and sandstones that now form the extensive outcrop of slaty rocks that underlie much of central Wales. At this time, geologists interpret the study region to have largely formed part of a broad shallow marine continental shelf that fringed this basin. This was dissected by active faults that traverse the northwest part of the project area and were instrumental in controlling the distribution of the sedimentary deposits, and across which dramatic changes in water depth are indicated by the structure of the preserved sedimentary deposits (e.g. Schofield et al., 2004; Schofield et al., 2009). The sedimentary deposits of this age also preserve the effects of global climate change, in particular the growth and retreat of a large continental icecaps at high latitudes, that affected not only the sea level, but also the variety and abundance of fauna living at that time (Cherns et al., 2006).

3.2.2 Llandovery Network report (JR Davies)

The richly fossiliferous early Silurian rocks of the Llandovery area in south central Wales attracted the attention of pioneering nineteenth century British geologists (e.g. *Murchison, 1839, 1867; Lapworth, 1879*) and their observations in the area contributed to the erection, subsequent re-definition and formal subdivision of the Silurian System (*Bassett, 1991*). However, it was the seminal work of O T Jones (*1921, 1925, 1949*) and his student Alwyn Williams (*1951, 1953*) that established the early Silurian succession of the Llandovery area in south-central Wales as one of the best studied and well documented in the UK. Jones' A, B and C divisions and subdivisions (e.g. C_1 to C_6) were initially lithostratigraphical conceptions. However, the co-occurrence of planktonic graptolite and benthic shelly fossils allowed these units also to be defined in biostratigraphical terms and, following Williams' (*1951*) work on brachiopod assemblages and lineages, they became widely adopted as biostratigraphical subzones for the UK Llandovery.

The late twentieth century drive for international correlation initiated a further period detailed study. Cocks and his co-workers (e.g. *Cocks et al. 1970; Woolands, 1970; Zeigler, 1966; Temple, 1987*) re-assessed Jones' mapping and structural interpretation for the Llandovery region. They rigorously re-examined the graptolite and brachiopod faunas and, for the first time, undertook a detailed study of acritarch assemblages (*Hill and Dorning, appendix in Cocks et al., 1984*). This work underpinned a new lithostratigraphical and architectural model that emphasised the intact nature of the succession and allowed the key biozonal events to be identified. This phase of research led ultimately to the landmark publication of *Cocks et al. (1984)*, which established the Llandovery succession as the international type area for early Silurian strata – the Llandovery Series (*Cocks, 1989*). The constituent Rhuddanian, Aeronian and Telychian stages all take their names from sections in the Llandovery area. Both the Aeronian and Telychian stages have their international stratotype localities in the area, the only international stratotypes currently located in Wales.

Many of the most important sections in the Type Llandovery area are described by *Siveter et al. (1989)* and as part of the UK's Geological Conservation Review by *Aldridge et al. (2000)*. Consequently many of the key sites in the area have already been identified and earmarked for conservation. However, during the last decade the British Geological Survey (BGS), with the help of co-workers from Leicester, Ghent and Durham universities, and from the National Museum of Wales, has undertaken a further detailed examination of the Llandovery succession. New graptolite assemblages have been collected and a thorough review of the published brachiopod data undertaken. Systematic microfossil sampling has allowed Hill and Dorning's acritarch biozonation to be refined and, for the first time, a chitinozoan biostratigraphy to be erected. Significant new discoveries underpin a radical re-interpretation of the type area's geological architecture and biostratigraphy. This phase of work has revealed the presence of a series of progradational sequences (progrades), the bases of which overlie glacioeustatic flooding surfaces. Each prograde comprises a coarsening upwards sequence from mudstone to sandstone, through sandy mudstones and muddy sandstones. Bioturbation is a ubiquitous feature of much of the succession, but varies in intensity within each prograde sequence. The new mapping has also demonstrated that unconformities and compound non-sequences are a feature of proximal regions of deposition, in the north and south of the type area, and shown that major slump units and slide planes are important, particularly in the distal facies of the central Llandovery area and in the upper parts of the succession. This new work has important implications for international Llandovery correlation and for the definition and location of the stage stratotypes.

Much of the new stratigraphy resulting from the recent mapping and biostratgraphal collecting is presented on the BGS maps for the area (*British Geological Survey, 2005a and b; 2008*) and summarised in accompanying sheet explanations (*Schofield et al., 2004, 2009; Barclay et al., 2005*) with key findings documented by *Davies et al., (2009 and in press)*. A selection of the key localities investigated as part of this study and their significance for Silurian stratigraphy was demonstrated during the September 2009 Ludlow Research Group Annual Field Meeting and a significantly upgraded version of the guide produced for that event is available from BGS (Davies et al., 2010). It is now clear that the current network of GCR sites in the Llandovery area fails to represent and document the results of this most recent work. Additional sites now need to be identified for conservation, and the descriptions and relevance of some of the existing GCR localities need to be reviewed and upgraded. The proposed RIGS address these requirements and, together with the area's GCR sites, establish a comprehensive network of Type Llandovery sections that should be a priority for conservation. It should be stressed that most of these new or revised sites have been selected principally for their historic and future scientific relevance and not *a priori* for ease of access and/or aesthetic value. However, many of the sites are readily accessible and have educational merit.

The South Wales RIGS audit has identified the following sites to represent the Llandovery geology within its boundaries: **Scrach Quarry, Ystradwalter Quarry, Felindre Quarry & road cutting, Glyn-moch track section, Fire Tower Hill, Troedrhiwfelen Stream section, Upper Cefn Cerig Road and farm, Afonbran,** and **Pen Lan Quarry**.

3.2.3 Wenlock and Ludlow of the Wye Valley and Eppynt escarpment (DI Schofield)

The Wenlock and Ludlow succession of Mynydd Eppynt and the Wye valley preserve locally fossiliferous strata that have been the subject of a number of detailed geological studies dating back to that of Wood (1900). However, detailed mapping of the region was not undertaken until the work of Straw (1937, 1953) and O T Jones (1947). The current stratigraphy and geological understanding stems largely from the recent survey work and biostratigraphical collection undertaken by the British Geological Survey (e.g. British Geological Survey, 2005a,b; 2008; Barclay et al., 2005; Schofield et al., 2004, 2009). Together, the sedimentary succession of this area uniquely records punctuated shoaling along the margin of the Lower Palaeozoic welsh Basin that passes up into strata of the Old Red sandstone of largely continental aspect.

The lower part of the succession is represented by laminated dark grey mudstones of Wenlock age, known as the Bulith Mudstones Formation and recording deposition in a quiescent marine basinal setting. These are overlain by chaotic slumped deposits of the Caer Beris Member of the Llangammarch Formation that together record the onset of marine shallowing and expansion of shallow, shelfal environments. The contact between these units is exposed in the **Builth Road A470 Cutting** [SO 0282 5364 to 0297 5382]. The same shallowing is also preserved further to the Southwest by bioturbated sandstones of the Sawdde Sandstone Formation preserved in the **Pwll-calch quarried crags** site [SN 7676 2852]. The **Clawdd Brythonig track section** [SN 8633 3687 to 8683 3661] also preserves a subsequent cycle of deepening and marine transgression followed by shallowing recorded by fossiliferous silt laminated mudstone of Ludlow age of the Irfon Formation passing up into strongly bioturbated silt and sand laminated mudstone of the Cwm Graig Ddu Formation. The fossiliferous Irfon Formation is also represented at the **Llangammarch Quarry** site [SN 9374 4720] which is notable for its unique palaeobotany (Cleal and Thomas 1995), while the transition to the Cwm Graig Ddu Formation is also represented in the well documented and accessible, **Cwm Graig Ddu road section** [SN 9635 4790 to 9606 4685].

The acme shallowing during Ludlow times is marked by expansion of shallow marine conditions across the region. In the geological record this is marked by deposition of spreads of shelly, burrowed sandstones of the Aberedw Formation. The transition to this unit from the underlying Cwm Graig Ddu Foramtion is illustrated by the **River Edw [**SO 0806 4730] and **Aberedw Rocks [**SO 0800 4660] sites adjacent to the Wye Valley. A similar succession is also preserved in the **Fibua track section and quarry [**SN 8900 3938 to 8914 3932] where a brief late Ludlow deepening event is recorded by fossiliferous silty mudstones exposed at the base of the overlying Fibua Formation. The **Cennen road section [**SN 6102 1898 to 6098 1914], **Cil-maen-llwyd quarry [**SN 6650 2070] and **Cae'r Mynach cutting [**SN 9790 4693] sites provide evidence for the final shallowing of the basin and passage through sublittoral and shoreface marine environments through to subaerial tidal flats. This transition is recorded by a lower Cae'r mynach Formation, locally overlying the Fibua Formation, which comprises beds of sandstone interpreted as being deposited from migrating offshore sand sheets. These pass up into thin bedded cross-stratified sandstones of the Tilestones Formation that record the influence of wave action and are though to have been deposited as shoreface or barrier sand bodies. These are overlain in turn by green-grey mudstones and siltstones of the Temeside Mudstone Formation which preserve calcrete nodules as evidence for subaerial exposure and the action of soil forming processes.

3.2.4 Wenlock and Ludlow of Usk and Cardiff

Within the South Wales RIGS area, rocks of Wenlock and Ludlow age outcrop mainly along the western margin. There are however two main areas where rocks of this age are found in the east. These are in the inliers of Cardiff and Usk. The environments in which these rocks were deposited are different to those in the west and are often correlated with rocks of the same age in the Wenlock Edge and Ludlow regions to the north of this project area.

Cardiff Inlier

In Cardiff the Wenlock and Ludlow Series outcrop in the Rumney and Pen-y-lan and are the oldest rocks to outcrop in the city. The inlier is the most southerly of a chain of Silurian inliers trending SSW from the Midlands to Cardiff. Here it forms an anticline with an E-W trending axis. It is also known from boreholes to extend beneath the Triassic cover of rocks in the south of the city. The Wenlock and Ludlow rocks are mudstones, sandstones and limestones, deposited in a shallow marine, muddy shelf environment.

The Wenlock in Cardiff is subdivided into the Pen-y-Lan Mudstone and the Cae Castell Formations. The Pen y Lan Mudstones are equivalent in age to the Wenlock Shales of Usk and the Welsh Borders and is composed of thin sheet sandstones. The Cae Castell Formation is the local equivalent of the Wenlock Limestone on Usk and the Welsh Borders. It is predominantly sandstone. (BGS)

The Pen-y-Lan Mudstones can be examined at the Penylan Quarry GCR and **Howardian Nature Reserve**. The formation is dominated by fossiliferous mudstones with thin sandstones and impure limestone horizons. The sediments are interpreted as being deposited in a mid shelf setting, in moderately shallow depths but deeper than normal wave base. The sandstone layers are sublittoral sheet sands associated with storm waves and storm surges. The limestones are thought to be reworked bioclastic deposits, also transported under storm conditions. (Aldridge *et al* 2000)

Rumney Quarry GCR and the Rumney River GCR each expose the Cae Castell Formtaion. Rumney Quarry exposes mainly the Rhymney Grit subdivision of the Cae Castell Formation and the rocks overlying them. The Cae Castell Formation is made up of sandstones and siltstones with minor mudstones and thin sandy conglomeratic limestones. There is also a thin ironstone and a bentonite. The Rhymney Grit is thought to represent a major subtidal sandbar. Sedimentary structures such as trough cross bedding indicate high energy environments. Compared to the underlying Pen-y-Lan Formation this unit represents a shallowing event (Aldridge *et al* 2000).

The Rumney River GCR also exposes younger Ludlow aged units. The Hill Gardens and Llanedeyrn Formations of the Cardiff Group can be examined at this site. The base of the Hill Gardens formation shows a transgressive event and a return to mid shelf conditions. A regression towards the top of the Cardiff Group shows the arrival of fluvial environments of the Raglan Mudstone.

Usk Inlier

The Usk inlier is composed of Silurian rocks (Wenlock and Ludlow and Downton), surrounded by younger Old Red Sandstone aged rocks. It is approximately nine miles from north to South and four miles wide. Structurally, the inlier is a complex, much faulted pericline (known as the Usk Anticline) with a NNE-SSW major axis, forming an area of uplift between the Carboniferous basins of deposition of South Wales and the Forest of Dean.

The oldest rocks exposed in the inlier are the Wenlock Shales, the base of which are not observed in the area. They outcrop in the eroded core of the anticline. They are soft, calcareous fossil rich mudstones and shales which grade upwards into micaceous sandy layers which form higher topographic features. The Wenlock Shales are succeeded by the Wenlock Limestone. This unit is variable in thickness and lithology but typically forms massive crystalline beds of limestone which are overlain by nodular limestones. The **Glascoed RIGS** exposes some of the oldest rocks in the Usk. It is also the stratotype locality for the Glascoed Mudstone which is the local equivalent of the Wenlock Shales. At Trostrey, The overlying Ton Siltstone Formation is exposed in a long roadside cutting and section down a banking to the river. Overlying the Ton Siltstone Formation is the Usk Limestone (Wenlock Limestone). This can be examined at the Cwm Ton and Cilwrgi GCR sites.

The Ludlow Series in the Usk inlier consists of calcareous siltstones and impure limestones. It is subdivided based on its faunal assemblages into the following formations within the Usk Inlier: Lower and Upper Forest Beds, Lower and Upper Llanbadoc Beds and the Lower, Middle and Upper Llangibby Beds. Upper Forest Beds can be seen at a very degraded site near the dam at **Llandegfedd Reservoir RIGS.** The Lower Llanbadoc Beds are well exposed at **Llanbadoc RIGS.**

The Ludlow Bone Bed and the overlying Speckled Grit Beds (Downton Castle) are important for correlation with rocks of the same age in the Welsh Borders and are the youngest of the Silurain starta exposed in the inlier. It is also the most southerly GCR locality with a Ludlow-Pridoli series boundary sequence that includes the Ludlow Bone Bed Member. These are found at the **Brookhouse** SSSI, GCR and **RIGS** were this is the only locality amongst the marine Silurian rocks of the Usk area that shows clearly the full Whitcliffe-Ludlow Bone Bed-Downton Castle-Raglan Mudstone sequence, evidencing the transition from marine Ludlow to the non-marine conditions of the Přídolí.

3.3 OLD RED SANDSTONE: (PŘÍDOLÍ.(SILURIAN), DITTONIAN(LOWER DEVONIAN) AND BRECONIAN (UPPER DEVONIAN))

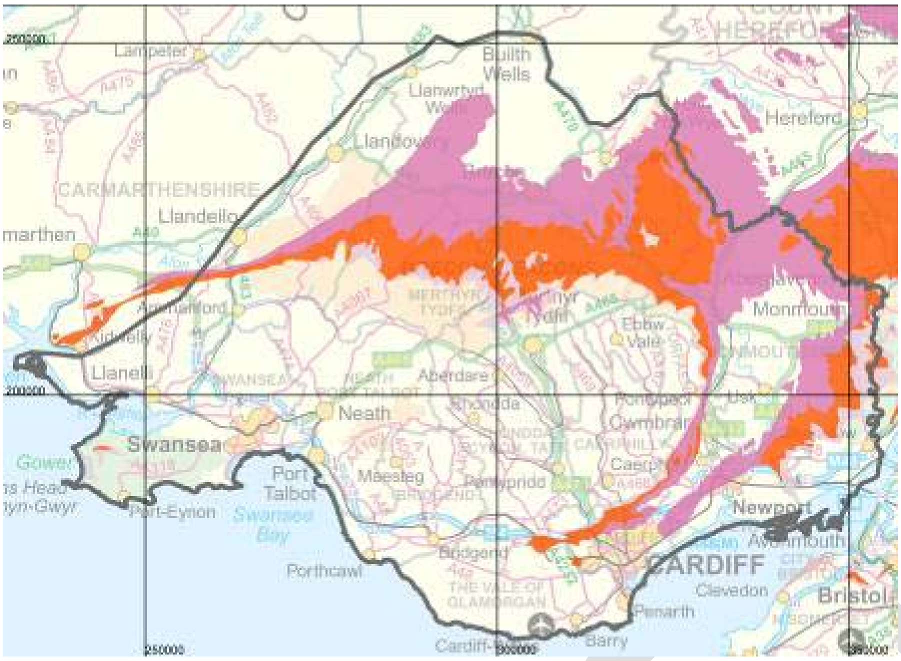


Figure 8 Distribution of Old Red Sandstone Rocks

The Old Red Sandstone is an informal term given to the predominantly red rocks of the very latest Silurian and Devonian. During the late Silurian and early Devonian, uplift resulted from the collision between Lauentia and East Avalonia. The new continental mass, together with Baltica combined to form Laurussia. The resulting “Calidonide” mountain chain developed along the collision zone. The rocks of this age are known as Old Red Sandstone and the accumulated in a basin known as the Anglo-Welsh basin south of the Calidonide mountain chain whilst the mountains were still being uplifted and during their subsequent erosion.

During the early Devonian, the shoreline was thought to be close to South Devon and Cornwall with marine Devonian sediments accumulating in this area in the evolving Rheic Ocean. To the north, land stretched through Wales into Scotland where there were extensive areas of fluvial, alluvial and occasionally lacustrine sediments, typical of the Old Red Sandstone. It is thought that Wales lay some distance south from the mountain chain. Rivers flowed predominantly south and east across this area.

Palaeomagnetic work suggests that Wales was subtropical lying at a latitude of 30º S and the climate seasonally wet, semi arid and tropical. Calcretes.

International boundaries for the base of the Devonian is based on marine faunas that are not found in Wales so its position is not known with any degree of certainty. It is thought however to be within the upper part of the Raglan Mudstone, just above the Bishops Frome Limestone member (Formerly known as the Psammosteus Limestone). The Townsend Tuff is an important marker in South Wales that may help with pin pointing the Silurian/Devonian Boundary.

The Old Red Sandstone succession in Wales is subdivided into three stages, The Downtonian (Silurian Přídolí.– Lower Devonian, Dittonian (Lower Devonian) and the Breconian (Upper Devonian. The Middle Devonian is missing in South Wales.

3.3.1 Přídolí (Silurian)

The oldest Formation in the Old Red Sandstone in the South Wales RIGS area is the Raglan Mudstone Formation. Although these deposits are extensive, large areas of outcrop are rare. A good example of exposures of the Raglan Mudstone Formation can be found at **Pwll y Wrach RIGS** near Talgarth, **Talachddu RIGS**, **Sychnant RIGS, Allt-yr-Yn RIGS,** and **Cusop Dingle**

RIGS. The Raglan Mudstone Formation comprises red mudstones and siltstones which exhibit pedogenic alteration to varying degrees. The pedogenic alteration occurs in cycles from calcareous mottling to increasingly large nodules of calcrete and occasionally coalescing to form massive rubbly limestones. These are particularly common in the upper part of the Raglan Mudstone Formation with a particularly well developed horizon being named as the **Bishops Frome Limestone Member** (Formerly known as the Psammosteus Limestone). At Pwll y Wrach this horizon is 2.5m thick forming a top of a waterfall but it also forms an easily mapped feature in the landscape being harder than the Raglan Mudstone Formation. An example of the Bishops Frome Limestone Member is also seen in the west of the area at **Sychnant.**

Another feature of the Raglan Mudstone Formation is the **Townsend Tuff** which is the most extensive and thickest of a series of air fall tuffs that occurs in South Wales and the Borders. It lies stratigraphically, approximately 50m below the Bishops Frome Limestone Member. It is exposed at **Cusop Dingle RIGS** and at **Disgwylfa RIGS** in Epynt.

The Raglan Mudstone Formation is thought to be deposited on a coastal alluvial floodplain which had frequent periods of soil forming conditions and occasional marine floods. The formation also includes sandstones which are deposited in shallow ephemeral streams and sheet floods.

3.3.2 Dittonian (Lower Devonian)

The St Maughans Formation (Dittonian – Lower Devonian) succeeds the Raglan Mudstone Formation. It has a wide distribution in South Powys and in the east of the South Wales RIGS area where it is visible in the landscape from the distinctive steps that it horn in the hills where sandstones and mudstones weather at different rates. This formation can be examined at **Allt Lom SINC**, **Pwll y Wrach RIGS**, **Crwcas Quarry RIGS**, **Priory Groves RIGS** and **Pantymaes Quarry RIGS**.

The St Maughans Formation is made up of a stacked succession of fining upwards cycles of sandstone-siltstone-mudstones. The base of the cycle contains intraformational conglomerates and cuts into the underlying mudstones of the top of the previous cycle. These are interpreted as channel sediments which fine upwards from channel sands though silts to floodplain mudstone deposits which often have calcretes developed within them. The sandstones are from red-brown to purple and green and are planar and trough cross bedded. They are fine to medium grained.

Senni Formation is represented in Powys by **Primrose Hill Quarry RIGS**, **Bloodstone RIGS**, and **Tremynfa Quarry RIGS** both of which display good sections of this formation in the north of the South East Wales Area. The Senni Formation is predominantly channel sandstones and is commonly green in colour. The sandstones are very fine to medium grained and coarser higher in the sequence. The sands are deposited in “tabular sheets which are lenticular, cross bedded channels with erosions surfaces.” Red-brown and grey green mudstone and siltstone interbeds are a common feature. The sandstones can contain calcretes and these are often reworked along with intrformational mudstone clasts. The depoist is cyclic, fining upwards from conglomerates, through sands and silts and muds which may be truncated by the cycle above it. The Senni Formation is thought to be deposited in low sinuosity, seasonal, braded streams. The finest components are thought to represent floodplane lake deposits or crevasse splays. The Senni Formation is renowned for its Early Devonian vascular plant fossils.

The Llanishen Conglomerate is thought to be the equivalent of the Senni Formation in the South of the South Wales RIGS area. It outcrops mainly in the core of the Cardiff Cowbridge Anticline, on the north west limb of the Rogerstone Anticline and in inliers at Michaelston-super-Ely and Drope. The type formation can be examined at the **Llanishen Railway Station RIGS** and a larger outcrop at the **Cefn Onn SINC**. The formation comprises red sandstones, siltstones and mudstones with conglomerates that include exotic clasts. Calcretes are also common. The sediments are thought to have a proximal alluvial fan origin, being deposited in low sinuosity stream channels. The calcrete component develops on flood plains and in abandoned channels. Evidence suggests that the sediment source for the conglomerate was from the south, possibly the Bristol Channel Landmass.

The Brownstones Formation is of Lower Devonian age and is dominated by mainly red-brown, purple brown and pinkish sandstones which are calcareous and micaceous. They are fine to coarse grained with occasional gravely pebble layers. Interbedded with the sandstones are red-brown mudstone and siltstones which fine upwards. Similar rocks in the Brecon Beacons are interpreted by Tunbridge 1981 as “low sinuosity, flash flood, channel deposits, merging downslope into muddy floodplain deposits”. They occur in “laterally extensive , tabular sheets of trough or planar cross bedded multistory units”(Brecon). The mudstones and siltstones represent floodplain deposits from suspension in lakes or slow moving waters. The following sites all show The Brownstones Formation : **Suckstone RIGS, Table Mountain and the Darren RIGS, Thornhill RIGS, Corn Du and Pen y fan RIGS**. (Barclay *et al* 2005). An example of the Brownstones to the south of the coalfield can be found at the **Thornhill Road RIGS** section and to the east is the **Newbridge on Usk RIGS**

3.3.3 Breconian (Upper Devonian)

Within the South East Wales RIGS region, the Middle Devonian is missing, eroded away during a period of uplift. The Plateau Beds overly the Brownstones with a very slight angular unconformity. The Plateau Beds Formation is harder than the Brownstones and so forms a resistant cap to may of the high mountains in the Brecon Beacons, giving rise the characteristic flat tops to the Beacons. The plateau beds are see at the Summits of **Pen y Fan and Corn Du RIGS** as well as the **Afon Waen RIGS** and the **Dyffryn Crawnon RIGS,** which is the type locality for this formation.

The Plateau Beds Formation is approximately 58m thick in the Breconshire. It is subdivided into three divisions which comprise a transgressive sequence beginning with fluvial and Aeolian to marginal marine deposits.

The Quartz Conglomerate Group is the youngest of the Old Red Sandstone units to outcrop in the South East Wales RIGS area. It can be seen at **Table Mountain and Darren Landslip RIGS** and the **Suckstone RIGS** in the north of the study area and **Craig Llanishen** is an example to the south of the coalfield.

The Quartz Conglomerate Group is made up of green-grey, locally pebbly, quartzitic sandstones. The sandstones occur as tabular, cross bedded units with red brown interbeds of siltstone. (Barclay *et al* 2003). These deposits are interpreted as “shallow, possibly ephemeral, sandy braded, south ward flowing streams of an alluvial fan complex.” (Barclay *et al* 2003)

3.4 CARBONIFEROUS

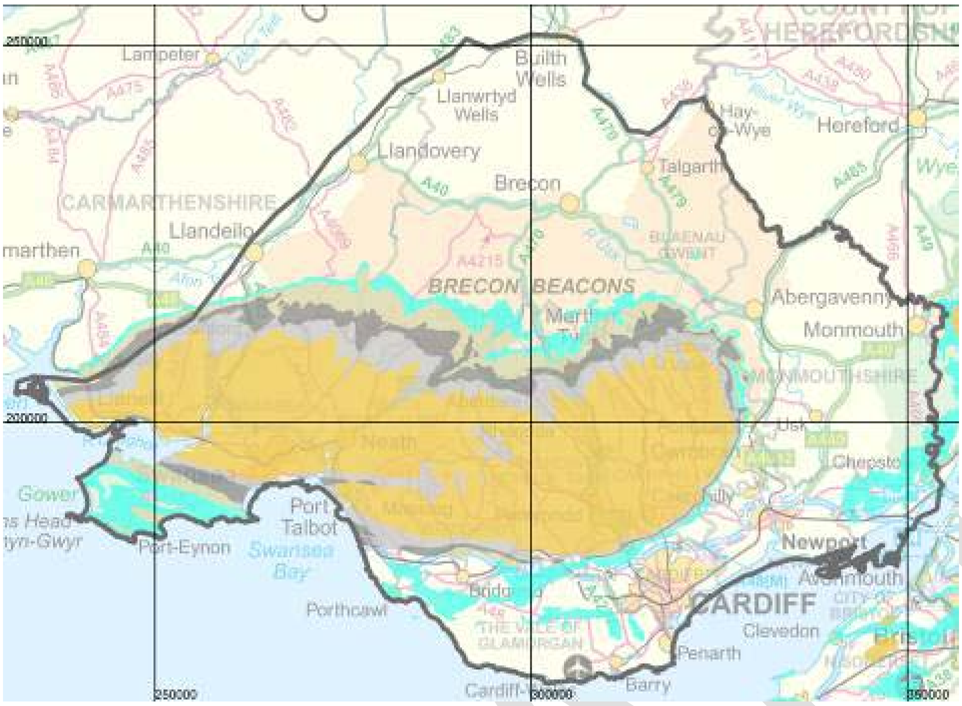


Figure 9 Distribution of Carboniferous Rocks

The Carboniferous System is South East Wales, as in elsewhere in the country, contain the rocks that have undoubtedly had the greatest impact on the lives of people and landscape of the regions in which they occur.

The oldest unit is called the Pembroke Limestone Group – formerly known as the Carboniferous Limestone. They are distributed in a ribbon surrounding the south Wales coalfield. They have been used down the centuries for lime to enhance the soils, as building stones and later aggregate. They have also been used as flux in the steel making process. The landscape which they form often supports rare plants and animals and has the look of pock marked Luna landscapes where the surface has collapsed into underground cave systems. The limestones of South Wales contain many of the largest systems in the UK.

The next unit is known as the Marros Group (Formerly the Millstone Grit). As the old name suggests, the rocks of this age were used for millstones but are also utilized as fire bricks and used as grit for polishing.

Overlying the Marros Group is the South Wales Coal Measures Group. This unit contains most of the productive coal measures as well as iron deposits and their extraction though mining has had the most impact on our communities and landscape. Bringing into the valleys a massive workforce to extract coal and iron and changing the land with quarrying and soil tips.

The highest unit of the Carboniferous in South Wales is the Pennant Sandstones. These rocks form this highest hills surrounding the Valleys and provided building stone for the housing. It is still used today for aggregate.

The importance of the carboniferous System in the region is such that it has been subdivided and written separately up in the next few sections.

3.4.1 Carboniferous Limestone Overview (JR Davies)

Figure 10 Distribution of Carboniferous Limestone Rocks

The Carboniferous Limestone of South Wales records the establishment and growth of a marine carbonate ramp and its evolution into an extensive low-gradient platform throughout the early part of the Carboniferous period, an interval previously known as the Dinantian (*George et al., 1976*), but which is now included in the internationally adopted Mississippian Series of North American usage (see *Waters et al., 2011*). Accumulation took place to the south of residual upland of deformed Caledonian rocks centred across mid Wales (St. George’s Land) and the South Wales Carboniferous Limestone thickens and becomes more distal in aspect southwards with the thickest and most off-shore successions occurring in west Gower and in south Pembrokeshire. Local and regional tectonism also influenced the location and orientation of facies belts, but current outcrop patterns principally reflect the impact of folding and faulting imposed during the end Carboniferous Variscan orogeny (e.g. *Wilson et al., 1988; Ramsay, 1989*). The effects of subsequent Mezosoic and Alpine phases of tectonism and associated mineralisation are also significant in some areas (e.g. *Fletcher, 1988; Wilson et al., 1990*). The lithostratigraphical nomenclature for these Mississippian rocks has been reviewed and revised by *Waters et al. (2009*) who erected two major groups: the Avon Group, which broadly embraces strata previously included in the Lower Limestone Shales; and the Pembroke Limestone Group that includes rocks referred to in the earlier literature as the Main Limestone and Upper Limestone Shales. Avon Group rocks everywhere overlie Upper Devonian continental red-bed facies (Upper Old Red Sandstone) and the Pembroke Limestone Group is succeeded by fluvio-deltaic Namurian facies, however, significant breaks in deposition characterise both contacts. Following earlier influential studies notably by *Dixon & Vaughan (1912)* and *Dixey & Sibly (1918)*, important regional synthesises and reviews of the South Wales Carboniferous Limestone and its tectonic history include those provided *by George (1927, 1933, 1958, 1974), Wilson et al. (1988), Wright (1986), Ramsay (1987), Adams et al. (2004) and British Geological Survey memoirs (e.g. Waters & Lawrence, 1987; Wilson et al., 1990; Barclay et al., 1988 and Barclay, 1989).*

The Carboniferous Limestone outcrop that flanks the South Wales Coalfield is conveniently divided in three areas: one to the north of the coalfield that stretches from Kidwelly in the west to Abergavenny in the east conventionally known as the ‘north crop’; an ‘east crop’ between Abergavenny and Taff’s Well; and a broad ‘south crop’ region that includes the Mississippian succession of the Vale of Glamorgan and the Cardiff area as well as the magnificent coastal sections of the Gower. Separate sub-network reports are provided for each of these regions. The early Courceyan Avon Group records the impact of a sustained late Devonian to earliest Carboniferous marine transgression which, by its close, had inundated the whole of the South Wales Region (e.g. *Burchett, 1987; Davies et al., 1991*). Later Courceyan to Chadian limestones and dolomites that form the lower part of the Pembroke Limestone Group record deposition on a southward-facing carbonate ramp that was strongly influenced by subsequent transgressive and regressive sea level movements. Proximal or inner ramp deposition is recorded by the succession of oolite shoal and back-barrier peritidal facies (Abercriban and Clydach Valley subgroups) that dominate the attenuated and condensed north crop succession (*Wright, 1987; Barclay, 1989, and et al., 1988*). In contrast, the much thicker and complete south crop succession is principally composed of front of barrier, open marine, crinoidal facies (Backrock Limestone Subgroup) across which oolitic barrier facies prograded only during periods of static and falling sea level (e.g. Brofiscin and Gully Oolite formations) (e.g. *Waters & Lawrence, 1986; Wilson et al., 1988; Wright, 1986; Burchette et al., 1990*). The succession within the intervening east crop area was deformed and deeply eroded prior to its overstep by Namurian strata, and also displays the effects of wholesale dolomitisation. Nevertheless, textural variations that allow coarse-grained facies to be distinguished show that this area occupied a pivotal, mid ramp setting that was a focus for oolite barrier growth. Such facies migrated northwards under the influence of rising sea levels only to prograde southwards as sea levels fell. Widely correlatable palaeokarstic surfaces with associated pedogenic alteration features show that many of these regressive events culminated in periods of subaerial exposure of the ramp surface (e.g. *Wright, 1987*). The area of ramp exposed during these events expanded as its profile evolved until by the late Chadian it extended well into the south crop area. The widespread palaeokarstic feature that formed during this period was recognised as the 'intra-Avonian unconformity' by early workers (e.g. *Dixon and Vaughan, 1912; Riding & Wright, 1981*). This can be correlated with the complex karstic surface that overlies the north crop Gilwern Oolite Formation, but here prolonged and multiple phases of emergence (e.g. *Wright, 1987*; and references therein) account for the absence of Chadian strata from this region (*Barclay, 1989*).

These evolutionary changes heralded a reconfiguration of facies belts during deposition of the upper part of the Pembroke Limestone Group. During the Arundian and Holkerian stages, facies of the High Tor Limestone Formation and Hunt's Bay Oolite Subgroup show that the focus for ooid shoal and barrier development gradually migrated southwards until, by Holkerian times, it was located within the south crop region anchored to a tectonic axis now recognised as the E-W trending core of the Cardiff-Cowbridge Anticline and its en echelon extension, the Cefn Bryn Anticline, on the Gower (*Wilson et al., 1988, 1989*). Contemporary east and north crop successions testify to the wide and sheltered ramp interior this migration created and which became the site of sustained peritidal and lagoonal facies accumulation (Arundian Llanelli Formation, Holkerian Dowlais Limestone and Stormy Limestone formations) (*Wilson, et al., 1988; Barclay, 1989*; and references therein). This shallow, flat lying area was precursor to the platformal phase carbonate deposition that prevailed during the following Asbian and Brigantian stages. Strata of this age are absent from the east crop, but the shoaling upwards cycles that characterise the Oxwich Head Limestone Formation of the north and south crop provide a record of frequent glacioeustatic sea level movements, as do the abundant palaeokarstic surfaces that cap these cycles and testify to the repeated emergence of the platform surface (*Ramsay, 1989*).

The widespread exploitation of Carboniferous Limestone strata for building, aggregate and chemical purposes accounts for the numerous active and abandoned quarries present throughout the south-east Wales region, and it is these that provide many of the sites recommended for RIGS status. Many of the sites described have been selected because of their importance in context of the development of ideas and models for the Carboniferous Limestone succession, or because they occupy positions that are critical in the context of its evolving palaeogeography. Some sites, in addition, display features that were the product of post-depositional, Variscan tectonism and of erosion and mineralisation during the Mesozoic era. The effects of more recent karstic dissolution and collapse are also well seen at some sites. These RIGS augment sites already earmarked for conservation as part of the Geological Conservation Review process, including the extensive coastal sites of the Gower peninsula (*Adams et al., 2004*) and provide alternative locations for research and educational purposes. However, it must be stressed, that due to natural degradation and vegetation growth, the quality of exposure at some sites has deteriorated markedly since they were first studied and the need for restorative action at these localities is urgent.

3.4.2 Sub-network Report: Carboniferous Limestone of the South Crop (JR Davies)

The south crop extends westwards and southwards from the Taff's Well area, north of Cardiff, embracing the extensive areas of outcrop in the Vale of Glamorgan and Cardiff area, as well as the superb coastal sections of the Gower. At up to 1.7 km, the south crop displays the thickest Carboniferous Limestone succession in the south-east Wales region. The basal Avon Group marine transgression, an Upper Devonian to earliest Courceyan event, inundated much of the Upper Old Red Sandstone alluvial land surface in South Wales and established the south crop region as the site where some of the deepest and most offshore Courceyan carbonate ramp facies began to accumulate (*Wright, 1987; Wilson et al., 1988*), situated furthest away from emergent uplands to the north (St. Georges Land). The subsequent vertical and lateral patterns of ramp facies deposition reflect the controlling influences of Courceyan to Holkerian sea level movements and regional tectonism. Accumulation throughout this interval established the broad low-gradient carbonate platform on which strongly cyclical Asbian and Brigantian strata later accumulated.

The principal Avon Group sections in the area are already designated under GCR process and archived core from BGS boreholes drilled at Cwrt-yr-ala and Eweny have provided important insights about the origins of these rocks (*Waters & Lawrence, 1987; Davies et al., 1991*). Succeeding outer ramp limestone facies, that include a lower, hummocky cross-stratified unit and an upper bioturbated division, are well seen in their respective eponymous type sections at **Barry Harbour** and **Friar's Point**, as well as on the Gower (e.g. **Rhossili**). To the north, in both the Vale of Glamorgan and on the Gower, the Brofiscin Oolite Formation records an intervening shallowing episode (e.g. **Candleston Quarry** and **Three Cliffs Bay**). Chadian shoaling towards the top of the dolomitised Friar's Point Limestone culminated in the progradation of the Gully Oolite Formation and, ultimately, in a prolonged period of emergence recorded at the top of this unit by a widespread palaeokarstic surface and associated pedogenic alteration features, relationships that are well seen at GCR sites on the Gower (e.g. **Caswell Bay**) and in working quarries in the north-east of the Vale of Glamorgan. Renewed deepening at the onset of the Arundian Stage saw lagoonal facies (Caswell Bay Mudstone) succeeded by off-shore High Tor Limestone ramp facies prior to the re-advance of Holkerian barrier facies (Cornelly Oolite Formation) across the south crop region (e.g. Argoed Isaf Quarry). The Stormy Limestone Formation records the subsequent accumulation of late Holkerian back barrier, lagoonal and peritidal facies under the influence of a slow, but sustained period of rising sea level (e.g. **Stormy Down Quarry**). A period of subaerial emergence and dissolution followed by quartz sand deposition characterised the onset of Asbian and Brigantian platformal conditions as recorded at the base of the Oxwich Head Limestone Formation (e.g. **Pant Mawr Quarry, South Cornelly**). Shoaling-upwards carbonate cycles, including distinctive pseudobrecciated and mottled facies, are a feature of this phase of limestone deposition throughout the South Wales region and testify to the influence of glacioeustasy (e.g. Oxwich Head and **Lock's Common**). Episodes of subaerial exposure accompanied the numerous marine regressions of this period and are recorded by the hummocky and pitted palaeokarstic levels and associated clay soils and calcretes that define the cycle tops (e.g. **Gaen Quarry**).

In addition to the insights they provide about the evolution of Mississippian limestone facies, many of the south crop sites allow the impacts of the Variscan Orogeny, and subsequent Mesozoic tectonism and mineralisation, that are evident throughout the region, also to be demonstrated (e.g. **Newton Fault at Black Rocks, nr. Porthcawl** and **Candleston Quarry**).

3.4.3 Sub-network Report: Carboniferous Limestone of the East Crop (RA Waters)

The east crop runs as relatively narrow band from just south of the Clydach gorge, near Blaenavon, in the north, to the Taff gorge, north of Cardiff, in the south. Due to overstep by Namurian strata, uppermost Holkerian, Asbian and Brigantian carbonates are not present on the east crop. Traced from north to south, the east crop embraces the facies changes that occur in the early to mid Dinantian in the transition from the inner to mid ramp. It separates the well documented, but markedly different, lithostratigraphies of the north and south crops. It is therefore a key area in understanding the architecture and development of the facies changes that take place across the inner to mid ramp boundary. There are however, several problems that make the study of this area difficult. Firstly, the succession is predominantly dolomitised, which makes the recognition and tracing of individual formations difficult. Furthermore, macrofossils are commonly destroyed by the dolomitisation, making dating problematical. Secondly and largely due to the first, the area has received little attention from geologists, there being only two definitive stratigraphical papers, the last being written over sixty years ago. The Geological Survey, when resurveying the Newport (249) 1:50k sheet in the 1960's, made matter worse by not subdividing the succession, simply mapping the divisions of the Avon Group and leaving the overlying Pembroke Limestone Group as undivided dolomite. The succession ranges in thickness from 60 m in the north to 645 m in the south, but this incorporates a major element of sub-Namurian overstep, that increases in an eastwards direction. Most formations however, thicken southwards.

At the base of the succession, the Avon Group of early Courceyan age, is present across the entire area and represents the initial flooding of the Old Red Sandstone of St Georges Land. The first transgression resulted in a storm dominated, muddy shelf that reached just north of Risca. It is represented by the interbedded limestones and mudstones of the Tongwynlais Formation which are exposed at the **Tongwynlais Road Section GCR**. Continuing transgression saw the northern part of the east crop drowned and the establishment of transgressive oolitic shoals. Eventually these shoals prograded back south over the Tongwynlais Formation. These transgressive /regressive oolitic shoal deposits are known as the Castell Coch Limestone, seen at **Castell Coch Quarry (e.g. Cwmynyscoy quarries East**). Renewed transgression saw the establishment of open marine shelf conditions across the east crop with the deposition of interebedded mudstones and thin limestones of the Cwmyniscoy Mudstone **(e.g. Cwmynyscoy quarries East).**

The Courceyan dolomites overlying the Avon Group north of Risca are best referred to the Clydach Valley Subgroup **(e.g. Cwmynyscoy quarries West and Craig Cynfyn Quarry)** and those to the south to the Black Rock Subgroup **(e.g. Blaengwynlais quarry, Cefn Garw and Cefn Onn Quarry 1).** The former contains five oolite units, three of which are named on the north crop (Pwll-y-Cwm, Blaen Onnen and Gilwern), interbedded with peritidal and lagoonal back barrier dolomites and the latter, an offshore succession of storm influenced dolomitised crinoidal limestones (Barry Harbour Limestone and Friars Point Limestone), separated by a single oolitic unit, the Brofiscin Oolite. There is no obvious lithological correlation between the two successions. Attempts to correlate them are further hampered by the fact that north of Risca to Pontypool, only the lowest part of the succession is preserved, as a result of intra-Dinantian and Namurian overstep. The highest oolite, the Gilwern Oolite has been considered to be Arundian or Chadian, but is here regarded as Courceyan. A tentative model for the east crop is that just north of Risca, a wide complex of oolite shoals persisted through much of the Courceyan, separating the inner from the mid ramp. During transgressions oolite shoals were driven northwards over back barrier deposits to be replaced by open marine carbonates, while during regressions/progradations, oolitic bodies prograded back south, only occasionally prograding any distance south of the Risca barrier and intertonguing with offshore carbonates. The acme of the main regression/progradation in the south is the middle part of the Brofiscin Oolite that caps the Barry Harbour Limestone. In the north, this event is difficult to pin down. The main transgression recognised is the lower part of the Friars Point Limestone in the south **(e.g. Cefn Onn Quarry 1)** and the base of the Gilwern Oolite **(e.g. Craig y Gaer on the north crop)** in the north. In the late Courceyan/early Chadian a major regression saw emergence across the ramp on the east crop. A paleokarst and paleosol at the top of the Friars Point Limestone **(e.g. Blaengwynlais quary and Cefn Onn Quary 1)** in the south probably correlates with the major paleokarst at the top of the Gilwern Oolite in the north **(e.g. Drum and Monkey Quarry on the north crop).**

Renewed transgression in the Chadian saw ooid shoals represented by the Gully Oolite, driven northwards across the proximal mid ramp to just north of Risca **(e.g. Blaengwynlais Quarry and Cefn Onn Quarry 1).** The inner ramp however, remained emergent so that the karstification of the Gilwern Oolite became further developed. The Gully Oolite shoals soon prograded back southward to leave another emergent surface with associated paleokarst and paleosol (**e.g. Blaengwynlais Quarry)** that extended across the entire east crop and northwards.

The Arundian saw renewed transgression. In the south, on the proximal mid ramp, peritidal deposits were deposited as the Caswell Bay Mudstone. Continuing transgression saw shoreface and offshore carbonates deposited as the High Tor Limestone. However, as the transgression lost impetus, a barrier shoal system (High Tor Limestone) was established at the southern end of the east crop. All the features of the Arundian transgression may be seen in **Blaengwynlais Quarry.** To the north of this barrier, peritidal deposits of the Llanelly Formation accumulated on the east crop on the inner ramp **(e.g.** C**efn Onn Quarry 2).** Towards the end of the Arundian, the barrier system eventually prograded southwards to leave the east crop emergent again.

A further transgression in the Holkerian saw the east crop flooded with a large scale oolitic barrier complex (Hunts Bay Oolite Subgroup) rapidly established on the proximal part of the mid ramp extending onto the southern part of the east crop as far north as about Risca (**e.g. Cefn Onn Quarry 3).** To the north of the barrier, a shelf lagoon developed in which was deposited the Dowlais Limestone. These shallow water limestones however, are not preserved on the east crop.

3.4.4 Sub-network Report: Carboniferous Limestone of the North Crop (RA Waters)

The north crop stretches as a relatively narrow band from Kidwelly in the west to Abergavenny in the east, with an outlier some 6 km to the north at **Pen-Carreg-calch**. Situated nearest to St Georges Land, the area embraces the inner part of the early Dinantian ramp, the back barrier deposits of the mid Dinantian and the proximal part of the platformal carbonates of the late Dinantian.

As a result of its palaeogeographical position, the north crop succession is the thinnest in South Wales, ranging from 45m at **Pen-Carreg-calch** to 240 m in the Ammanford area. The succession is characterised by shallow water carbonates, embracing high energy oolitic shoal deposits, behind which low energy back barrier deposits ranging from peritidal calcite mudstones to lagoonal skeletal limestones accumulated. Offshore, open marine carbonates form only a minor part of the succession compared to the south crop of the Carboniferous Limestone. Evidence for long lasting periods of subaerial exposure are manifested as widespread paleosols and paleokarstic horizons. The east of the area is fairly well known due to spectacular exposures of varying types of paleosol, the best being GCR sites. In contrast, the west has attracted little attention and is poorly documented in terms of modern literature

At the base of the succession, the Avon Group of early Courceyan age, is present across the entire area and represents the initial flooding of the Old Red Sandstone of St Georges Land. The transgression saw the establishment of oolitic shoals that eventually prograded south leaving back barrier peritidal carbonates across the north crop. These oolitic and peritdal limestones, known as the Castell Coch Limestone rest erosively on the Old Red Sandstone. Renewed transgression saw the establishment of open marine conditions across the area with the deposition of interebedded mudstones and thin limestones (Cwmyniscoy Mudstone Formation).

In contrast, the overlying Courceyan to Arundian succession is only preserved in the east, mainly due to sub-Holkerian overstep in the west. The Abercriban Oolite Subgroup in the west and the Clydach Valley Subgroup in the east record the development of the inner ramp during the early to mid Courceyan. The Clydach Valley Subgroup comprises peritidal dolomites and calcite mudstones punctuated by three oolite units, the Pwll-y-Cwm, Blaen Onnen and Gilwern oolites **(e.g. Darren Ddu tramway quarries, Pwll du and Gilwern Quarries, Clydach Halt, Coed Pantydarren quarries and Craig-y-Gaer Quarry)**. Traced westwards into the Abercriban Oolite Subgroup, the succession thins and becomes dominated by oolite with very subordinate dolomite **(e.g. Abercriban Quarry and Blaen Onneu Quarry).** Each oolite/dolomite couplet is thought to record a transgressive/regressive cycle. Each cycle begins with transgressive peritidal dolomites being deposited over an emergent surface. With increasing transgression, shoreface deposits migrated northwards over the peritidal deposits followed by the development of oolitic barrier shoals. Eventually the oolite shoals prograded back southwards to leave an emergent surface and paleosol development. During the latest Courceyan and throughout the Chadian, the inner ramp became subaerial for a prolonged period leading to the development of a major regional palaeokarst and paleosol at the top of the Gilwern Oolite **(e.g. Darren Ddu tramway quarries, the Drum and Monkey Quarry and Craig-y-Gaer Quarry).**

Marine sedimentation resumed on the inner ramp with a major transgression in the Arundian. The succession is only preserved in the eastern most part of the north crop and comprises the Llanelly Formation, a thin unit of back barrier peritidal carbonates, an oolite and alluvial clays **(e.g. the Darren Ddu tramway quarries and the Drum and Monkey quarry)**. Punctuated by pedogenic horizons, it represents deposition behind a barrier shoal, situated many miles to the south in the Cardiff area, around the junction of the inner and mid ramp. The uppermost part of the Llanelly Formation comprises alluvial deposits with paleosols recording a widespread regressive event.

A major transgression in the Holkerian saw the establishment of a shelf lagoon across the north crop. This lagoon, deeper than those developed previously, was situated behind a major oolitic barrier complex that developed pene-contemporaneously on the mid ramp/platform on the south crop. The deposits of the lagoon, the Dowlais Limestone, comprise dark argillaceous skeletal and oolitic limestones **(e.g. Welsh quarry and Pant Mawr quarry).** The formation exhibits an erosive base, that in the west, oversteps onto earlier formations.

By the Asbian, platformal conditions had been established across the pre-existing ramp. As a result, cyclic carbonates, the Oxwich Head Limestone, were deposited across the north crop. However, they are are only preserved in the west, due to sub-Namurian overstep in the east. Driven by glacioeustasy, they comprise units of skeletal limestones separated by emergent surfaces manifested as palaeokarstic surfaces and clay paleosols. On the north crop, sandstones and oolitic limestones are developed in the basal part, reflecting their proximal position on the inner platform **(e.g. Welsh quarry).**

By the late Brigantian an increase in the supply of terrigenous material onto the platform led to the waning of carbonate production. This resulted in the deposition of the Oystermouth Formation comprising open marine interbedded argillaceous limestones and mudstones. The unit is only preserved on the west of the north crop.

3.4.5 Carboniferous Marros Group, Coal Measures and Pennant

(Namurian, Westphalian, Stephanian)

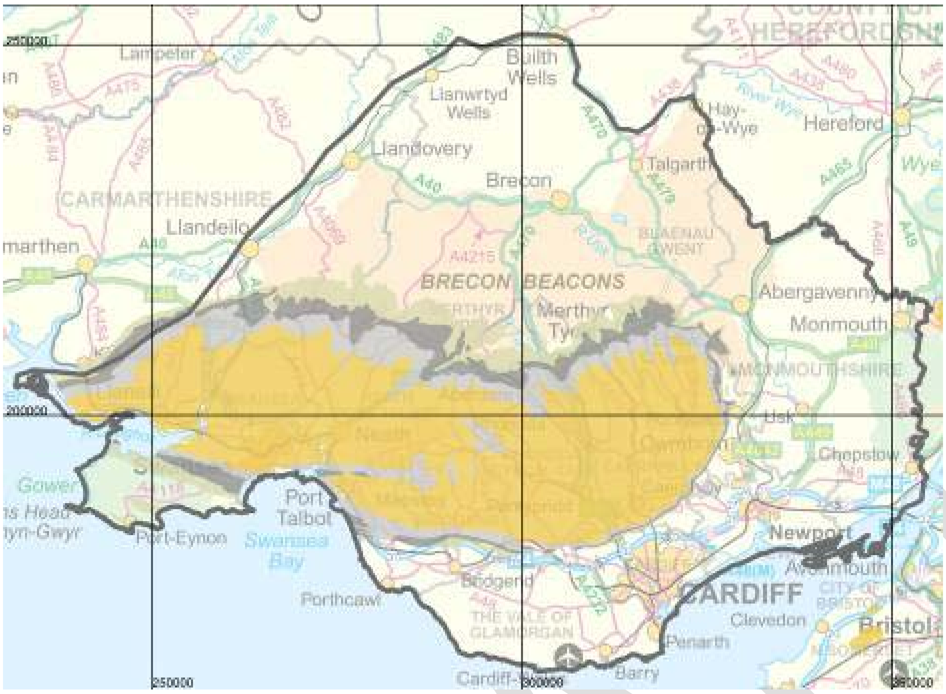


Figure 11 Distribution of Carboniferous Marros Group, Coal Measures and Pennant Rocks

During the Carboniferous, the Variscan Orogeny caused periodic uplift, and the land was temporarily emergent. High ground provided a source of coarse clastic material which was deposited in brackish deltas and fluctuations in sea level caused periodic inundation of the land by the sea (marine bands). The low lying coastline and deltas supported tropical rainforest and the vegetation which subsequently accumulated in the swampy conditions produced peat, which in time, lithified to produce the coal seams of the Upper Carboniferous. The numerous coal seams are the result of this process being repeated as tectonism caused the basin in which the sediments were being accumulated subsided.

By the Upper Carboniferous the Variscan Orogeny had reached its climax, folding sediments and forming a mountain chain. This mountain range reached from Southern Ireland in the East to North West Europe and the east west trending syncline in which the Carboniferous sediments are preserved in South Wales is a remnant of this ancient mountain chain.

Namurian

The Namurian aged sediments in the project area are known as the Marros Group but were formerly called the Millstone Grit. The Marros Group is subdivided into a lower Formation called the Twrch Sandstone which is overlain by the Bishopstone Mudstone Formation. Example of the Twrch sandstone (formerly known as the Basal Grit) can be seen in Dyffrynoedd nedd a Mellte a Moel Penderyn SSSI near Pontneddfechan which it is exposed in river gorge and at Dinas Rock. It is also visible at the **Henllys Vale RIGS** and **Dinas Silica Mines RIGS** where the quartzitic sandstones were mined. The Twrch Sandstone Formation consists predominantly of quartzitic sandstone with conglomerates and thin beds of mudstones and sandstones which are likely to have a littoral environment of deposition. The Twrch sandstone also contains palaeosols and roots and trunks of fossil trees, indicating a terrestrial setting (Howells 2007). An example of the Bishopstone Mudstone formation can be seen at the **Craig Derlwyn Quarry RIGS.** The

Bishopstone Mudstone Formation is a mudstone dominated formation with minor quartz sandstones. It has three major coarsening upwards deltaic sequences identified within it. The sandstones are mouth bar and coastal deposits (Howells 2007).

Westphalian

The Westphalian overlays the Namurian and includes the Lower, Middle and Upper Coal Measure Formations that have been responsible for much of the industrial history of our area. It also includes the Pennant Sandstone Formation which, being relatively resistant to erosion, defines the highest hills in our valleys and has been the source of much of the building stones which characterise the buildings and terraces of the valleys.

The South Wales Coal Measures Group is the name given to the productive coal measures and are divided in the Lower Middle and Upper Coal Measures Formations and were deposited to the South of the Wales-Brabant High. The group is thickest in the south west and west of the coal field. In the Swansea are it is approximately 900m thick in the east this thins to 240m elsewhere.

The South Wales Lower Coal Measures are grey mudstones and siltstones with seat-earths, coal seams and minor sandstones. In the lower part of the formation, between the Subcrenatum Marine band and the Garw Coal, the coals are thin and impersistant and marine bands are common. There are also a few thick sandstones, including the Farewell Rock. Between the Garw Coal and the Vanderbeckei Marine Band, the number of marine bands decrease and thick coals are more common. The sandstones represent predominantly southward prograding deltas, fluvial sands and channels. The South Wales Lower Coal Measures can be seen at the **AberLledle** and **Georgetown RIGS** and also at the **Heol Llan** and **Heol Las** SINC's.

The South Wales Middle Coal Measures are grey mudstones and siltstones with seat-earths, minor sandstones, which is more common in the north east and thick persistent coal seams with ironstone bands. The sandstones in the north east of the coalfield are southward progradational delta lobes. Examples of the South Wales Middle Coal Measures can be seen **at South Ty Rhos Crags RIGS and Blaen Pig and Canada Tips RIGS** as well as underground at **Big Pit RIGS** where coals of this age and Lower Coal Measures age can be seen.

The South Wales Upper Coal Measures are grey coal-bearing mudstones and siltstones with seat earths. The formation also includes minor grey, quartz rich sandstones, coals and ironstones and is deposited in an increasingly northerly derived Fluvio-lacustrine environment (Howells 2007). The formation is very poorly exposed but can be seen in small isolated, stream bed outcrop at **Cwm Lluest RIGS**

The Coal Measures Group is overlain by the Warwickshire Group. This includes the Deri Formation, The Pennant Sandstone Formation. (Waters *et al* 2009). The Deri Formation is only seen in the far east of the coalfield and has very limited outcrop. The Pennant Sandstone Formation has a wide distribution thoughout the centre of the coalfield. The Pennant Formation is subdivided into: Llynfi, Rhondda, Brithdir, Hughes and Swansea members. Pennant type sandstones are described as "grey-green and blue grey, feldspathic, micaceous, lithic arenites" (Waters *et al* 2009). They are derived from the south and occasionally contain conglomerates and thin mudstones and siltstones and seatearths with thin coals. The facies are arranged in fining upwards channel sequences (Waters *et al* 2009). A network of sites which illustrate the Pennant is given in the table below:

Mynydd Bach Quarry	SINC	Hughes
Crumlin Quarry	RIGS	Hughes
Navigation Quarry	RIGS	Hughes
Craig yr Hesg and the Berw Falls	RIGS	Brithdir and Hughes

Pembrey	SINC	Brithdir and Gwscwm coal
Wattsville	SINC	Brithdir
Fern Bank	RIGS	Brithdir
Court Wood	RIGS	Brithdir
Aberddulais	RIGS	Brithdir
Melincourt Brook	RIGS	Rhondda and Brithdir
Craig Gwilym	RIGS	Rhondda Beds
South Dinas (Graig yr Eos) quarry	SINC	Rhondda
Garth Hill	SINC	Rhondda
Cox Quarry	RIGS	Rhondda
Cwmcarn	RIGS	Rhondda
Cwm Lluest	RIGS	Rhondda
Tarren Felen Uchaf track cutting	RIGS	Llynfi and Rhondda
Above Wyndham	SINC	Llynfi

Stephanian

The Stephanian sequence is only present in isolated areas of the coalfield where it is preserved in downfaulted blocks and synclines. There is only one formation which represents this period in South East Wales. This is the Grovesend Formation and it can be seen at the **Llanhillith (Tyrpentws)** site. The Grovesend Formation is dominantly argillaceous, being made up of mudstones and siltstones with coals. Locally thick, lithic sandstones occasionally occur within the formation, along with some red beds in the type are of the Village of Grovesend (Waters *et al* 2009).

3.5 MESOZOIC

Figure 12 Distribution of Mesozoic Rocks

The Mesozoic Era includes three geological time periods, the Triassic, Jurassic and Cretaceous, of which only the lower two are represented in the rocks of SE Wales. Within Wales, rocks of this age are mostly restricted to the Vale of Glamorgan with small areas in the Gower and Pembrokeshire.

During the Permian and the early part of the Triassic a period of uplift caused large-scale erosion throughout South Wales. Therefore rocks of this age are missing from the geological column. During this time, the British Isles was desert with hills across Wales. The Zechstein Sea which lay to the north east of Wales gradually encroached the area with the Welsh Landmass being almost entirely surrounded by water by the Mid Triassic. The landscape of exposed Carboniferous rocks was being heavily eroded and there was oxidation of the desert surface (reddening). The earliest deposits were water lain conglomerates and breccias of alluvial fans.

3.5.1 Mercia Mudstone Group

The earliest Mesozoic deposits preserved in this area are those from the Mercia Mudstone Group (formerly known as the Keuper Marl).

The Mercia Mudstone Group is split into three parts, the “undivided red mudstones”, which pass laterally in to the “marginal facies”. Combined, they form the majority of the group, and the Blue Anchor Formation at the top.

The transition from mudstones to marginal facies was controlled by proximity to areas of high ground which supplied coarser material. In the Vale of Glamorgan, the Cardiff-Cowbridge Anticline formed limestone ridges with softer Lower Old Red Sandstone exposed at its core. The marginal facies, can be seen in places plastered against this palaeo-landscape with the concentration in clast types changing with proximity to the various lithologies exposed by the eroding anticline (dominantly limestone but occasionally ORS and others). The Mudstones are predominantly red (occasionally green), massive and dolomitic with common gypsum nodules and layers. They are also commonly seen infilling fissures and caves in the Carboniferous limestone. The “red mudstones” are thought to be deposited in a lake or inland sea, which periodically dried out.

Rocks of the Mercia Mudstone Group and its Marginal Facies are seen at a number of GCR sites in the region. These include Sutton Flats, Barry Island, Ogmore to Southerdown, Hayes Point to Bendrick Rock and Sully Island. These sites are all SSSI’s. This project has identified a number of other sites as RIGS in support of the SSSI’s. These are **Plymouth Woods RIGS and SINC Radyr Quarry** RIGS and the **Llandaff Playing Fields SINC** (see building stones Chapter). These two quarries, along with the **Western Avenue SINC** give opportunity to examine the marginal facies, especially the sedimentary features associated with alluvial fans and the changing clast assemblages referred to above that change with proximity to different source rocks. **The Llandaff weir** site is also of interest because it shows well the variation in grainsize and sedimentary style, being much finer grained and bedded than other outcrops It also displays an unconformity on underlying Lower Old Red Sandstone rocks (more commonly in the district, the underlying unconformity is with Carboniferous Limestone).

The RIGS at **Goldcliff** exposes a rock platform 600m wide, developed along several bedding planes within the topmost red mudstones and the lowermost units of the Blue Anchor Formation of the Mercia Mudstone Group. This rock platform extends westwards from the point for about 900 m. This is the most extensive exposure of the Mercia Mudstone Group in the Newport district and a good example of the finer grained mudstone dominated sections typical of the Group. At **Sudbrook Point**, the Mercia Mudstone Group occurs as a sandstone unit. This is unusual in Wales, and so the sites have been included as RIGS. The Sudbrook Sandstone is used locally and historically as a building stone (See chapter on Building Stones) .

It should also be highlighted here that the Mercia Mudstone group is important locally for yielding some of Wales’s only vertebrate fossils (Dinosaur foot prints at Sully and early mammals at Ogmore). These will be discussed in more detail in the chapters on Building stones and Palaeontology, later in this volume.

The Blue Anchor Formation forms the top part of the Mercia Mudstone Group. It mainly comprises a sequence of green-grey mudstones, with thin beds of dolomite and limestone and subordinate interbedded red mudstones. It is considered to have been deposited subaqueously, mainly in a lacustrine environment (Waters and Lawrence, 1987), although a marine influence is recognised towards the top of the unit at Lavernock (Orbell, 1973).

The RIGS site at **Ely Brick Works RIGS** in Cardiff displays the full sequence through the Blue Anchor Formation. The basal transition from the red mudstones of the Mercia Mudstone Group to the green-grey mudstone of the Blue Anchor Formation are well displayed in the cliff sections and the transition to the overlying Penarth Group is also present at this site. The Blue Anchor Formation is also well displayed in the cliffs at the Penarth to Lavernock GCR**.**

3.5.2 Penarth Group (E Burt)

Overlying the Mercia Mudstone Group is the Penarth Group (formerly known as the Rhaetic Beds), which is also Triassic in age. This group comprises a sequence of mudstones with subordinate sandstone and limestones, deposited in a shallow marine environment (Warrington et. al. 1980; Waters and Lawrence, 1987).

At the type section of the same name in the Cardiff district the Penarth Group is made up of the Westbury Formation and Lilstock Formation, the latter of which includes two members, the Cotham and the Langport (Warrington et. al. 1980). However, in the Bridgend district the Penarth Group is often represented by a Marginal Facies, which is unique in South Wales.

This Marginal Facies is represented by the RIGS sites at **St Mary Hill** and **Quarella and Old Vicarage SINC**. The site at St Mary Hill shows the sandstone sequence which is equivalent to the Westbury Formation of other areas. The sandstones are interpreted as shoreface deposits, probably depositing around low islands (Waters and Lawrence, 1987). Sedimentary features consistent with this interpretation can be seen at the St Mary Hill site.

The RIGS site at **Quarella** in Bridgend also shows sandstone of the Marginal Facies. However, this site is most important because of the historical industrial use of these sandstones as high quality, easily carved building stones and as the material to make silica bricks. The Quarella area was the source of 'Quarella Stone' which was used in many important buildings, both in the local area and further afield.

3.5.3 Lower Lias Group (E Burt)

The marine transgression in the Jurassic laid down the rocks of the Lias Group; a thick interbedded sequence of deep marine mudstones and limestones. The Lower Lias Group comprises: Marginal facies, Porthkerry, Lavernock Shales, St Marys Well Bay and the Bullcliff Member. The lowest formation of the Lias Group, the Blue Lias Formation is well represented at the coastal GCR sites between Lavernock and St Mary's Well Bay and Pant y Slade to Witches Point. The RIGS site at **Bull Cliff** is a useful additional site where the St Mary's Well Bay Member, the lowest member of the Blue Lias Formation can be studied in detail and also where hammering for educational purposes may take place. This site is the type section of the Bull Cliff Bed (Waters and Lawrence, 1987), the lowest part of the St Mary's Well Bay Member, and also shows the transition to the overlying Lavernock Shales Member higher up in the cliff. The Lower lias can also be examined at **Coedbychan**.

Although during the Jurassic the district was largely covered by the sea local shorelines resulted in the formation of the Blue Lias Marginal Facies. This is well displayed at the **St y Nyll** RIGS site on the outskirts of Cardiff. The Marginal Facies in this area is comparable to the stratigraphically highest member of the Blue Lias Formation, the Porthkerry Member. At **St y Nyll** it comprises irregular bedded shelly limestone, some of which contain ooids, indicating the closeness of a shoreline in the area.

The rocks of the Blue Lias Formation are the highest stratigraphic unit of the Mesozoic in South Wales. No Cretaceous age rocks are present and the Jurassic rocks are often overlain by deposits of Quaternary to modern age.

3.6 QUATERNARY (A HUMPAGE)

The Quaternary is the most recent period of geological time, extending from 2.6Ma to the present day. It covers a time of repeated natural climate change driven by changes in the Earth's orbit around the Sun which has varied the amount of solar radiation received and by movements of the Earth's crust, the changing position of the continents modifying particularly the circulation of ocean currents. The Quaternary is divided into two Epochs, termed the Pleistocene and the Holocene.

Prior to the Quaternary, crustal movements along pre-existing structures were causing crustal flexure and warping. Much of the area of Wales was land, and sedimentation was largely limited the Irish Sea basin. Onshore, deep weathering formed regoliths, and whilst deposits of Tertiary age have been proven within cave systems in North-east Wales, non have been so proven in the South Wales RIGS area, despite the extensive cave systems development in the area.

Although evidence is lacking, by Neogene times, uplift of the Welsh massif had occurred, and the landforms were becoming erosional. Uplift was probably dome-like and sporadic, and consequently, stepped landscape profiles developed. Brown (1960) recognised four major peneplains at varying altitudes, each ranging through 100 m or so and ascribed them to sub-aerial erosion and eustatic uplift. Nearer the coast, lower erosion surfaces developed. This development is best represented by **Garth Hill**, where the "Low Peneplain" surface and at least two "wave-cut" platforms are identifiable. High interfluves in the Black Mountains, such as at the **Bloodstone** similarly reflect these uplifted surfaces whilst in the Wye valley, the incised meanders at **Lancaut** are also a response to uplift and rejuvenation of the fluvial system probably during Neogene times.

Through Palaeogene and Neogene times the Welsh climate progressive deteriorated and reached its nadir when, as a result of dramatic global cooling, ice accumulated in upland areas and high latitudes and spread southwards. During the Pleistocene repeated phases of cooling and warming resulted in the repeated waxing and waning of ice sheets across the continents. Much of the early Pleistocene was subjected to fluctuating periods of warm and cold climate.

Whilst ice cores from Greenland indicate the probability of repeated advance of ice into Wales, the first direct evidence in South Wales is that of the Anglian glaciation found on the Gower, with a suggested age of 430 -480ka for the **Paviland** moraine. Evidence of the following Hoxnian Interglacial and "Wolstonian" cold phase is preserved as raised beaches and in cave deposits on the Gower coast (see **Karst**), much of which is statutorily designated as SSSI.

Across South Wales, it is the late Devensian (Dimlington Stadial) glaciation for which there is the greatest evidence. Well-developed cwms, glacial troughs and other glacial erosion features such as **Cwm Parc** dominate the uplands, whilst extensive spreads of glacigenic deposits fill the valleys and mantle upland slopes, all of which obliterate the evidence of earlier ice cover. From the mid-Devensian warm period (Upper Warren Interstadial Complex), the climate deteriorated and by 26ka ice cover was developing, reaching its maximum extent and thickness about 22ka. Undisturbed, till deposits are not easy to find within South Wales due to the human activities, but **Gilfach Goch** represents a well-preserved valley sequence in the Coalfield, whilst at the **Hermitage**, more research is needed to understand whether or not the deposits here are truly glacigenic. The maximum extents of the Late Devensian ice sheet are recorded in terminal moraines such as that at **Usk Terminal Moraine,** whilst just beyond the ice margins, complex overflow channels and proglacial lakes such as that at **Llantilio Crosenny** developed and ice marginal outwash sheet deposits such as those at **Stanton** were laid down, often modifying the glacial geomorphology. On the ice sheet margins, where the ice blocked former drainage routes, incised glacial spillways such as that **Cwm Coed** were eroded through bedrock ridges to establish new drainage paths. During or immediately after the Late Devensian was a long period of frost action in a periglacial environment. One of the consequences of this is well developed "patterned ground" - sorted stone polygons exposed by eroding hill peat. These stone circles and polygons can be seen at **Carn Pen Clogau RIGS** and **Tair Carn Uchaf RIGS**.

By 20ka, the ice was retreating, and in valley glacier systems, ice front stillstands and minor readvances resulted in the formation of cross valley moraines such as **Kemys Commander**, **Nevill Hall**, **Dyffryn-mawr**, **Llandetti**, **Cradoc** and **Cefn Crai**, and complex decoupling of main and tributary glaciers (**Llanfrynach** and **Pentrefelin**); very often melting blocks of ice resulted in the formation of kettle holes in these features. Less well understood was the interaction between ice streams, and in localities such as the Llangorse Lake Basin, decoupling between the Wye valley and Usk valley glaciers resulted in dead ice features such as those at

Tregunter and **Felin-Newydd**, and meltwater spillways from an enlarged Llangorse Lake at **Llanfellte** where northward drainage to the Wye was still blocked by ice, but the Usk valley in this area must have been ice free. The melting ice also created space for ice marginal deposition along the sides of still extant valley glaciers, initially as lateral moraines as at **Ffrwdgrech**, but with increasing volumes of meltwater, ice contact deposits such as those at **Twyn-y-felin** formed, and extensive fluvio-glacial deposits were laid down as kame terraces such as **Llanbradach** and **Gwaelod-y-garth**, or in kame-moraine complexes such as **The Bryn**. At some of these localities, there is apparent evidence of downwasting of the ice surface with stepped levels visible. Ice transported boulders were deposited as erratics, such as **Arthur's Stone** on the Gower, which has an exposure date of c.22.8ka.

As climatic ameliroarion continued, the glacier retreated into the mountains, and sites such as **Cefn Cul** and possibly **Craig y Fro** preserve the last remnants of the Dimlington Stadial ice. Continuing landscape adjustment followed the melting of the glacier ice. Former valley routes dammed by morainic material or ice forced the newly established rivers, often with high water flows from meltwater to establish new courses, very often cutting narrow incised gorges in bedrock as at **Priory Groves** and **Nant Ffrwd**.

Even as the ice melted, the climate, particularly during winter, remained cold. Some areas, beyond the Devensian glacial limits, were exposed to millennia of cold temperatures, and periglacial phenomena, such as ice wedges, which require a mean annual air temperature below -40°C are indicative of the climatic extremes. Ice wedges are in Wales, but a series are exposed in the cliffs at **Sully**. In the uplands, frost shattering and granular disintegration of exposed bedrock resulted in the formation of tors such as those at **Craig Ogwr** and **Cwm Parc.** Some of the highest altitudes plateaux, such as the top of the Black Mountain, may have remained upstanding above the ice surface as unglaciated nunataks, and here periglacial activity in the near surface active-layer, which thawed and froze every annual cycles, resulted in the development of patterned ground, as illustrated at **Carn Pen-y-clogau**. In areas such as the Black Mountains, which lay beyond the ice sheet limits, but which would have still experience heavy snowfall, permanent snow patches formed on sheltered hillslopes in the lee of the prevailing wind. Whilst not true cirques filled with glacier ice, these nivation hollows did form distinctive features such as that at **Maes-y-ffin**. On **Fan Gyhirych**, where there was limited opportunity for significant snow accumulation, a similar feature can also be seen.

From 13,500 to about 11,200 years ago, the climate fluctuated during a period known as the Late-Glacial Interglacial Transition (LGIT). The climate warmed significantly (the Windermere Interstadial), possibly even becoming warmer than today and vegetation quickly established round small water filled basins such as **Craig y Fro** and **Waun Du**. Unstable slopes, either mantled in glacial material or oversteepened by glacial erosion or deep weathering failed as large landslides, such as those on **Fan Dringarth** and at **Cwmyoy, Blaen Taf and Bournville**. A short-lived return to very cold conditions, the Loch Lomond Stadial (or Younger Dryas) lasting about 1200 years resulted in the return of small cirque glaciers to the highest parts of the Brecon Beacons. **Blaen Caerfanell**, **Craig Cwm-du**, **Cwm Crew**, **Cwm Pwllfa**, **Fan Bwlch Chwyth** and **Pen Milan** all developed terminal moraines at the snout of these glaciers. Other parts of the Brecon beacons developed permanent snow patches, resulting in the formation of pro-talus ramparts at **Blaen Senni**, **Cwm Cynwyn** and **Cwm Oergwm,** and as the snow melted the release of water contributed to the development of long thin debris flows in loose material on the steep slopes. The remains of drumlin fields can be seen at the Hirwaun Drumlin SSSI but also at the **Cefn Rhigos RIGS.** The return to cold conditions also saw the loss of vegetation as see in the sediment records of bogs at **Waun Du** and **Craig y Fro,** and tributary rivers full of annual snowmelt formed large low angle alluvial fans at their mouths (**Twyn-y-felin**).

Climatic warming at the end of Loch Lomond Stadial was dramatic, with mean annual temperatures rising by some thirty degrees probably in less than a century. Vegetation returned to the landscape and fluvial regimes stabilised. The reduction in sediment load allowed rivers to begin incising through flvio-glacial deposits and start developing floodplains and terrace systems, as seen at **Aberbran to Abercamlais**, where the highest terrace is the remains of the glacio-fluvial sandur surface. Fluvial activity continues to dominate to the present day, and localities such as **Spudder Bridge** and **Gilfach Goch** illustrate the modification of formerly glaciated valleys by rivers to establish floodplains which continue to be prone to flooding in the present day.

On the coastal margins, sea levels rose by about 100m at the end of the Dimlington Stadial, reaching current levels about 7,500 – 8,000 years ago when extensive low lying areas flooded. Since then, extensive intertidal deposits formed over Pleistocene deposits at localities such as **Goldcliff** near Newport and it is on slighter higher, drier sites in marshes such as this that some of the earliest evidence for human occupation is found with evidence for Mesolithic, and possibly Late Palaeolithic activity on small islands in the levels.

3.6.1. Wells

Throughout Wales, human activity has often centred on wells and springs and even today, many rural areas remain on their own supply. Whilst many wells have holy, or pagan, significance, it was during the Victorian era, that “taking the waters” became major tourist attraction and spa towns developed in South and mid Wales to accommodate the thousands of visitors arriving by train. Many of the wells were considered to have healing properties because of their mineral conent. Those at **Llanerch-Coedlan Wells** and **Llanwrtyd Wells** were sulphur wells, as is the **Billy Wern Sulphur Spring**, whilst at **Llangammarch Wells**, chalybeate and barium waters could be taken, this location being the only Barium spa outside central Europe. All the well houses and pump rooms are now abandoned and in some cases in ruins. At **Taffs Well** is located the only thermal spring in Wales and the fourth hottest in the UK, with a history dating back to Roman times. Temperatures have been recorded up to 22.3^{o}C and average 21.64^{o}C.

3.6.2. Historical

Many monuments and geological localities draw on the underlying geology of the South Wales RIGS area. Some sites are natural, such as the **Suckstone** which have long attracted visitors, whilst sites such as the **Bloodstone** record mediaeval events during a time of Welsh uprisings against Norman rule. Similarly, the **Brechfa Common Bomb Craters** record another traumatic time in more recent history, when much of South Wales was subjected to bombing raids by the German Luftwaffe during the Second World War. A more recent monument, again drawing on the natural geology is the memorial to **Aneurin “Nye” Bevan** in the heart of his former parliamentary constituency of Ebbw Vale. Located on the hillside above Tredegar, this memorial of limestone blocks celebrates his pivotal role spearheading the establishment of the National Health Service, which provides medical care free at point-of-need to all Britons.

In the groupds of Llandaf cathedral isa monument to one of the areas more famous geologists. **Conybeare** was a 20th Century geologist who named the Carboniferous System and also coined the generic name Pleisiosaurus. Both terms are still in use today.

3.7 BUILDING STONES

Many of the rocks in the South Wales area are utilised as building stones. A number of RIGS have been chosen which are either as a source of building stones or are buildings that utilise local stone in construction or decoration.

Traditional local building materials are often seen in important old buildings in the area. Many are protected by Listing (*CADW 2011*) and fall within the town and country planning system or are designated as ancient monuments, under the "Ancient Monuments and Archaeological Areas Act 1979 Chapter 46 (*RCAHMW*). For that reason, this project has not considered these building or monuments as RIGS as their protection is already afforded by these designations.

Many of the rocks that outcrop in South Wales, can and have been used locally for construction of buildings, walls and monuments etc. There are however a few that have properties that make them excellent building stones or are easily carved and so are more widely utilised. They tend to be known by local names rather than by their formational stratigraphic names. Most of those described in this chapter are Mesozoic age rocks such as Lias, Quarella Sandstone, Sutton Stone, Sudbrook Sandstone, Radyr Stone and Penarth Alabaster. The Namurian "Blue Pennant", used through the valleys is however Carboniferous in age and Old Red Sandstone rocks are commonly used in the north of the area

Old Red Sandstone

The buildings of the Brecon Beacons, and the villages to their north and east such as Sennibridge, Brecon , Hay-on-Wye, Abergavenny and Monmouth have buildings of red-brown and green sandstones. These are from the Old Red Sandstone (See Chapter on the Old Red Sandstone) and are Devonian in age. Examples include Tintern Abbey, Raglan Castle, Great Castle House in Monmouth and the Baptist Chapel at Abergavenny, **Bloodstone RIGS** to name but a few (*Lott and Barclay 2002*). Quarries, designated as RIGS that supplied Old Red Sandstone for building stone include: **Pwll y Wrach RIGS, Tredomen RIGS, Tremynfa RIGS** and **Pantymaes RIGS.** At the base of the Old Red Sandstone, the long linear Silurian – age **Tilestone Quarries** form a distinctive feature in the landscape on Mynydd Myddfai and Mynydd Bach Trecastell.

Carboniferous

The Carboniferous Limestone was used as a building material in Roman times in Caerleon and Caerwent as well as in the castles of Newport and Chepstow. It is also used in Railway viaducts in the "Heads of the Valleys". Pennant Sandstone is used throughout the South Wales Valleys. More famous examples include Caerphilly Cyfarthfa and Swansea castles but throughout the 18th and 19th centuries, it was extensively used for the terrace houses, clubs, pubs chapels and churches (*Lott and Barclay 2002*). A good example of a building stones quarry in the Pennant is the **Craig y Hesg RIGS.**

Triassic

Radyr Stone is the local name given to the Marginal Facies of the Mercia Mudstone group. This conglomeratic rock is red with clasts of various colours, making it an attractive architectural resource. Although it was used as the principle building stone in many houses and bridges in the Cardiff area, it is more commonly found as copings on walls or as decorative bands within walls of buildings. It is also forms the **Gorsedd Stones** in Cathays park in Cardiff. **The Radyr RIGS** and **Plymouth Wood RIGS** are both examples of quarries in this rock.

Also within the Mercia Mudstone Group are a number of sandstones which are utilised as building stones. The Quarella Sandstone was quarried in the Bridgend area and used mainly in that area. One of the more famous examples of its usage is the castle at Margam Park. The **Quarella Sandstone Quarry** is proposed as a RIGS. In the east of the area, another sandstone has been exploited for building stone, This is the Sudbrook Sandstone and it has a long history of use with examples in the Roman buildings of Caerleon and Caerwent, in Norman Castles, including Caldicot and in many of the medieval churches in the area. Sudbrook Sandstone can be seen at **Sudbrook Point RIGS**

Penarth Alabaster is another important resource used in buildings in the Cardiff area used to create decorative architectural features. The exact source of the alabaster is contested but it is thought to be from the area between Lavernock and Penarth where it is seen to outcrop in the cliffs. The Alabaster is an evaporate deposit, known as gypsum, occurring within the Mercia Mudstone Group and it ranges in colour from white to deep pink. It can be seen in the field at **Penarth to Lavernock RIGS** and Penarth to Lavernock GCR. Examples of the stone in use can be found in Cardiff University, Main Building where it tiles the main staircase. It is also used in arches, fireplaces and in an elaborate balustrade at Insole court in Llandaff. Another example is St Margarets Church in Roath where it again forms tiles and mouldings as well as featuring in columns and an elaborately carved pulpit.

Jurassic

Sutton Stone, can be seen in outcrop at the mouth of the Pantyslade valley near Ogmore. It is Lower Jurassic (Lias) in age. The Sutton stone varies in texture from a uniform granular limestone to a coarse conglomeratic limestone with clasts of limestones and cherts. Where it is used in buildings, it is initially bright white colour but weathers to grey but the other distinctive feature is that the clast tend to fall out on weathering giving the stop a pock marked appearance. It was mainly utilised local to the area from the 11th to the 16th centuries. Sutton Stone can be seen in use in Ewenny Priory and Ogmore Castle has a dressed fireplace of Sutton Stone (Howe 2008) and also in the Romanesque arches at Llandaf and St Woolow's Cathedrals (Davies 2010).

3.8 INDUSTRIAL (A HUMPAGE)

The industrial history of South Wales is inexorably linked to its mineral wealth with centuries of mining and working its resources. The most obviously linked industry with the region is Coal Mining and open cast, iron extraction and the manufacture of steel, Aggregate quarrying, millstones, quartzites, Lime, minerals. Building stones are discussed in the (3.7 Building Stones) chapter.

Most of the evidence for this history has been lost with quarries being in filled or overgrown and buildings demolished. What is left is generally well protected by listed building or schedule monuments statuses being applied. This project has highlighted only a few such sites, due to the protection being already so good.

Coal was the principal economic output from the region for around 150 years and has resulted in a huge influx of people to extract it. Many of the South Wales Valleys communities owe their existence to the need for workforce and the social history relating to this and the steel industry cannot be under estimated. Since the Mid 1980's the coal industry has been in rapid decline with a corresponding loss of associated sites and buildings which marked their existence. Most of the pit head buildings associated with old collieries, which still exist are listed so this project has not added any new RIGS. There are however a number of open cast sites and colliery tips and have been included as RIGS. One of the earliest opencast sites in the UK is to be found to the north of Blaenavon, known as **Canada Tips**. This site also includes extensive areas of tips. The differing types of tipping of colliery spoil are well illustrated at **Llanbradach Colliery Tips** where both traditional tipping and later conveyor tipping to form large conical mounds can be seen. Many of the tip sites in South Wales have been reworked and landscaped or removed entirely as part of landscape remediation with only these few sites left to remind us of the important part coal mining played in our social history. **Rudry Common RIGS** illustrates one of only a few sites where evidence of bell pits, an early method of mining coal can still be seen.

Iron ore (siderite) was also extensively mind in the South Wales Coalfield where they occur in the Lower and Middle Coal Measures as tabular beds or as nodular concretions. Just like coal, there were originally open casted but were subsequently deep mined. **Big Pit RIGS** contains one such example – the Coity Pit. Latterly utilized as a colliery up-cast shaft, it was originally sunk to exploit the Spotted Ball and Bottom Vein mines. Once extracted, the iron was often transported only short distances, and numerous ironworks and forges developed, often in wooded areas where charcoal was produced. **Coed Ithel** was one of the earliest blast furnaces in Britain, and its double cone shape can still be seen today, whilst Brecon ironworks in **Priory Groves** was once one of the most productive in South Wales before the use of coke moved iron production farther south into the South Wales Coalfield. Another early ironworks was that at Melin Court in the Neath valley, similarly superseded as the iron and then steel making technology developed. Even rural Breconshire need not escape metalliferous mineral exploitation, as revealed in the copper mine at **Talachddu**, a source of musing as to the origin of the mineralization by Murchsion when he visited the site in the 1830s.

South Wales has many examples of places where steel has been produced. The manufacture of steel in the area also involved a huge workforce and the industry developed in the area because of its mineral resources. Iron ore was extracted locally and initially local firewood and then coal was utilized to manufacture the steel, with the addition of limestone, also locally abundant as a flux. Many of the limestone quarries around the edge of the coalfield are likely to have had limestone extracted from them, to some extent, for this flux. Examples identified in this project are **Pwll Du** and **Gilwern Quarry RIGS.**

The quartzites of the Lower Marros group are often exploited. At **Dinas Sillica Mines RIGS**, it was mined to produce refractory bricks for the lining furnaces. This stone was also used for polishing.

The clay rich soils which dominate the farming areas to the north and east of the coalfield have created a demand for lime to help break up heavy soils. Small quarries in the carboniferous limestones, Silurian Limestones and occasionally the calcretes within the Devonian rocks are often suspected to be the result of quarrying, for very local use of lime. These sites are often associated with small kilns. Along the north crop of the coalfield, evidence for this is very common but an example where this work was done on an industrial scale is **Herberts Quarry RIGS and also at Henllys Vale RIGS**.

Many of the rock formations within the project area have been used for aggregate. Limestone, Dolomite and sandstone are have all been quarried for buildings stone, flags or crushed stone aggregate. Although none of the RIGS in this project as designated primarily because the sites have been exploited in this way, many of the RIGS in this report are the result of this kind work, exposing interesting geology. Most of the limestones are resistant to abrasion but have low polish resistance so are unsuitable for road surfacing so are utilized for most construction uses.

A range of metal minerals have been historically extracted through the South Wales RIGS region. These include include lead and zinc and are discussed in more detail the minerals section.

3.9 CAVE AND KARST AND ACCESSIBLE UNDERGROUND SITES (A KENDALL)

The South Wales limestone deposits contain a large number of cave and Karst features that contribute significantly to the scientific understanding of the landscapes as well as providing cultural, educational, recreational and economic benefits to the area. Identification of Karst sites for the RIGS project has benefitted immensely from the work of the caving fraternity who are rigorous in documenting sites with the Cambrian Cave registry, and whom have en-masse published a large amount of works on the development and distribution of Karst sites. The GCR volume Karst (Waltham *et al* 1997) and the Quaternary of Wales volume (Campbell, S. and Bowen, D.Q. 1989) between them identified 8 Cave sites, 4 general Karst Sites, 7 caves containing Pleistocene/Quaternary deposits and 3 sites for Pleistocene vertebrate remains. Some of these sites have been extended and clarified as they are combined within SSSI designations a further set of sites have been added as RIGS with a total of 22 Cave and Karst, or underground RIGS Sites which are not designated in other parts of this work.

RIGS Selection process and site definition

The cave sites selected for this RIGS study have been selected from a database of over 1600 cave sites held by the Cambrian Cave Registry. The selection process was to filter out all sites with no known details such as sites registered as “Dig” or “Hole”. The remaining 800 sites were then manually reviewed against key caving and geological literature as listed in the references below (especially Oldham, Jones and Ockenden). From this process a number of key sites and areas were selected as being of specific value or being excellent examples of certain aspects of caves as described in the RIGS forms for each site. The list of sites was peer reviewed by a number of cave scientists and the selection agreed as appropriate.

The selected sites were then plotted on the BGS GIS and boundaries compared to existing boundaries where protected status such as SSSI was in place and the boundaries either confirmed or amended. With caves the boundary of a site is not only related to the immediate surface outcrop near any entrances. There are often many kilometres of underground passages and watercourses that can be damaged by surface activities many hundreds of feet above. For this reason it is usual to list the catchment area of any know water that feeds into the cave either from a key surface feature or at the minimum from the point where the water sinks underground and therefore a number of SSSI boundaries have been increased as part of the RIGS designation e.g. **Mynydd Llangynidr**

Site visits

It has not been necessary to make an extensive site study of all of the sites because so many of them are well documented within the caving press and any issues are recorded rapidly within that set of publications.

The descriptions of those sites that have been specifically visited for this study have been enhanced with the authors own knowledge from visiting and photographing many of these sites over a 25 year period, a number of photographs within the site visit reports have been taken across this period, but especially in the last 10 years since digital photography made photographing underground sites much easier

As underground sites require special equipment, training and experience they are not recommended for the general public, but many of the sites have interesting and accessible surface features and related karst landscape features and therefore they have generally been given 2 safety and accessibility ratings.

The cave systems are able to be entered where the limestone outcrops in this area the bulk of that is the Carboniferous limestone’s surrounding the South Wales Coalfield basin and therefore the cave systems and RIGS sites follow this outcrop closely.

General geological setting

As can be seen from this diagram the limestone extends beyond mainland Wales and can be seen again outcropping on Flatholm island and indeed on Steepholm island and Weston super mare in England, and again in a series of up-folded areas across to the Mendip hills.

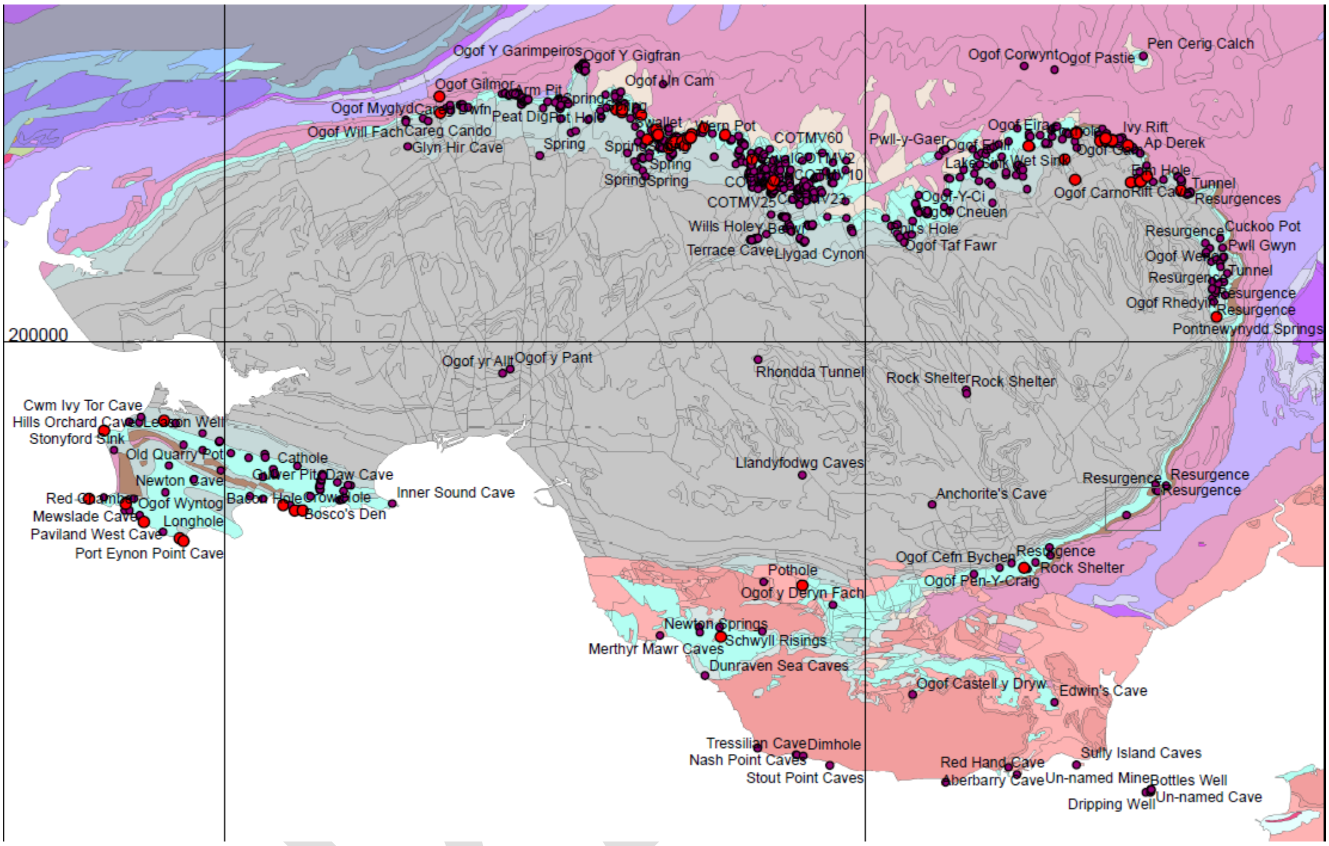


Figure 13 Distribution of Limestone and cave sites

Structure plays an important part in cave development, the dip in the South Wales Coalfield is generally towards the basin centre, but there are a number of major fault zones which intersect the limestones at and below the surface and have a significant effect on cave development in the area. Most notably the Carreg Cennen disturbance that forms the North Western boundary of the coalfield and the Swansea and Neath. There is a cave at **Carreg Cennen**, but the RIGS designation is more wide ranging considering the structural as well as cultural aspects of the site.

There are a number of cave systems where the effect of faulting is clearly seen in the direction of passages within the caves, most notably **Ogof Draenen** which is proposed to be designated as a RIGS and SSSI where the Western boundary of the system is marked with a very deep rift trending precisely in-line with the orientation of a fault, and the major systems of **Dan yr Ogof, Ogof Fynnon Ddu** and the **Llangattwg Cave systems.**

There are other Limestones in the South East Wales Rigs area, most notably the Jurassic Lias limestone which is seen most spectacularly at Southerndown and Nash point. The caves in these limestones are however not well developed because of the abundance of shale layers in these rocks which inhibits water flow over extensive distance and therefore no significant Karst features.

Within the study area there is one example of a Turlough, a seasonal lake with no surface river input which is common in Ireland, but a unique karst surface feature in mainland UK. This is **Pant-y-llyn** and is included as a RIGS site because of its rarity. The RIGS designation for this site includes the related cave system not described in the SSSI designation.

A number of other well-known mine and sea cave sites were evaluated as part of the study because they are actively visited by cavers or are tourist attractions which are cave related.

Cave explorations & Tourism

Cave explorations have been made in this area since times before modern recorded history and there are a number of key archaeological sites, especially in the southern crop caves. Therefore a number of sites have been designated on the basis of historical and cultural interest.

The earliest well documented cave exploration was that of 18th century archaeologists including the Reverend Dean Buckland, Sir William Boyd Dawkins and Rutter. The obvious open caves along the coast of the Gower Peninsula attracted early attention, Paviland Cave, with its famous 'Red Lady' skeleton of the Aurignacian period, found by Buckland in 1823, Minchin Hole, Culver Hole, Bacon Hole and Cathole Cave all provided important finds on the Gower. These sites are included within the **Eastern South Gower** and **Western South Gower** and **Llethrid Valley** RIGS sites.

Llygad Llwchwr is designated a RIGS for historical reasons as it was one of the first caves in Wales to be systematically explored with Thomas Jenkins of Llandeilo reaching the 4th river chamber in 1841. It is also of note as the source of the River Lougher. The Morgan Brothers of Abercraf carried out the first recorded cave exploration in the Swansea Valley when they penetrated the river entrance of **Dan-yr-Ogof** in 1912, found the climb up into the present show cave and reached the Third Lake.

Caves have provided a rich source of cultural, educational and economic benefit as there are records of tourism to see caves as far back as 1870 when the Cardiff Naturalists explored the limestone area and heard a report of tourist trips into **Porth-yr-Ogof** cavern (Evans 1872), and more recent explorations (Standing & Lloyd 1970) . This site is designated RIGS because of its major cultural status as a local tourist attraction as is **Dan-yr-Ogof**.

Active interest developed in the late 1930’s but modern cave exploration and study really developed at an increased rate in the post war period with the South Wales Caving club being formed in 1946. In the 1950’s onwards a number of caving clubs took root in South Wales, notably, Westminster Speleological Group and Chelsea Speleological Society in the 1950s and later on the Croydon Caving club (formed 1964). This level of activity means that many cave sites are designated as RIGS on the basis of their sporting use as well as the scientific basis. All of these clubs have published journals in which a large amount of high quality science and history regarding the caves is recorded. In addition many members of these clubs, and other researchers regularly published in the National Caving literature especially those of the Cave Research Group and the British Speleological Association who were merged in 1971 to form the British Cave Research Association. Key journal runs consulted during this work were: -

CRG - Transactions	(1947 – 1973)
BSA - Journal and Proceedings	(1947 - 1973)
BSA - Caves & Caving	(1937 & 1938)
BCRA - Transactions	(1974 - 1981)
BCRA - Cave Science	(1982 - 1993)
BCRA - Cave & Karst Science	(1994 onwards)

There are also many non-technical and discovery related articles in the BCRA news magazine, Caves and Caving (retitled to Speleology in 2003) and in Decent Magazine which were used for detailed information. There are also because of the tourism a number of excellent non-technical books regarding the caves of the area (e.g. Farr 1997 & 2002)

Speleological studies and importance

A detailed study of the underground passages has in more recent years (the 1960s onwards, and especially the 1980's onwards) given rise to a much greater understanding of how the caves relate to past climates and topographies. The caves provide an oportunity to identify and study deposits that are no-longer available or no-longer untouched in surface localities. Sites that are especially noted for this and therefore included as RIGS sites are **Mynydd Llangattwg Caves** and the **Clydach Gorge Caves**,

The nature of cave development provides a unique ability to relate the development to the geology and geomorphological history in a three dimensional manner and are therefore in many ways more valuable than surface exposures. This is described extensively in the GCR review (Waltham et al 1997)

Economic aspects

Some cave systems are key economic or industrial sites and of these the 2 main springs used for water within the study area **Schwyll Risings** and **Pontnewynydd Springs** are both proposed as RIGS sites with consideration of their catchment areas being described.

Many of the RIGS designations cover many named cave sites because they are geographically close or because they form part of a major system. A summary of the sites and caves is given here

System	Cave Entrances	
Carno Adit and Cave	Carno Adit	Carno Adit Cave
Carreg Cennen Cave		
Clydach Gorge Caves	Shakespeare's Cave Ffynnon Gisfaen Ogof Rhaeadr Ddu Ogof Clogwyn Pwll-y-Cwm Clydach Springs	Ogof Capel Limekiln Resurgence Ogof Craig-a-Ffynnon Rock & Fountain Cave Elm Hole
Coed Y Mwstwr Woods Cave		
Dan-yr-Ogof	Dan Yr Ogof Tourist Entrance Sinc Y Giedd Tunnel Cave Giedd low flow Sink Giedd low flow Sink Waen Fignen Felin Main Sink Dan Yr Ogof Tourist Entrance Dan Yr Ogof Resurgence	Pwll Y Wydden Sink Ogof Yr Esgyrn Step Cave Ogof Carreg Lem Tunnel Cave Lower Cavers Entrance Tunnel Cave Top Pwll Dwfn

System	Cave Entrances	
Dinas Silica Mines		
Dunraven Sea Caves		
Eastern South Gower	Ravenscliff Cave Bacon Hole	Minchin Hole Bosco's Den
Lesser Garth Cave		
Little Neath Caves	Little River Neath Main Sink Little Neath River Cave Resurgence Little Neath River Cave Flood Entrance	Town Drain Bridge Cave Ogof Igam Ogam
Llangattwg Caves	Ogof Pen Eryr Eglwys Faen Ogof Gam Llangattwg Swallet Agen Allwedd	Pwll-y-Gwynt Waen Rudd Swallet Cwm Pant Lladron Crochen Sion Hopkin Ogof y Darren Cilau
Llethrid Valley Caves	Llethrid Swallet Tooth Cave	Cathole
Llygad Llwchwr		
Mynydd Llangynidr Caves	Crescent Cave Ogof Cynnes	Chartist Cave
Nant Glais Caves	Ogof Rhyd Sych	Ogof-Y-Ci
Ogof Draenen	Tumble Resurgence Siambri Ddu Ogof Drws Cefn	Ogof Draenen Tumble Resurgence 2
Ogof Ffynnon Ddu	Ogof y Ffordd OFD Resurgence Ogof Ffynnon Ddu 1 Downey's Cave Ogof Pant Canol Powell's Cave Whiskers Cave Cwmdwr 2	Cwmdwr Quarry Cave 2 Large Doline Ogof Ffynnon Ddu Top Entrance Wern Pot Pwll Byfre Pant Mawr Pot Ogof Ffynnon Ddu Cwm Dwr Entrance
Otter Hole		
Pontnewynydd Springs		
Porth yr Ogof	Porth yr Ogof - Main Entrance Porth yr Ogof - Tradesmans Entrance	Porth yr Ogof Alternate entrances Porth yr Ogof Risings
Schwyll Risings		
Western South Gower	Port Eynon Point Cave Culver Hole Port Eynon	Worm's Head Cave Mewslade Cave

System	Cave Entrances	
	Paviliand Cave / Red Lady Cave	

On-line resources

BCRA publications	http://bcra.org.uk/pub/index.html

This site also includes information on BSA, CRG and other related publications

Chelsea Speleological Society	http://www.chelseaspelaeo.org.uk/index.html
Croydon Caving Club	http://croydoncavingclub.wordpress.com/
Descent Magazine	http://www.wildplaces.co.uk/
South Wales Caving Club	http://www.swcc.org.uk/
Westminster Speleological Group	http://www.wsg.org.uk/index.php

3.10 PALAEONTOLOGICAL

Fossils are fairly common throughout the South Wales RIGS region and through the geological column and can be seen at many of the RIGS identified by this project. Fossils are important in geology for a number of reasons. They tell geologists about the environments in which sediments are deposited and can also be used to date rocks.

The Silurian rocks of the Usk Inlier and to the west of the project area are very fossiliferous, containing marine shelly faunas such as brachiopods, crinoids, trilobites and graptolites.

The Devonian rocks are noted for their early plant sites, many of which are SSSI's and are internationally important as they give evidence of the early evolution of land plants. The Devonian is also known as the age of the fish and fragments of fossil fish are common especially in the sandy units of the St Maughans Formation, along with arthropod trackways.

Whilst not easy to collect, the Carboniferous limestones are often packed with fossil coals – solitary and compound, sponges and crinoid ossicles. Fossils are also common within the coal measures. Within the marine bands, goniatites can be found. These are important as they date the strata in which they are found but they are difficult to find and identify. The coal measures are most famous for their plant fossils. These range from large fossil trees, sometimes seen in life position in open cast sites to the delicate foliage of ferns and their cones and seeds. These are getting more difficult to find as the old colliery spoil tips in which they were often found are leveled and landscaped.

Within the Triassic rocks of the Vale of Glamorgan are fossil dinosaur trackways. The majority of these are within the SSSI at Bendrick and this project has suggested an extension to the boundary towards Sully where more trackways are known. Triassic aged sediments, infilling irregularities in the underlying Carboniferous limestone are also know to contain early mammal remains.

The Jurassic rocks (Lower Lias) age are exposed along the coastline in the Vale of Glamorgan. Fossils are commonly found amongst the boulders on the beaches. Crinoid ossicles, bivalve shells such as *Productus* and *Pina* and common along with the famous Devils Toenail – Gryphea. This stretch of coastline also produces ichthyosaur vertebra.

It is strongly recommended that fossils be observed and recorded rather than collected. If it is really necessary to collect of fossils, the numbers removed should be kept to an absolute minimum and then, only lose samples should be collected, to ensure that outcrops are not damaged. Fossil localities are fragile in that over collection will result in a site being no longer of interest and the scientific information provided by the fossils lost forever. Many sites are SSSI's and damaging the sites will result in a fine.

In order to protect some of the sites identified in this study, some of the more vulnerable do not have full RIGS write ups but do have contact information incase information is required for research or a planning application that may impact the site is received.

3.11 MINERALOGICAL (L GARFIELD)

Identification of mineralogical sites for the current RIGS project has benefited from the dataset, principally of old mine sites, put together for the earlier study of Bevins and Mason (2000). They identified five Geological Conservation Review (GCR) sites and seven RIGS. The GCR sites were adopted in 2010 (Bevins and Mason 2010), but the RIGS were never followed through. For two of the GCR sites (Machen Quarry, Mwyndy Mine), the current project was asked to propose RIGS status prior to eventual SSSI status and protection; it was also asked to identify a coalfield site. Of the seven RIGS identified by Bevins and Mason, six have been re-examined and confirmed. A further six sites (three from Bevins and Mason's dataset, three new) are also proposed as RIGS. This gives a total of 15 mineralogical RIGS sites for the South Wales project.

The principal types of mineralisation in South Wales are (Bevins and Mason 2000): millerite-bearing ironstones of the coalfield; oxide-facies iron; iron-manganese; cavity infill in limestones; Mississippi Valley Type (MVT) lead-zinc-barium-fluorine; wavellite in Carboniferous rocks; late iron sulphide veins; evaporites; supergene Pb-Zn-(Cu) alteration.

Minerals in the coalfield are found notably within the clay-ironstone nodules widespread in the Westphalian (Upper Carboniferous) Coal Measures. These clay-ironstone nodules often show internal diagenetic "septarian" cavities lined with siderite. In addition they may contain ankerite and small amounts of other minerals (some rare), often as attractive and well-formed crystals, in varying amounts and distribution. These minerals include quartz ("Merthyr diamonds"), calcite, baryte, dickite, carbonate-fluorapatite, hydrocarbons (hattchettite and others), and sulphides including sphalerite, galena, chalcopyrite, pyrite, marcasite, millerite, more rarely siegenite, also alteration products. The coalfield is internationally renowned for its fine sprays of millerite needles. Bevins and Mason (2010) assigned GCR status to these nodules, but were unable to select any specific site; current coalfield sites are either temporary working open casts or tips which are becoming reclaimed or grassed over. Of the latter, after some consideration, **Cilfynydd coal waste tip** near Pontypridd is now proposed as a RIGS.

Oxide-facies iron ore deposits occur mainly along the once important Llanharry to Taffs Well regional iron orefield. This once hosted several mines, the largest, Llanharry, closing in 1975. The ore forms massive bodies of haemetite and goethite in Mississippian (Carboniferous) limestone, not far below the overlying Trias, with local occurrences of pyrite, manganese, quartz, baryte, calcite and rare barytocalcite. After much debate over the years, the ore is now considered (Bevins and Mason 2000, 2010) to be an earlier phase of the regional MVT mineralisation (see below). An area of tip at the west end of the old **Mwyndy Mine** (south of Llantrisant) is now a GCR site (also RIGS leading to SSSI) – "the minerals .... best remaining material representative of the iron ores" in the ore field - an excellent research site. In contrast, the western part of the nearby **Bute Iron Mine** area is now the only accessible part and almost the only reminder of this former mining area; it is proposed as an educational/heritage/historical RIGS. Moving to the east end of the orefield, Forest Fawr hosts an extensive area of old iron workings east of the River Taff. A locality within **Forest Fawr** which shows industrial, historical and geological features all in close proximity is proposed as a RIGS. To the west of the Taff, the proposed RIGS of **Garth Wood and Mine** is a historically important site in need of protection; there is main adit c.450m long which opens into a number of huge underground chambers. Nearby the proposed RIGS of **Taffs Well Quarry** hosts iron-oxide facies and other mineralisation types, readily seen in fresh quarry faces.

Manganese is sometimes present with the iron. At Ty Coch near Porthcawl, iron-manganese was once mined, and interesting vanadium bearing minerals have been found. Proposed as a RIGS in 2000, it is reported to be in a poor state and has not been revisited.

Cavity infill in the Mississippian (Carboniferous) Pembroke Limestone Group is particularly spectacular in quarries north of Cardiff. The area is renowned for scalenohedral calcite crystals over 15cm in length overgrown by rhombohedral calcite ("Taffs Well calcite"), often lining large cavities. Referred to by Bevins and Mason (2010) as metasomatic cavity-fill deposits following attack by "particularly aggressive groundwaters" possibly as an early phase of the regional MVT mineralisation, it is difficult not to envisage them as having at least some relation with much more recent karst formation. The proposed RIGS of **Taffs Well Quarry** shows excellent examples from time to time, that of **Blaengwynlais Quarry** and **Creigiau Quarry** illustrates the development of mineralisation.

There is a regional Pb-Zn-Ba-F orefield of Mississippi Valley Type (MVT) across South Wales. Nearly half of all the sites reported on for this project are of this type. Occurrences, of which quite a few have been mined on a small scale in the past, comprise lead and zinc minerals (galena, sphalerite and alteration products) in Mississippian (Carboniferous) limestone, marginal Triassic dolomitic conglomerate, and basal Liassic limestone. Other minerals include calcite, baryte, quartz, iron minerals, pyrite, marcasite, copper sulphides and their alteration products, fluorite, alstonite. "*MVT deposits are formed from hydrothermal fluids that have migrated for considerable distances ... from their source. They consist of veins and replacement bodies ... precipitated from low-temperature, highly saline metalliferous brines expelled from deep sedimentary basins. These are typically found within limestone-dominated districts ... The classic ... model ... involves the migration of the brines from the sedimentary basins into carbonate rocks typically associated with basement highs ... The fluids migrate via permeable strata and fracture-systems...*" (Mineralogy of Wales website). What has been noted from the site visits is the variation in the deposits across South Wales, and the scope, indeed need, there is for further investigation into the nature of the mineralisation and the contribution it can offer to a greater understanding of the regional geology. In addition to the GCR site at Ogmore, proposed RIGS, selected in part to demonstrate these variations, include **Machen Quarry** (GCR - RIGS leading to SSSI, antimony and mercury), **Sully Island** (fluorite - uncommon in South Wales), **Bendrick Rock** (good exposure, structure, age of mineralisation), **Llantrisant** area (dolomitic conglomerate, unusual barium minerals), **Blaengwynlais Quarry** (wide range of dolomitisation, development of mineralisation, other geological features) and **Clive Mines** (secondary minerals (some quite rare), Roman mining, "interesting area of old lead mines", good public access), also **Taffs Well Quarry** (several phases).

Wavellite is an "uncommon but locally abundant mineral" (Tindle 2008). It Wales, it occurs only in Gower and Pembrokeshire. On Gower, only two of the four classic sites are accessible and have wavellite that can still be found. As these occur in contrasting geological environments, both are proposed as RIGS. At **Pwlldu Bay**, wavellite occurs in occasional chert pebbles on the beach. The host is considered to be the Carboniferous Limestone seen in nearby cliffs. In recent years, other rare minerals (cacoxenite, crandallite, varisicite) have been identified in association with the wavellite. Around **Cilifor Top**, wavellite occurs on joint surfaces of Millstone Grit sandstone. Although Plant and Jones (2001) attempt to give a synopsis of how it might have formed, there has been no specific research on this mineral on Gower and further work is indicated.

A late Jurassic phase of iron sulphide vein mineralisation described by Bevins and Mason (2000) is recognised, among a few localities, in **Machen Quarry**.

During the late Trias, the coast of Glamorgan lay close to the margins of a large inland hypersaline lake. The exposed Mississippian (Carboniferous) limestone was covered by sediments now assigned to the "marginal" Mercia Mudstone Group. A variety of evaporite related features are present in these red beds, notably nodules probably originally formed as gypsum in soils, since (much) replaced. **Sully Island** is proposed as a RIGS for the minerals in such nodules, namely quartz and calcite with rare celestine and gypsum; it is already a GCR site for its sedimentological hypersaline marginal red bed facies, and the minerals enhance its importance even more. To the east, the coast between **Penarth and Lavernock** is proposed as an excellent easily accessible educational mineral RIGS. The large nodules of pink and white alabaster with minor copper minerals in the red beds in the cliff at Penarth have been used historically for several buildings; the cliffs could be said to have iconic status. Along the coast, towards Lavernock, above the red beds, the cliff contains one of the few areas for strontianite mineralisation in South Wales (and the best in Wales), also the best blue celestine crystals in Wales; both are also found in boulders on the beach below. Several other geological features are shown along this stretch of coast.

Bevins and Mason (2000, 2010) describe "locally intensive secondary alteration" of some of the MVT mineralisation. It is best seen at **Machen Quarry** (GCR - RIGS leading to SSSI), where the minerals are described as a "supergene mineral assemblage of national importance". Galena has altered to cerussite, anglesite ("some of the finest specimens in the UK"), lead-antimony oxides, also (reportedly) scotlandite and matthedleite. Chalcopyrite has altered to goethite, malachite, linarite, aurichalcite and rosasite. Sphalerite has very extensively altered to abundant fine hemimorphite, smithsonite and hydrozincite. Cinnabar, fraipontite (the first occurrence in Wales), bindheimite, covellite, chalcocite and manganese minerals have also been reported. This "extensive secondary mineralisation has … resulted in a wide range of attractive secondary minerals". It is also of note at the **Clive Mines**.

In addition to the sites referred to above, of a further 106 sites (not including duplication), 54 have been given an up to date report/audit as at 2010-11 (48 from B&M, 6 new). Most have been visited; for only a few has no trace been found of any mine or any mineralisation. In looking at the sites, it was soon found that prior research ie previous accounts of a site, going back sometimes to the original references, and old maps to show a more exact location (although not all were marked on old maps), was invaluable in saving time and in providing a better understanding.

3.12 STRUCTURAL GEOLOGY

The earliest phase of mountain building, obvious in South Wales is known as the Caledonian Orogeny. It was caused by the opening and closure of the Iapetus Ocean which occurred from the Cambrian through to the Devonian in a series of orogenic events. The Silurian and Devonian Rocks of the South Wales region were being deposited during this time and their makeup reflects the changing geography at that time. Caledonian structural features are most easily illustrated by the large faults trending from north–east to south-west. These include the Neath, Swansea and Carreg Cennen disturbances. The faults zones have a history of subsequent reactivation which means that they influence younger rocks as well as those originally affected by the Caledonian Orogeny.

The tectonic movements that were a forerunner to the Variscan Orogeny affected sedimentation thoughout the Devonian and early Carboniferous and culminated during the late Carboniferous. The Variscan phase of deformation was the result of the collision of the Gondwana and Laurussian plates. The Variscan orogeny tended to produce east west trending folding. Dip faults trend north-north-west but become more north easterly trending to the east.

After the end of the Variscan Orogeny, the British Isles became part of a stable continental mass with events such as the opening of the North Atlantic in the Early Cretaceous and the Alpine Orogeny in the Cretaceous to Miocene, having only small affects on Wales.

Many of the structures visible in the region form large landscape scale features, such as the spectacular **Carreg Cennen Castle** which lies on an outlier of Carboniferous limestone which is associated with a Caledonian trending fault system, reactiviated during the Variscan. Structures are also evidenced by vertical and overturned folds in Gower such as at **Rhossili Bay.** Many of the RIGS selected for this project display elements of structural geology. The following list of RIGS all contain structural features but may not be the primary reason for their choice as a RIGS:

Dinas Silica Mines, Dan yr Ogof, Bendrick Rock, Black Rocks, Porthcawl (Newton Fault), Carreg yr Ogof, Cefn Garw Quarry, Coed Pantydarren, Garth Hill, Llwyn Cus Stream and Quarry Section, Ogof Fynnon Ddu, River Edw, Aberedw, Sully Island, Taffs Well Quarry, Tarren Felen Uchaf track cutting, Welsh (Glangwenlais) Quarry.

Appendix 1 Blank RIGS Description Form

South Wales RIGS Group Site Record
RIGS Description

Section A

General	South Wales
Site Name:	**File Number:**
RIGS Number:	**Surveyed by:**
Grid Reference:	**Date of Visit:**
RIGS Category:	**Date Registered:**
Earth Science Category:	Owner: Planning Authority:
Site Nature:	**Documentation prepared by:**
Unitary Authority: Council	**Documentation last revised:**
OS 1:50,000 Sheet	**Photographic Record:**
OS 1:25,000 Explorer Sheet	
BGS 1:50,000 Sheet	

RIGS Statement of Interest:

Geological setting/context:

References:

SECTION B

PRACTICAL CONSIDERATIONS: Please score Accessibility and Safety Red Amber or Green			
Accessibility:			
Comment:			
Safety:			
Comment:			
Conservation status: There are no known conservation designations of this RIGS			

OWNERSHIP/PLANNING CONTROL:

Owner/tenant:

Planning Authority:

Planning status/constraints/opportunities:

There are no known planning constraints or opportunities

CONDITION, USE & MANAGEMENT:

Present use:

Site condition:

Potential threats:

Site Management:

SITE DEVELOPMENT:

Potential use (general):

Potential use (educational):

Other comments:

Photographic Record

Insert photographs. Use separate sheet if required

Annotated Sketch

(as appropriate) Use separate sheet if required

Site Plan

To obtain a site base map or aerial photograph please contact BGS Cardiff on 02920 521962 Email bgswales@bgs.ac.uk

Once received, please carefully delineate boundaries of RIGS site in red

Appendix 2 Example of a completed Site Visit Form

South Wales RIGS

Geoconservation

South Wales RIGS Group
Site Visit Record

SWRIGSFOLLOW-UP

Site details added to database? ☐
Site Reviewed ☐
No further action ☐ *Potential RIG?* ☐
RIGS Reference No: ___________

SECTION A – Desk Study

Site Name	Nant Transh-yr-Hebog	Grid Reference (*Inc Sheet No*)	ST 1790 8446
Ref No	Site_SWGA_CCC_31	Date of Visit	26th Nov 2008
Recorder	Rhian Kendall	Contact details	BGS Cardiff Columbus House Greenmeadow Springs Tongwynlais Cardiff CF15 7NE 029 2052 1962 RHND1@BGS.AC.UK
Does the site still exist?	YES / NO If yes, continue to section B		

SECTION B – Site Visit

Description of location and access (*ie 100m South of Church*)	To the west side of the footpath, the stream section in in a small waterfall below two clay pipes carrying water through a rough wall
Description of the sites condition (*i.e. overgrown by brambles.*)	Site is in good condition. Easily & safely accessible with suitable footware to wade very shallow stream
Recommended designation	RIGS / SINC / None / don't know
Interest: Stratigraphical / palaeontological / mineralogical / petrological / geomorphological / industrial / historical / Educational / Social / Soils / Structural / Sedimentological / Other:	

Description of site. Detailed notes to possibly include any fossils found (inc stratigraphic horizon if possible), minerals, rock descriptions, descriptions of structures (inc dips). Continue on separate sheet if required

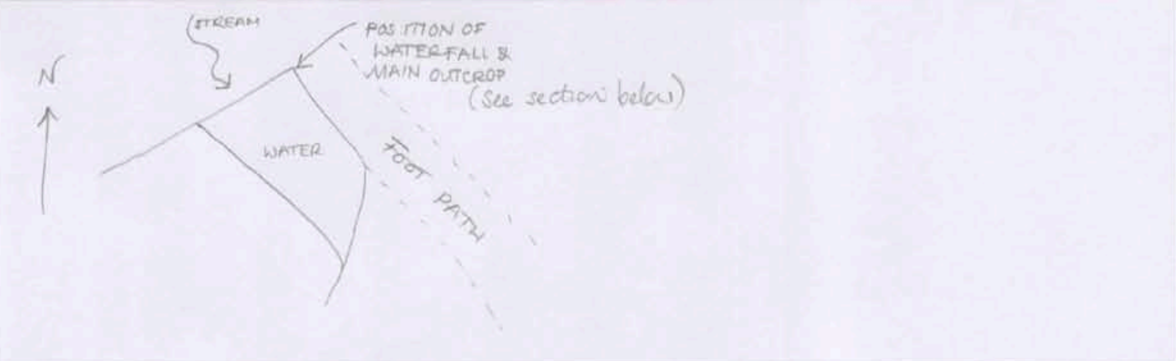
Short stream section exposing "Llanishen Conglomerate" (Lr Devonian) in a small waterfall section. Dominated by conglomerate, rarely grading to very coarse sandstones with subordinate marl layers. Section is approx 2m high.

CONGLOMERATE :- Clasts are most commonly approx 1cm in diameter but can be up to 15cm in diameter. made up of a range of lithologies: limestones, fine grained sandstones, quartzites & white quartz pebbles, mainly red or grey in colour, sub to well rounded clasts. Clasts are commonly seen to lie flat within the bed. Conglomerates are variably clast or matrix supported. Matrix is red or grey, very fine to coarse grained sandstones & silts

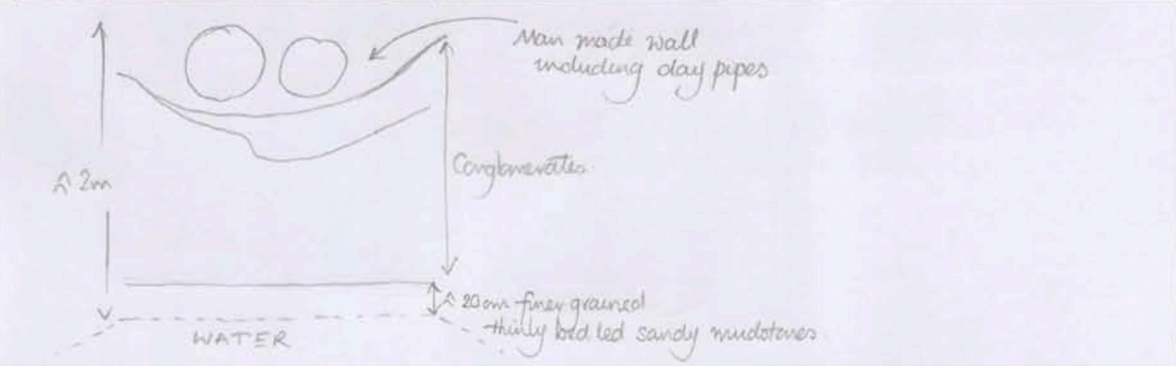
Bedding dips 24° @ 344°N

Previous visit by South Wales Geologists' Association observed exposures of marl in the track below the stream section

Site Plan
Please carefully delineate boundaries of RIGS site and annotate any location numbers or positions of features of interest (Use separate map if required)



Annotated Sketch
(as appropriate) Use separate sheet if required



Other comments: ***(Could include: known threats, thoughts on potential usage, land ownership if known or references that you found useful)***

Very easily accessible example of Llanishen Conglomerate. Would make good site for teaching & as supporting site for Llanishen Railway Station which is the type Location for this unit. Tranch-yr-Hebog has more exposure.

Photographic Record
If you have digital photographs, please insert thumbnails here or continue on next page. High resolution images can be posted on CD to the address below.

Please see attached.

Thank you for your contribution to the South Wales RIGS project. Please return this completed form to: British Geological Survey, Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE Tel: +44 (0) 2920 521962 Email: bgswales@bgs.ac.uk

South Wales RIGS Project

Site Visit Form Nant Transh yr Hebog

Locality Map

Please carefully delineate boundaries of RIGS site in red

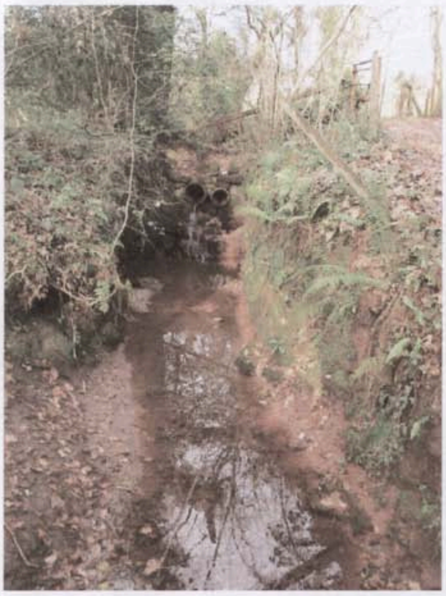


Figure 2 General View of Location

Figure 1 General view of section showing main outcrop

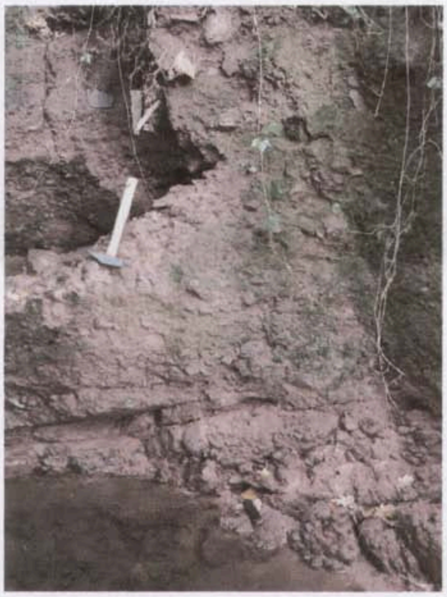


Figure 3 bedding in Llanishen conglomerate

Figure 4 Detail of fabric of Llanishen Conglomerate

Appendix 3 Map of RIGS and SINC's and South Wales Audit area

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