An introduction to the South Wales Pennant Formation: its origin, outcrop and conservation

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Abstract. In the South Wales coalfield the Pennant Formation is widely distributed and is responsible for controlling much of the landscape seen today. The typical scarp and slack features of the northern margin are complemented by central, relatively high plateau areas that are typically incised by substantial rivers and streams to form a complex network of valleys. The Pennant Formation of South Wales has been generally accepted as being composed of relatively monotonous sequences of coarse sandstone, with several thin uneconomic coal seams. This Pennant lithology is very different to that of the underlying Productive Coal Measures (Langsettian to middle Bolsovian) where the sequences are dominated by mudstones and thick coals deposited in extensive marginal swamp forests. The change was primarily due to the northerly advancing Variscan causing uplift and erosion of the landmass to the south of the South Wales Coalfield Basin. Exposures of these strata are extensive and provide the ideal setting for the establishment of a UNESCO Geopark.


Key words: Pennant Formation, South Wales, late Westphalian.

Introduction

Geological records of the Upper Carboniferous of South Wales date back to the early 16th century, but it was not until 1815, when William Smith published his first geological map of the district that research really began. During the 19th century, this research was very much coal-based, following closely on the development of the industrial revolution and progress in engineering techniques. Particular emphasis at this time was given to seam correlation and the recognition of variability in quality and rank of coal (Bassett, 1961, 1963 presents a full list of the
relevant publications). Geology, being a relatively new science, was employed to great effect to aid the production of coal and iron, which was critical to the industrialisation and socio-economic development of, not only south Wales, but the world.

Much of this information on the coalfield remained uncorrelated until Strahan, Gibson, Cantirill and Dixon began to work on the available records for the Geological Survey in the early 1900s (again, see Bassett, 1961 for a full list of these publications). This synthetic approach helped facilitate significant and what was in many ways groundbreaking scientific geological work on the coalfield. Much of the work was based on underground workings and mine records, but later studies highlighted the need for and importance of natural surface outcrop. This favourable trend towards the study of surface outcrop can be observed in some of the later memoir-revisions, such as those by Woodland and Evans (1964), Archer (1968), Barclay et al. (1988), Wilson et al. (1988) and Barclay (1989).

During the 1960s-1970s, a number of papers were published on the sedimentology of the Pennant Formation (e.g. Bluck and Kelling, 1963; Kelling, 1968, 1969, 1974). However, these focused mainly on the Rhondda Beds, and little or no consideration was given to the upper Pennant Formation. More recent research has been on the fossil floras, their diversity and implications for biostratigraphical correlation (Thomas, 1978; Cleal, 1978, 1997; Thomas and Cleal, 2001).

Topography

Over most of the coalfield there is a clear line of division, both lithological and topographical, between the soft shales of the Middle Coal Measures and the massive scarped sandstones of the overlying Pennant Formation. The Pennant Formation dominates the Coalfield landscape where their massive resistant sandstones form a regular plateau level across much of the area at between 250 and 400m above Ordnance Datum (OD, = 'sea-level') (Fig. 1). The erosion and subsequent incision of this plateau has given rise to a complex network of river valleys which roughly trend north-south.

Valley-formation across much of the coalfield has been controlled by glacial action and fault position. Glacial action has also been responsible for many of the spectacular cirques with their exposed crags and backscars which are a characteristic geomorphological feature of the coalfield (Fig. 2). Numerous landslips mark the valley-sides in the east of the coalfield, caused by the resistant sandstones over-lying soft mudstone in glacial steepened valley-sides.

Fig. 1. View looking east showing coal tips on upland plateau. The line of tips indicates the position of the Wenalt Seam (middle Westphalian D). Grid Ref. SS848999
The coalfield is surrounded by older rocks – Millstone Grit (Namurian), Carboniferous Limestone (Viséan) and Old Red Sandstone (Devonian) – but is almost free of younger rocks except for drift and river deposits in the many river valleys that cut through the coalfield itself. Only briefly on the southern margin does the Triassic overlap unconformably with the Carboniferous Coal Measures.

Structure of the South Wales Coalfield

The structure of the coalfield is complex (Owen and Weaver, 1983). The main synclinal structure with an east–west axis is interrupted by several broad subsidiary anticlines and synclines, arranged more or less en echelon, and roughly parallel to the main axis. A pronounced anticlinal system runs from Risca on the south-eastern margin of the coalfield, through Pontypridd to Swansea Bay. This structure, together with the Moel Gilau Fault at the western end, in effect divides the eastern and central coalfield into a main basin and a smaller subsidiary basin to the south. It is in the main basin that the majority of the historic coal exploitation has taken place and where details of shaft sections have been most abundant.

The western half of the coalfield has a broad and deep synclinal structure that continues westwards from the main basin of the eastern half, but here the total thickness of the Coal Measures is much greater. This increase in folding, thickness and therefore depth of burial has increased the rank of coal throughout much of the succession to anthracitic grade. The anthracite region extends from the northern marginal outcrops towards the centre of the basin where the productive seams are presumed to extend much deeper (>1000 m below OD) than elsewhere in the east. The total thickness of measures beneath the Pennant Formation, which themselves have been worked to depths of 500 m in the central part of the coalfield, may theoretically exceed 2000 m below OD.

Faulting within the coalfield can be roughly divided into three main systems. Normal faults that traverse the coalfield in a NNW-SSE direction. They usually form boundaries to mine workings, having throws of 40 m and are frequently found in pairs where they form small graben features. They generally become more frequent in the
The southern part of the coalfield is affected by another system, related to compressive stress that formed the east-west subsidiary anticlines and synclinal folding. These faults are often associated with folding and overthrusting, especially on the southern margin of the coalfield. The deformation has had only a marginal affect on the Pennant Formation with the argillaceous strata of the Middle and Lower Measures being most disturbed by these structures.

The third fault system is associated with the northeast to southwest trending Neath Disturbance, a deep-seated, sub-Devonian Caledonoid structure (Owen, 1954). The region surrounding this major fault has also been affected by significant compressional disturbance, with rocks in the region exhibiting overthrusting and lag-faulting. The effect of this has been to increase the difficulty of systematic mining of the seams in the area, while it has also played a part in increasing coal-rank in the marginal formations to anthracitic grade.

Commercial exploitation of coals

Many coals are found within the Pennant Formation and, because of their many valley side exposures, were among the first to be worked in South Wales by the Romans. Subsequently their exploitation increased but, until early deep mining techniques evolved, the Pennant coals, especially those of the Rhondda Members, were particularly important. These coals were easily worked by drift-mining techniques, which required little engineering skill since the massive sandstone roofs were frequently self-supporting. Although over 40 coals are recognised throughout the Pennant succession, they only account for about 5.7% of the total volume of extracted coal. The coals themselves are sub-anthracitic grade and the upper Pennant seams, especially in the east, have the lowest rank and are therefore the most useful for palynological analysis.

The complex and inconsistent seam-nomenclature in South Wales has for a long time been a serious stumbling block in its research and investigation; even for the principal seams, a completely different suite of names is used in the central, eastern and western regions. There are many local variants, and it is not uncommon to find the same suite of seam-names used in adjacent districts for quite different sequences of seams. An early attempt to provide some form of seam correlation, in terms of a table of synonyms was made by Jordan (1910) and, while useful in the early years of geological understanding, was superseded by BGS in 1950 which tried to correlate nomenclature for the central region (Adams, 1967).

Lithostratigraphical divisions

Buckland and Conybeare (1824) first recognised the variability of the South Wales Coalfield lithology and proposed that the sequence be divided into three: the Lower Coal-shale, the Pennant Grit and Upper Coal-shale. De la Beche (1846) accepted this division and used it in his first coalfield memoir and in the many subsequent editions. Moore (1948) later proposed the division of the Pennant ‘Series’ of the eastern district of the coalfield into Lower, Middle and Upper units.

In the late 1950s, the Geological Survey fundamentally revised the classification of these rocks, with the introduction of a unit known as the Pennant Measures (Woodland et al., 1957). This was defined as being equivalent to the Upper Coal Measures that had been introduced in the other British Coalfields (Stubblefield and Trotter, 1957) but recognised its distinctive fluvial arenaceous facies. They subdivided their Pennant Measures into a series of ‘Beds’ or members, separated at major, coalfield-wide coal seams, and this subdivision is still generally recognised. However, some question has been raised as to the lithostratigraphical credentials of the Pennant Measures as a whole. The base was defined at the more or less isochronous Upper Cwm Gorse (or Top Maine Band irrespective of lithology, which thus makes the Pennant Measures more of a chronostatigraphical unit than a strictly lithostratigraphical one. Cleal and Thomas (1996), therefore, proposed a reversion to a more lithostratigraphical approach, and defined the base of the (South Wales) Pennant Formation as being at the base of the first prominent sandstone unit above the Upper Cwm Gorse Marine Band. In some parts of the coalfield, there is relative little difference in the positioning of the base of this Pennant Formation and of Woodland et al.'s Pennant Measures. In the eastern part of the coalfield, however, the difference is more significant as the Pennant lithology does not appear until some distance above the Upper Cwm Gorse Marine Band.

This change in definition also affects the upper part of the succession. In the scheme of Woodland et al. (1957), all of the beds above the Upper Cwm Gorse Marine Band belong to the Pennant Measures irrespective of lithology. In many parts of the coalfield this is not a problem. However, in the Swansea area, the youngest part of the succession is in a very different, argillaceous facies, which is difficult to reconcile with the Pennant
Formation if defined strictly lithostratigraphically. Buckland and Conybeare (1824) had recognised this fact and referred to this interval as the 'Upper Coal-Shale'. This name could potentially be confused with the quite different Upper Coal Measures of Stubblefield and Trotter (1957), and so Cleal and Thomas (1996) proposed the alternative name, the Grovesend Formation.

Sedimentological summary

The main Pennant Formation successions were deposited as a response to increased Variscan earth movements in the middle and late Westphalian. At this time, sediment supply within the basin switched from the north, to become dominated by coarse sandstones from the south and south-west (a typical outcrops of such sandstone is shown in Fig. 3). This sandstone sediment was generated by the rapidly rising, northwards advancing Variscan landmass that was being rapidly eroded. Previous work suggested that this uplift and subsequent erosion reworked Devonian Old Red Sandstone since both the Pennant and the ORS share similar mineralogy. The sediment itself is predominantly a feldspathic, micaceous grit with immature grain shapes. The Pennant is generally a blue/grey colour when fresh, weathering to a rusty brown/green, sometimes referred to in the literature as khaki.

The Pennant Formation frequently includes reworked coals, plant material, ironstones, and conglomeritic quartz pebbles. Lag deposits are common, as are log jams and coal rafts. The sediments were transported quickly, over relatively short distances from their eroding hinterland source to their deposition environment – a rapidly subsiding foreland basin. Sediment architecture suggests that the massive sandstone units were probably deposited in large braided, low sinuosity streams and rivers. Cross-bedded sandstones abound (e.g. Fig. 4) and are found to display a degree of cyclicity, many having conglomeritic erosive bases, fining upwards through trough and ripple cross-bedding to silty sandstones and thin
mudstones, which are thought to represent interdistributary lake and over bank deposits.

While in most of the coalfield the Pennant Formation sandstones are the stratigraphically highest deposits, just north of Swansea they are overlain by a widespread interval of argillaceous sediments and red bed conditions of mainly northeasterly derivation, known as the Gravesend Formation. Because of their softer lithology, these beds are not as easily observed in the field as the Pennant Formation. In contrast, in the east of the coalfield the deposits of equivalent age to the Gravesend Formation are sandy and more typical of the true Pennant succession. At this time it is unclear why there is this variation in sedimentation in different parts of the coalfield. It may reflect differences in sediment-source, in which case mineralogical investigation should shed some light on its origin. Alternatively, complex basin dynamics may have created localised differences in the sedimentary environments at this time. It has also been suggested that an unconformity may exist in these eastern formations, and that the lack of argillaceous material and the general thinning of these eastern measures may be attributed to such a feature. No firm evidence for this unconformity has been found in field exposures of the appropriate age, although important exposures of the appropriate age have been recently been identified. Further sedimentological and mineralogical research is clearly needed in order to interpret the detailed history of this part of the basin.

Further details on the sedimentology of these beds can be found in Bluck and Kelling (1963) and Kelling (1968, 1969, 1974).

Palaeobotanical record

There has been detailed work on the palaeobotany of the Pennant Formation, initially by Davies (1929) and Dix (1934), and subsequently by Thomas (1978), Cleal (1978, 1997), and Thomas and Cleal (2001). This evidence is mainly from the mudstones and siltstones found between the massive bodies of sandstones. Much evidence of plant material can be found in the sandstones themselves, however, it usually consists of undifferentiated log-jam material or occasional casts of trunks, sometimes found in situ. Occasionally smaller fossils are found, however, the coarse nature of the sediment detracts from the quality of preservation. On the other hand, there are occasions when anatomical preservation occurs in plant material within the sandstones (e.g. Crookall, 1931).

The preservation within the mudstones of the Pennant and the Gravesend formations is generally very good with many specimens exhibiting...
exceptional detail. However, the number and extent of good collecting localities is limited, since the mudstones members only comprise a small portion of the Pennant thickness. In addition, the soft fissile nature of these argillaceous intervals causes them quickly to become heavily weathered or vegetated. Consequently, much of our knowledge of the palaeobotany of these deposits is derived from material obtained from underground coal workings.

Over most of the coalfield, the rank of coalification is too high for maceration work to allow the study cuticles or in situ spores/pollen. However, in the eastern part it is somewhat lower and it is possible to obtain in situ spores (Thomas, 1978) and potentially cuticles.

Geoconservation

These exposures represent an internationally important geological resource, as they are one of the few places in Europe where extensive outcrops of rocks of this age can be seen, and the only place where they occur in this particular facies. Conserving these sites is therefore important for the scientific community, especially those participating in IGCP 469. To this end, for the past two years, the Countryside Council for Wales (CCW) and the National Museums and Galleries of Wales (NMGW) have together been investigating the extent and quality of Pennant Formation exposure in South Wales. The primary aims and objectives of the work are as follows.

1. To identify the critical sites for showing the geology of these deposits. Published information on the exposed sites (as opposed to underground and temporary surface workings) showing the Pennant Formation is very limited. Initially, therefore, there had to be extensive map-based investigations (both geological and topographical maps) to try to identify potential sites of importance, followed-up by ground-truthing to confirm what can actually be seen there. Over 300 localities were investigated in this way.

2. To determine those sites which most merit conservation. It would clearly be impractical to conserve all of the sites identified, and so it was important to identify those of greatest scientific importance. None of the sites can be regarded as 'unique' in any meaningful sense, and even determining the 'best' sites is difficult in view of the large number of exposures available. The main criterion used was therefore determining those sites which are most 'representative' for showing the geology of the Pennant Formation. Factors taken into account were how typical the site really is (oddities were normally excluded, except where there is some specific scientific reason for including them); the extent and thickness of the exposed stratigraphy; the quality of the exposure (for instance, does weathering hinder what should be visible); the presence of associated coals and fossil material; and the locality continuity (sites that occur in groups or within a reasonably local area are more likely to be selected because of their feature associations and lack of potential spatial variability). As a result, 11 sites have been recognised as being of critical scientific importance for showing the Pennant Formation, and should be conserved.

3. To prepare detailed descriptions and stratigraphical logs for the critical sites. There is little published geological information on these sites and so much of the documentation necessary to understand their scientific importance had to be done from scratch. Palaeontological samples were also taken (including palynological samples being investigated by Prof. Ken Higgs, University College Cork, Ireland).

4. Where necessary, to develop plans to 'clean' the sites. In some cases, the sites will have to be excavated ('cleaned') in order for the geology to be fully visible.

5. To develop management plans for the sites. It is intended that the critical sites will be designated by CCW as Sites of Special Scientific Interest (SSSIs) and thus given statutory protection. To help with this, preliminary management plans have been established for each site, identifying what needs to be done to maintain their long-term survival.

6. To identify portions of missing stratigraphy and to assess remedial works required to create exposed sections to fill-in the gaps. Unfortunately the known (from borehole and mine records) sequence of the Pennant Formation is not fully exposed in the field. Many of the old localities have subsequently been lost – frequently hidden by dense forestry or redeveloped beyond all recognition – and several parts of the succession simply were never extensively exposed in natural or man-made outcrop. Without remedial intervention, exposure of many of these parts of the succession will ever be seen again. A plan was therefore developed for excavating new sites to fill-in these gaps in the available exposed stratigraphy.

The 11 important sites identified in this project are spread throughout the coalfield and truly demonstrate the diversity and extent of the upper Westphalian of South Wales. They offer the amateur and professional geologist a unique opportunity.
to study a considerable thickness the Westphalian succession amongst a beautiful, geologically controlled landscape containing an array of exceptional outcrops. The sites are highly variable and comprise natural stream sections, disused quarries, road and railway cuttings as well as old colliery sites and coal tips. Each site is exceptional and represents an important portion of the Pennant stratigraphy. The detailed stratigraphical section constructed from the numerous localities can be drawn together to comprise a composite record of the upper Bolsovian and Westphalian D in South Wales.

South Wales Coalfield Geopark

In 1996, the European Association for Conservation of the Geological Heritage (ProGEO) proposed that special ‘Geosphere’ reserves should be established. UNESCO have developed this proposal and the resulting reserves have become known as Geoparks. A Geopark has the dual function of enhancing the scientific value of the sites that it encompasses, whilst creating employment and promoting regional economic development within the area.

The Countryside Council for Wales and the National Museums and Galleries of Wales are working together to formulate a strategy for the development and interpretation of a South Wales Coalfield Geopark. The Pennant Formation and the underlying Productive Coal Formation (Evans et al., 2003) are the best exposed Carboniferous terrestrial rocks anywhere in Europe, possibly in the world. They tell the story of one of the critical times in the geological evolution of Europe (the Variscan Orogeny) and one which also has important resonances for today (the role of tropical forests in controlling greenhouse gases and climate). Furthermore, the geology has had a profound impact on the evolution of the spectacular scenery here, as well as being fundamental to the cultural and economic development of the area. This close relationship between exceptional geology and the historical development of an area, and the use of this scientific resource as means of helping renew economic and cultural activity there in a sustainable way, makes this an ideal area for the development of a Geopark.

The planned South Wales Coalfield Geopark will include an area sweeping across the northern rim of the Coalfield, from Blaenavon in the east to Grovesend in the west. It will cover the Upper Carboniferous strata (Namurian and Westphalian Series) and the landscapes that have formed there, and will tell the story of changing environments and the impact that this had on global climate change. It will also link in with the industrial archaeology of the Coalfield, and will try to show how the geology has influenced the social and cultural development of the area.

The park will be based around some of the exceptional geological sites found in the South Wales Coalfield, including the Pennant Formation sites mentioned earlier in this paper. Conservation of the sites in collaboration with CCW will be a key part of the programme, so as to ensure that they will remain available for future research, education and tourism. There will be innovative interpretation schemes for the sites and for the Coalfield as a whole, in a variety of media and formats specific to audience and locality. Links will be established with existing heritage centres in the area, such as the mining museum at Blaenavon (‘Big Pit’), as well as with local communities in the vicinity of the sites to try to instil a sense of ‘ownership’ of the geological heritage in their neighbourhood. Site and landscape interpretation will also be used to educate and raise awareness of geoconservation, geodiversity, and the role of geoparks in the wider conservation of our shared geological heritage.

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