The mortar particle size distribution of a Welsh vernacular farmworkers cottage in the parish of Llandeilo Tal y Bont.

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The Welsh School of Architecture, Cardiff University
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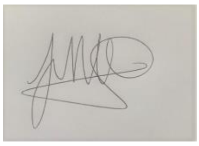
Signed  (Joe Moriarty) Date: 17/02/2020

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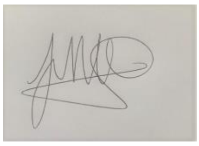
Signed  (Joe Moriarty) Date: 17/02/2020

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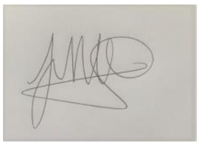
Signed  (Joe Moriarty) Date: 17/02/2020

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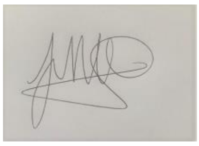
Signed  (Joe Moriarty) Date: 17/02/2020

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Abstract.

The mortar particle size distribution of a Welsh vernacular farmworkers cottage in the parish of Llandeilo Tal y Bont.

Although mortars have utilized earth, both as an aggregate and a binder for thousands of years, little is understood as to how vernacular earth mortars are dependant on the types of soils that are found locally to the place in which that mortar is to be used.

The goal of this study was to firstly build a picture of the historical, geographical and physical elements that would have affected the materials used to create the mortar and then from onsite samples, look for correlation between these samples in order to make evidence based decisions to the suggestion of a suitable repair mortar.

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1 Introduction.

The aim of this paper is to use a combination of qualitative and quantitive data to build a picture of the type of mortar that was used in the construction of an early 19thC vernacular farmworkers cottage in the ancient parish of Llandeilo Tal y Bont.

Using archive material and modern data sets, as well as samples taken from site, I intend to be able to, by the end of the piece of work make suggestions for the selecting and sourcing of materials that would be suitable for the formulation and production of a repair mortar.

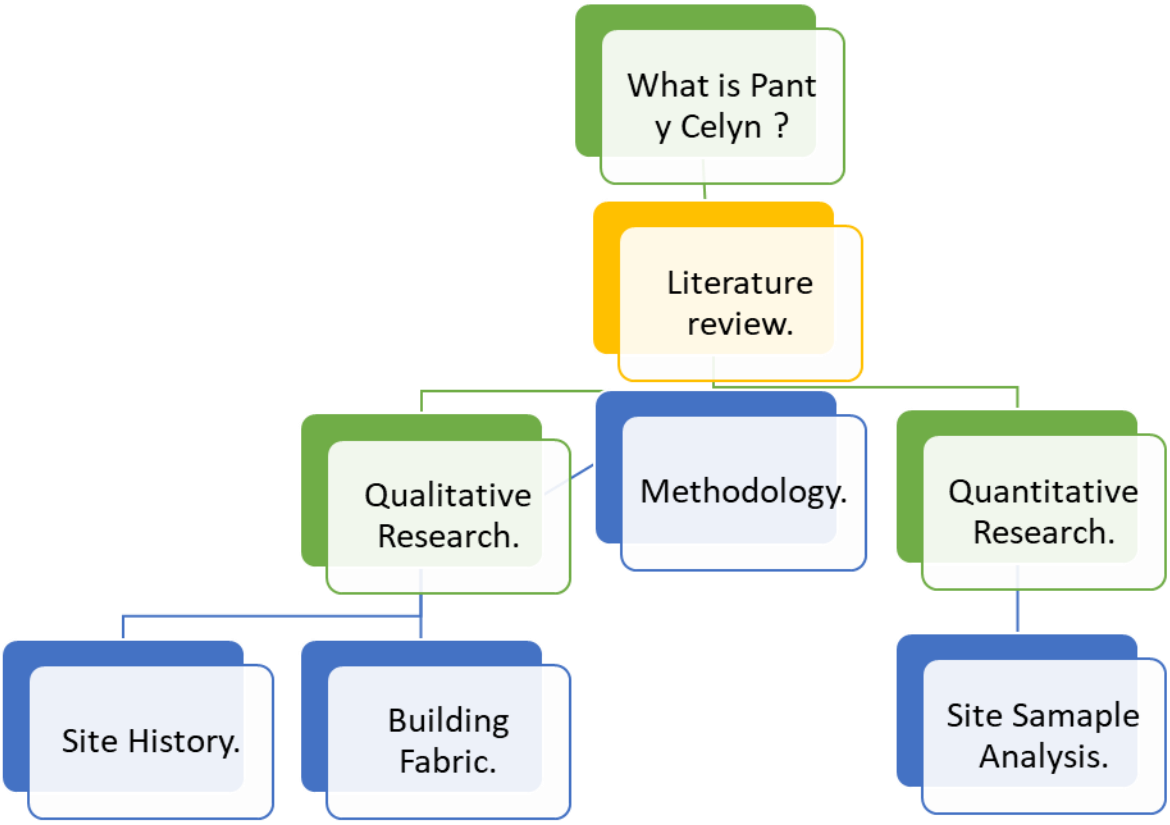
By gaining an understanding of local history, the natural materials found locally that have been utilized by local craftsmen or vernacular builders in the construction of traditional buildings will, I hope start to build a picture of what Pant Y Celyn once may have looked like, its building fabric and more importantly for this work, the materials that went into the mortar used in its construction.

Throughout the paper, I intend to use a wide range of sources that will help me understand the history, processes and breakthroughs that are associated with traditional mortars, there evolution and the current thinking in how these mortars have been used and should be used in the future.

Using this information, along with data obtained from onsite samples, I hope to be able to ascertain where the materials that went into making the mortar came from, the properties of those materials and the effect the quantities and quality of those material may have had on the mortar.

On completion of this work I hope to be able to provide a possible guide or reference as to how to select, formulate and produce a suitable repair mortar made from locally sourced materials that have been used in many of the traditional buildings in South Wales.

Although this study is very much focused on the area in and around the Parish of Llandeilo Tal y Bont, I hope that by using the methodology that this paper follows any persons anywhere in the world that has access to the relevant data could use this as a guide in selecting of materials for the repair and maintenance of other vernacular buildings.



2 Literature review.

As a traditional builder, often I am asked to re build or carry out repairs of masonry structures that are in many cases hundreds of years old, in my experience, the original mortars used in the construction of these buildings and walls bear little to no resemblance to the mortars often specified to carry out these works.

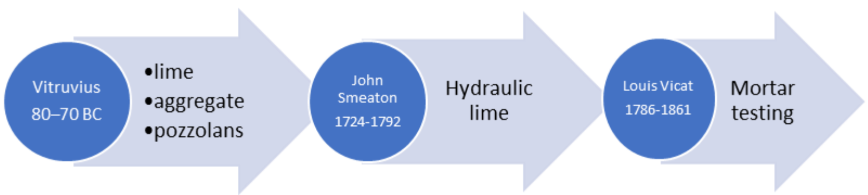
Over the last two hundred years or so the materials used to produce mortars in the conservation and maintenance of traditional buildings have gone through significant change.

The aim of this literature review is to highlight and critically analyse the works that I consider to be key to understanding and evaluating the mortar used in the construction of Pant y Celyn, how the mortar was produced and how it was intended to function.

Over the last two thousand years many books, articles and academic papers have been written on the subject of lime mortars and from my research it has become apparent that what was relevant to early writers and academics almost two thousand years ago and over the last three hundred years is as relevant today as it was then, with many of the writings since using and citing philosophy and methods set out in these texts.

It could be concluded that early texts and research conducted relatively recently are more important to today's builders and conservation practitioners than it was to their forebearers as over the last one hundred years much of the knowledge gained over two thousand years of experimentation and trial and error has been lost due to factors such as the large scale loss of life during two world wars and by the adoption of relatively modern cementitious binders in the production of mortars.

With the subject material (Earth/Lime Mortars) being in use for thousands of years I have created a timeline of what I consider to be the literature and scientific breakthroughs that have been seminal and influential in the field of lime mortar production and has gone on to influence current thinking on the subject.



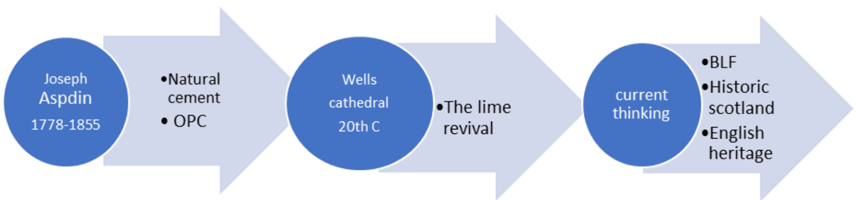


Figure 1 Literature review timeline.

Vitruvius. Ten Books on Architecture.

Marcus Vitruvius Pollio, most commonly know as Vitruvius could be seen as the most influential writer on the subject of lime mortars over the last two thousand years.

His “Ten Books on Architecture” have influenced builders, architects, planners and academics all over the world, by providing written accounts of the way in which the Roman Empire went about the planning and construction of fortifications, towns, individual buildings and walls.

For the purpose of this paper the most influential of theses ten books has been “Book II”.

Chapter one (Book II) describes the evolution of buildings and highlights that essentially this evolution was driven by the simple need of shelter from the elements of weather, providing a place that was warm and dry for its inhabitants.

Vitruvius discusses the needs of early builders to be able to adapt the style in which they constructed shelter to the types of materials that could be easily found in the location in which they lived.

This need to construct shelter from materials that can be found abundantly and close to the vicinity of that in which the building is to be situated changed little in the two thousand years since these books were written, it is only in the last two hundred years since the industrial revolution with the development of efficient and relatively speedy modes of transport with networks that stretch the length and breadth of many countries in the industrialised world which encouraged the standardisation of construction materials and the use of building materials that are sourced and manufactured in many instances great distances away from there intended place of use.

In the following chapters Vitruvius describes the materials that were being used in his time and how they can be sourced, selected and utilised for use in construction.

I feel the chapters most integral to this piece of work are the chapters on **Sand, Lime and Pozzolana** where Vitruvius sets out his opinions and gives descriptions of these materials and as to which types of these materials work best in a given scenario.

As a builder I found the use of such descriptive text most useful as I can relate to and find relevance in these descriptions, for example Vitruvius gives discerption of the type of sound he believes an aggregate should make, making reference to how it should “Crackle” when rubbed between fingers which as someone who has used many types of aggregates can Identify as the sound produced by an aggregate that is course in nature.

Vitruvius recognises how different sources of aggregate will have an impact as to how mortars and plasters set and function and is very aware of the results of using materials that contain salts, which even today as I write this, still is something that is of relevance for todays architects and builders, with the evidence of efflorescence caused by salts contained in much of the building sand that is readily available being a common sight.

When discussing the use of lime, anyone who is familiar with the process of first burning then slaking limestone for the use in mortar would very easily recognise the process in which he describes the way in which limestone is transformed by burning it in a kiln, then using this material as an additive to aggregates to form a workable mortar that has varying degrees of set or hardening over a period of time.

Although Vitruvius was not aware of the actual chemical change the process involved that altered the properties of limestone by heating, he was able to describe how the process drives out water from the limestone and how this material then easily blends with aggregates and though the process of carbonation, returns to a stone like material.

In my opinion the way that Vitruvius describes the use of Pozzolans to develop mortars that had the ability to set harder, faster and in some cases even under water is the single biggest contribution in the history of lime mortar production.

Without this information and his observations, many of the advances in mortar science, production and works written since, like those of John Smeaton, Loui Vicat would in all certainty have been more difficult and taken longer to achieve.

In my opinion, any persons who had the ability to read the text written by Vitruvius over the course of the last two thousand years, could with minimal knowledge or experience, use this descriptive text as a guide in the production of lime-based mortars.[1]

John Smeaton.

John Smeaton was born in 1724 near Leeds, in 1742 he moved to London and began work as a dealer in measuring instruments, he was an avid fan of engineering and joined the Royal Society and increased his knowledge of engineering and particularly enjoyed subjects that required the careful measurement and observation as one may expect from someone how was a dealer in measuring instruments.

In 1756 Smeaton was given the task of re-constructing the Eddystone Lighthouse, having been give this task Smeaton set about comparing the different limestones of the United Kingdom to ascertain which of the limestone that could be found would be most suitable for construction, bearing in mind the violent conditions that the lighthouse would experience in the English Channel.

Form his experiments he was able to conclude that the best types of limestone to use in the pursuit of a mortar that will set underwater, all had larger proportions of silica or clays and had little to do with the hardness of the stone, which had been alluded to in writings that came before it by the likes of Vitruvius and Richard Neve.

After many experiments conducted with various types of limestone with proportions of clay, he decided upon Aberthaw limestone with the addition of pozzolan for his mortar, this mortar was found to have an excellent hydraulic set when mixed at a ratio of one measure of sand to one Aberthaw lime and one pozzolan.

These experiments carried out by Smeaton changed the way in which construction of buildings that require a hydraulic set were built and have gone on to be the precursor for

[1] Vitruvius, M. (1914). Book Two. In: Morris Hicky Morgan *The Ten Books on Architecture.* New York: Dover Publications. P 38-48.

the many different types of “cements” and “hydraulic lime” that followed over the next one hundred years or so.[2]

L J Vicat. Mortars and Cements

During the 19th C the French engineer Louis J Vicat studied the properties of hydraulic limes and materials classed as “natural cements” these cements were manufactured using limestone that contained impurity’s greater than 25%.

As will be discussed over the course of the piece of work the hydraulicity of a binder is highly variable, following on from the works conducted by Smeaton, the French engineer Louis Vicat developed tests to develop the Hydraulicity index, using the data developed by the likes of Smeaton, Vicat built upon the discovery that the degree of hydraulic set that a mortar will achieve will be dependent on the amount of silica and alumina present in the limestone used.

Vicat described limes with the ability to set under water as “Hydraulic” but under this heading he separated them into three subcategory’s, limes that were **slightly hydraulic, hydraulic lime** and **eminently hydraulic** limes, these terms are still in use today but are often misunderstood where by the modern equivalents are classed using the same terminology.

Vicat based these categories on the behaviour of limes by noting the time and vigour in which they slaked, the ability of the mortar to set under water and the consistency of the mortar after one year.[3]

The importance of having a well graded aggregate is also something that was studied by Vicat and tests he carried out using four different aggregates consisting of different matrixes of particle size and shape showed the relation between the content of fines and

[2] Pasley, CW (1838). *Observations on lime*. London: John Weale. P 3-9. & English Heritage. (2011). Materials & History of Use. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p 11-16.

[3] English Heritage. (2011). Materials & History of Use. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. P 36-47.

the amount of shrinkage that would occur in a mortar, these tests also related the type of aggregate to the overall strength a mortar may achieve. [4]

Today much of the basic understanding regarding compressive strength in relation to aggregates can be traced back to tests carried out over one hundred years ago.

Joseph Aspdin.

In 1824 Joseph Aspdin patented wat is now considered to be the first type of Portland cement, named after its supposed resemblance of Portland stone and was described as being an artificial stone. Up until this time the materials used for construction in places that required mortars that had an ability to set in very wet conditions where termed has being a hydraulic lime or a natural cement, natural cements were obtained by burning limestone that naturally contained high quantity's of clay minerals, as apposed to artificial cements that were made from a blend of limestone and clay.

Advancement in kiln technology, enabling kilns to reach higher temperatures was major factor it the availability of natural and artificial cements.

Artificial cements required higher temperatures exceeding that of those needed for traditional lime production, it was the burning at a higher temperature that formed complex calcium silicates and aluminates that included tricalcium silicate which when cooled was ground to a powder, this material had a very rapid set and to retard that set and allow longer workability gypsum was added

Projects such as the new drainage system in London and the Thames tunnel that both required a mortar that had a high degree of hydraulicity were major driving factors in the way that artificial cements were used and advocated.

[4] Vicat, L J. (1837). On the Theory of. In: Donhead Publishing *Mortars and cements*. London: John Weale. p 128-132.

The use of mortars that had such high bonding strengths, often exceeding that of the materials it was to be used with was even questioned this early point in its use, which at present time seems to have been with some degree of foresight.[5]

For over a thousand years buildings where constructed using mortars that were many times softer and with very little hydraulic set in comparison with the mortars that were developed just prior to the industrial revolution and in the years after.

The adoption of these new materials continued in to the twentieth century, and during that time much of the knowledge of more traditional mortar production and use was lost, Ordinary Portland Cement became the go to material for most construction projects, especially after the second world war when the need for large scale re building of many of the towns and cities across the British Isles drove the requirement of mortars with a speedy, strong and hydraulic set.

In many cases this adoption of what we call cement was not necessarily a problem when used in modern construction methods, its when this material started to be used instead of more traditional mortars for the repair and maintenance of traditional solid wall or timber framed buildings that it became problematic, these cementitious mortars and plasters causing moisture to be trapped in building walls and timbers which accelerated decay of parts of the building it was supposed to protect.

<u>The Lime Revival.</u>

During the period between 1974 and 1986 major repair and conservation works carried on stone sculptures at Wells Cathedral became a turning point in the way conservators and crafts people used lime.

The exterior was cleaned using what was to be called the lime method, developed by Robert baker who was the Professor of Ceramics at the Royal College of Arts, this method involved

[5] English Heritage. (2011). Materials & History of Use. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. P 18-46.

the use of non hydraulic lime putty mortars that were occasionally mixed with a pozzolan of fired clay materials called HTI.

The work carried out by Baker and his team was for the most part trial and error, with much of the knowledge of nonhydraulic limes and pozzolans lost in just over one hundred years of OPC being adopted as the main binder in the production of mortars.

This trial and error method consisted of the reading of selected historical texts, the observations of the small number of practitioners still versed in the use of lime and experience gained from the use of lime in Europe.

Through trial and error in an effort to accelerate and improve the hydraulicity of nonhydraulic lime putties, occasionally small quantities of cement were added which after testing carried out by English Heritage in the 1990's proved to have the opposite effect of which it was intended, due to the addition of cement hindered the carbonation of these materials.

These discoveries started to influence a change of thought in the way in which lime was to be used in the next twenty – thirty years and encouraged the use of Hydraulic lime which was still in use in continental Europe.

Although these materials were in some cases better than the use of hard, impermeable cements, it has been concluded by conservationists and users of lime mortars that in many cases the use of modern Natural Hydraulic Limes in all probability had not been achieving the desired level of flexibility and breathability that they were thought to achieve.

Studies carried out by English Heritage in the form of the Smeaton Project, by historic Environment Scotland in their Technical Advice Notes and by the Building Limes Forum in many articles published in their Journals have gone one to change the way we look at modern hydraulic limes.

This train of thought has gone one to be a driving factor behind what could be described as the second lime revival, with many conservators and trades people looking at the use of more traditional “Hot Mixed” lime mortars and plasters with the addition of pozzolans where needed.[6]

Current Thinking.

With current thinking regarding the probable over use of modern hydraulic limes or NHL’s the conservation industry is at what could be seen as a crossroads in the way we use lime for the production of mortars and plasters.

During the summer of 2019, the Building Limes Forum, in conjunction with English Heritage and Historic Environment Scotland hosted the Traditional Mortars Symposium in York, over the course of the three day event a number of current case studies and programs of research were discussed covering topics such as revising guidance for like for like repair, using “Hot Mixes” in Scotland and the functional performance of traditional lime mortars.

During these talks much was discussed regarding the properties, function and performance of traditional mortars in Scotland and England but there was no representation from a Welsh conservation perspective.

With much advice and guidance from Historic Environment Scotland and English Heritage, there seems to be a lack of research coming from the Welsh equivalent of these two bodies, CADW.

At the moment there is a risk of not fully understanding traditional mortars, their properties and how they function in Wales that may result in the case of “What works for them should work for us” mentality.

I believe unless this lack of understanding is addressed, the risk of failure with regards the use of “Hot mix mortars in Wales will be high.

[6] English Heritage. (2011). Materials & History of Use. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p 24-26. & Henry, A. (2018). Hot mixed Mortars: the new lime revival. *Context*. 154 (1), P 30-33.

Another major factor in how we will go forward using materials associated with more traditional mortars is the lack of a British standard regarding the use of materials such as earth and Quicklime.

Without such standards the ability to of materials such as earth and quicklime will struggle to become mainstream.

2.1 What is Pantycelyn?

Pant y Celyn is at present time is a small derelict ruin of a vernacular farmers cottage in a field that is part of Castell Ddu Farm, in the town of Pontarddulias, in Swansea, South Wales. During the summer months it would be easy to miss as it has succumbed to its unforgiving costal location and the irrefutable forces of nature have laid claim to its aging and exposed building fabric.

Figure 2 Pantycelyn. image Joe Moriarty.

The building itself is of a coursed rubble stone and quarried Sandstone construction with what from inspection seems to be an earth lime mortar.

Figure 3 Pant y Celin Building Fabric. Image Joe Moriarty.

As can be seen from the image in figure two, the building that once stood at this site has now almost been completely enveloped by ivy, trees and grasses, and in its present state it is very difficult to ascertain precisely what it once may have looked like.

To gain a better perspective as to how this building once looked, its building fabric and its purpose, I feel it is important to look at the key factors that may have influenced the design and function of this building and other vernacular buildings on the Gower.

2.2 A brief introduction to vernacular buildings of the Gower.

As like many other vernacular buildings in Wales, these buildings were often built by the people that lived in them, from materials that could be easily found and transported in the vicinity of those buildings.

It was often the case that these builders did not own the land that they worked and lived on but were tenants of larger estates owned usually by wealthy landowners.

The tenancy of land would often be spread over generations with the lease being transferred to sons and even the grandsons of the original tenant.

With this in mind, it would be fair to assume that during the course of these tenancies, many alterations and improvements may have been carried out at different times by the tenants and how vernacular buildings may have evolved over the years to fit the needs of those tenants.

At the start of the eighteenth century, the primary employment in and around the Gower was farming and the quarrying of Limestone and Sandstone, these roles were often seasonal, with tenant farmers working the land from Spring through to Autumn, then gaining employment in quarries through the winter, the Limestone was often quarried on the cliffs of the Gower Peninsular and was a vital material used in both construction and agriculture, it was then loaded on to boats and shipped around the Welsh coastline.[7]

As farm labourers and other working poor at the time often had learned skills passed down through generations usually from father to son in the construction of walls to create field boundaries and other agricultural buildings, theses farmers and quarrymen were also architects and builders with craft skills that today would be attributes of a trades person who specializes in their chosen field, with knowledge of masonry, woodworking and the sourcing and selection of building materials.

As vernacular buildings are in many cases, constructed from materials that could be scavenged from the land local to the builder, it can be concluded that the local materials available would have an impact on how those buildings looked and functioned, with the types of stones and earth used being of colours that fit in their surroundings.

On Gower and the surrounding areas around the peninsular, stone was the predominant building material available to build walls at the begging of the nineteenth century.

Timber on the Gower would have been in short supply as the area is of a hilly, open grassland nature with few forests on common land to harvest timber. In many cases timber that had been washed ashore from shipwrecks along the Gower coastline would have been regarded as precious salvage and incorporated into local buildings.

On Gower and surrounding areas, locally available stone tends to be one of three types, soft reddish-brown Sandstone, grey/blue Carboniferous Limestone and harder quartz Conglomerate sandstones. while much of this stone was quarried locally, in many instances it was common for farm workers to harvest stone from the fields in which they worked.

From looking at other vernacular buildings and ruins on the Gower it is possible to identify other small traditional buildings that could give a clue as to the appearance of Pant y Celyn as at the time many small vernacular homes followed a standard format.

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[7] The Gower Society. (2003). Vernacular Gower… In: *Vernacular Gower*. Carmarthenshire: Dinefwr Press. p7-9. Iorwerth C. Peat (1940). *The Welsh House A Study in Folk Culture*. Felinfach: Llanerch Publishers. P 10 - 31.

Most buildings were small in stature, with low A frame style roofs covered by straw thatch or stone tile often with bedrooms formed within the roof space with a chimney at either end of the building. Windows would have been small to reduce costs and in probability owing to the fact that in hours of daylight, the people who built and lived in these buildings would have been engaged in their work with little need for their buildings to take advantage of daylight.

With measurements taken from the site at Pant y Celyn, it is reasonable to assume that since a majority of small vernacular builds in the area followed a standard form, being able to identify a similar building on the Gower that is approximately of the same size, shape and with similar materials used in its construction will be of use.

2.2.1 Vile cottage Llangennith.

Figure 4 Vile cottage, Image Old Gower Farmhouses.

Vile Cottage is a six meter by four-meter vernacular ruin just outside the village of Llangennith on the westerly tip of the Gower peninsular

As is seen in figure 4, Vile cottage is in a similar precarious state as Pant y Celyn, with its roof and first floor timber work completely disappeared and with only a single Gable remaining, as with Pant Y Celyn, the front and rear walls are now spread over the floor, over grown by vegetation and with much stone “borrowed” for other uses.

Although the measurements of Vile Cottage are smaller than those of Pant y Celyn, with the front elevation being six meters to Pant y Celyn's four eight the dimensions are quite similar, I am of the opinion that these two buildings would have looked remarkably the same, due to the materials used to build both properties and the standard building form of the time.

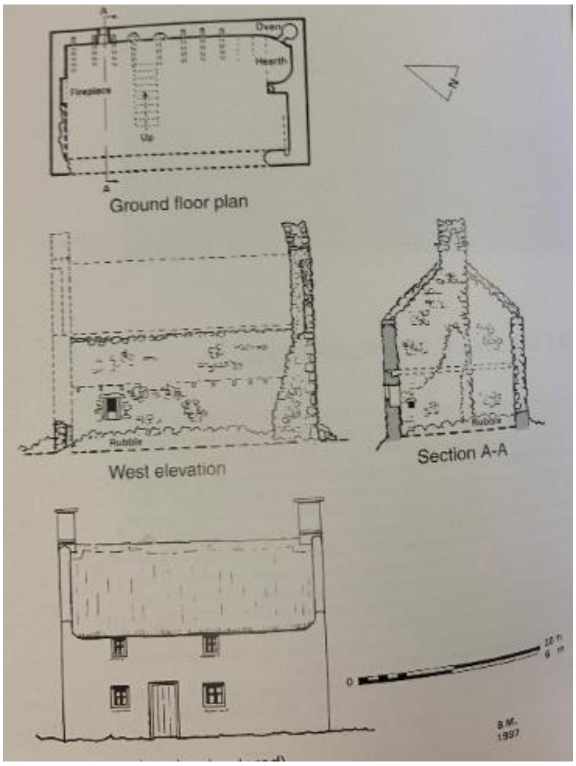

Figure 5 Vile Cottage, image Old Gower Farmhouses.

The image in figure five shows an impression of how Vile cottage may have once looked, with small windows, thatch roof and chimneys on each gable, with one end of the building accommodating the cooking space with bread oven, hence the longer distance from window opening to the corner of the building.

Pant y Calin also has chimneys at either gable but at the present time are obscured by ivy.

Figure 6 Pant y Celyn. Joe moriarty

I believe the following factors to be significant in understanding and giving context to Pant y Celyn, its building fabric and function but more importantly for this paper, factors that will have influenced the type of materials used in the preparation of mortar at the site.

3 Influencing factors

Over the last six years I have been fortunate to have played a part in the renovation, restoration and conversion of many types of traditional vernacular buildings in the South of Wales and Southern England, with no two buildings being the same in their construction, each with subtle differences that have been influenced by external factors.

When assessing the factors to be considered for the replacement or repair of traditional building fabric such as masonry or mortars I believe the following points to crucial as inevitably they will play apart in how the building was designed and how it was intended to function.

Building location.

- Where is Pant y Celyn?
- Ownership.

- Its relation to local industry.
- Historical significance of the area.
- Climate at the site.
- Geology of the area.

Building fabric.

- Type of stone used in its construction.
- What is and how was the mortar made for the building of Pant y Celyn.
- The availability of local building materials. (stone, lime, aggregate, timber, water and roofing materials.)

3.1.1 Building location.

Pant y Celyn sits in the town of Pontarddulias and is in the ancient parish of Llandeilo Talybont.

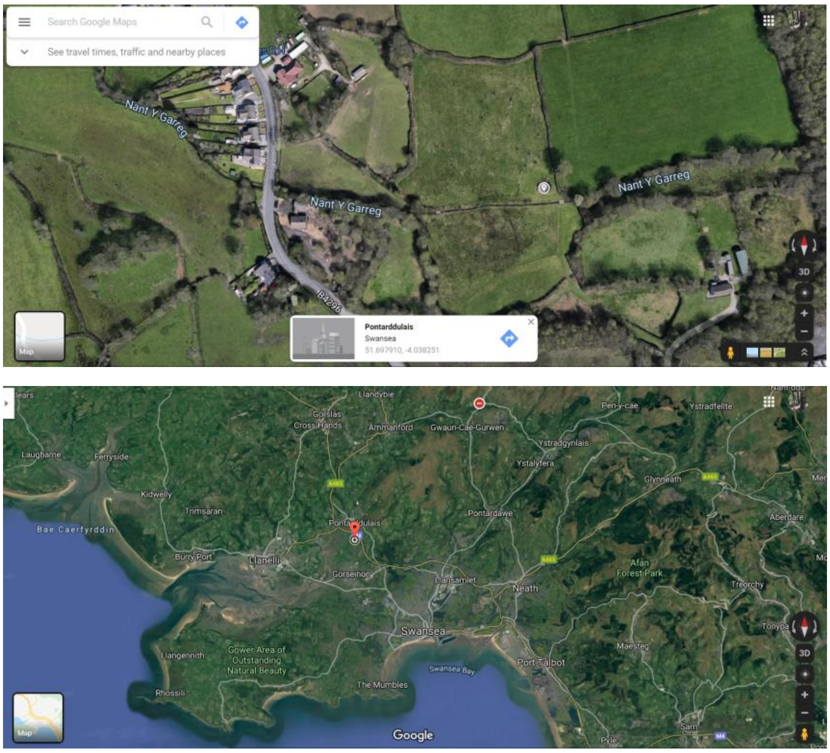

Figure 7 Location of Pant Y Celyn, image google maps.

As can be seen in figure six, the town of Pontarddulias sits at the point at which the Gower peninsular meets the main body of the rest of Wales.

3.1.2 Pontarddulais

Pontarddulais translated from welsh to English, simply means Bridge over the Dulais, the Dulias being the river that's source starts in the Black mountains to the north, flowing southwards until meeting the Bury estuary.

Above Pontarddulais you find the steep sided slopes of Griag Fawr and Cefndrum, covered by ferns, with rocky outcrops of Sandstone reaching around three hundred meters and carved by gully's, this then gives way to the low-lying marshy wetlands of the river Loughor.[8]

The area around Pontarddulais is rich with history, a First century Roman fort at the mouth of the River Loughor its Roman name being Leucarum with its main link road to the forts at Moridunum now known as Carmarthen, heading in a north direction through the town of Pontarddulais.

The first written account of this fort can be found in the Antonine Itinerary (the Itinerary of Emperor Antoninus) written in the second century, describing the post as half way between Carmarthen and Neath.[9]

The River Loughor was also an important feature in medieval times with the presence of three motte and Bailey castles, Castell Ddu, Talybont Castel and Hugh's Castel, built at the narrowest point of the river close to the ancient parish church of Saint Teilo

Figure 8 Castell Ddu (Coflein)

[8] The History of Pontarddulais (1985). E Lewis Evans, Translated by I Griffiths. Page 3-5

[9] Barry C. Burnham, Jeffrey L. Davies (2010). *Roman Frontiers in Wales and The Marches*. london: Royal commission on the Ancient and Historical Monuments in Wales. P 94.

Figure 9 Castell Ddu (Coflein)

Castell Ddu is the only remaining mound, it can be found on the South side of the M4 as the motorway crosses the River Loughor, the mound is approximately ten meters high with a round base that measurers forty five meters in diameter, it is assumed that the fort was of wooden construction a there is no trace of a stone structure.

It is possible that the fort was older than its Norman period dating as the Normans in all probability would have utilised and adapted what was already in existence.

Castell Ddu is first mentioned in Chronicles as far as I can tell, when it was attacked by the Welsh Price Rhys Gryg,[10] in 1215, in the Brut y Tywysgion (the Chronicle of the Princes), the Brut is one of the most important sources of information regarding early Welsh history before the conquest by Edward the first.

Sitting out on marshy grasslands of the Loughor estuary, is the site where once stood the Church of St Teilo.

[10] The History of Pontarddulais (1985). E Lewis Evans, Translated by I Griffiths. Page7.
Coflein. (2019). *Castell Ddu.* Available: https://coflein.gov.uk/en/site/303962/details/talybont-castle-hughs-castlecastell-du#archive. Last accessed 28th OCT 2019.

Figure 10 Saint Teilos church, St Faggins.

St Teilos Church is thought to have been constructed during the late twelfth or thirteenth century on what was an earlier Celtic site of importance. The oldest parts of the building are thought to be the nave and chancel, during its many years the church faced many alterations, during the fourteenth century small chapels were added to the north and south elevations of the chancel. In 1984-5 the building was painstakingly dismantled with the view of re-building it at the Museum of Welsh Life in St Fagan's, Cardiff.[11]

3.1.3 A walk through Pontarddulais.

The Welsh poet, collector and antiquarian Iolo Morganwg walked through Pontarddulais in 1796, making note of the local Inns and architectural styles of the town.

"Pontarddulais…. A village with excellent inns, LLanedi where I started my observations is a neat village with a good farmhouse with fine outhouses. The roads are bad, I have notion that the shire was enclosed at a later time than Glamorgan, the fields are squarer and the hedges straighter.

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[11] Coflein. (). *StTeilos.* Available: https://www.coflein.gov.uk/en/site/94698/images/. Last accessed 28th OCT 2019.

National Museum Wales. (). *St Teilos.* Available: https://museum.wales/stfagans/buildings/st_teilos_church/. Last accessed 28th OCT 2019.

I did not see any colliery for may miles. The cottages are not so pretty and far from neat, as far as I can see there is only one floor, as there are no windows to be seen anywhere else, except in the ones lately built."[12]

This description gives a sense of the small almost ramshackle nature of building in and around Pontarddulais at the time when Pant Y Celyn was constructed.

It seems that at the beginning of the nineteenth century the population of the parish of Llandeilo Talybont was small, the population in 1801 being 595,[13] with agriculture and the presence of a few mills and the emergence of small drift mines begging to appear in the area.

Most of the inhabitants of the town made a living from the surrounding natural resources, farming the land and fishing of the Loughor river, the use of coracles was prominent in the area for not just fishing but also to access the small parish church of Saint Teilos that was sat out on the marsh.

It was the arrival of a railway connection between Swansea and Llanelli with a station at Pontarddulais in the 1840's that would be the driving force for the future industrial growth of the town.

This combined with the natural features of the town, mainly the steady flow of the two rivers and the availability of raw materials such as coal, which became even more abundant in 1870 with the opening of the Graig Merthyr colliery just three miles away in the village of Cwmdulais that would bring the Tinplate industry to Pontarddulais with the arrival of the Hendy Works in 1866. Within the next ten years the industry had grown exponentially with the development of a further three Tinplate works, the Glamorgan, Cambria and Clayton.[14]

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[12] The History of Pontarddulais (1985). E Lewis Evans, Translated by I Griffiths. Page 20
Pontarddulais town council. (2019). *Potted history of Pontarddulais.* Available: http://www.pontarddulaistowncouncil.gov.uk/Pontarddulais-Tc/potted_history_of_pontarddulais-7023.aspx. Last accessed 28th OCT 2019.

[13] The History of Pontarddulais (1985). E Lewis Evans, Translated by I Griffiths. Page 20-21

[14] Gerald Davis, Maybery Evans, Huw Jones (2017). *Pontarddulais Tinplate 1866-1961*. Swansea: Macmillan Distribution MDL. p1-6.

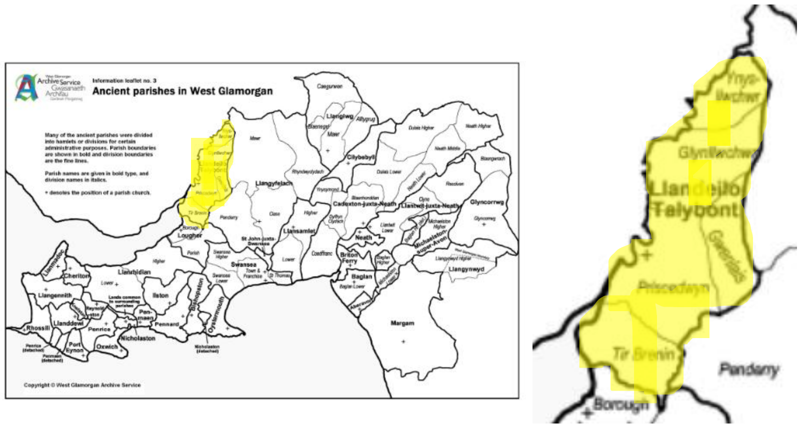

Figure 11 Ancient parishes of West Glamorgan.

As can be seen in figure eleven highlighted in yellow, Llandeilo Talybont is split into five hamlets, Ynsyllwchwr, Glynllwchwr, Tirybrenin, Gwenlais and Pryscedwin.

Pant y Celyn itself is in the hamlet of Pryscedwin.

From researching archive information at Swansea archives collection and online data found in the Tithe Maps and the first Ordinate Survey maps of the area it is possible to match the field in which Pant y Celyn is found with field numbers which then allow us to ascertain the ownership of the land and the house.

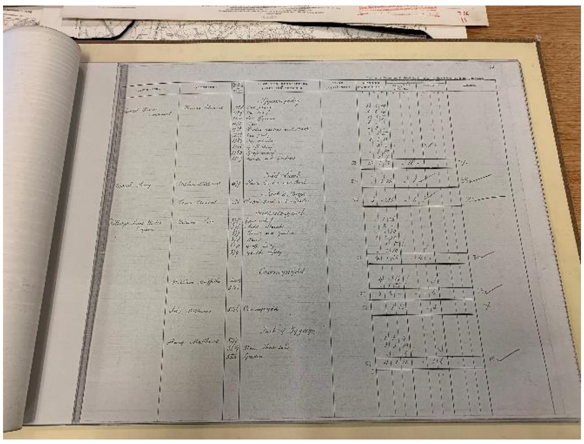

Figure 12 Tithe Register, Swansea Archives.

The Tithe maps were produced between 1838 and 1850 following the Tithe Commutation act of 1836. Tithes were payed to the local parish and recorded ownership of land, buildings, land occupiers and land use. Field numbers were taken down and also showed how much Tithe was paid to the local parish.

Figure 13 Satellite overlay of Tithe Map of Pant Y Celyn. *Figure 14 Tithe Map of site of Pant y Celyn.*

As can be seen in figures thirteen and fourteen in 1844, the owner of Pant y Celyn is listed as Dillwyn Lewis Weston with the land occupier being Henry Mathhews.

Although little information could be found regarding the tenant Henry Mathhews, the landowner, Lewis Weston Dillwyn was a prominent businessman, landowner, scholar and philanthropist in Swansea in the nineteenth century.

The Dillwyn family arrived in Swansea at the beginning of the eighteenth century, with Lewis's father, William Dillwyn buying a controlling share in the Cambrian pottery works in Swansea.

William placed Lewis, his only son in charge of this new business and in 1803 moved to Swansea and settled at Burrows lodge, which once stood where the car park for the Swansea Leisure Centre currently sits.[15]

The family were successful in growing the business to become one of the most renowned makers of fine porcelain around the world, this success furthered the prosperity and wealth of the family.

[15] Coflein. (). *Burrows Lodge.* Available: https://www.coflein.gov.uk/en/site/18149/details/burrows-lodge. Last accessed 7th Nov 2019.

Figure 15 Lewis Weston Dillwyn. National Museum of Wales.

Lewis Weston Dillwyn was also renowned for published works on botany and the study of Mollusc shells and in 1804 he was elected as a Fellow of the Royal Society.

Upon retiring from his role at the Cambrian pottery works Lewis Weston Dillwyn became the High Sheriff of Glamorganshire, later going on to be elected as Mayor of Swansea in 1839.

In 1807 Lewis Weston Dillwyn married Mary Adams, daughter and heiress of John Llewelyn of Penllergare in the parish of Llangyfelach, they went on to have six children, their daughter Mary becoming a prominent photographer.[16]

4 Climate and Environment at Pant y Calen.

To fully understand the function of Pant Y Calen's building fabric and more specifically the way in which the building was designed to manage the climate in which it sits, it is important to take in to account the buildings location and how the climate in which it sits will have influenced its design and the materials used in its construction.

[16] Emlyn Thomas. (1987). The Dillwyn Family. *Llwchwr Society.* 12 (6), p 31-35.

The climate and environment of which any building is exposed, will have significant influence and bearing on how building fabric is selected and preforms over a given period.[17]

The United kingdom's Island location and temperate maritime climate means that often we experience a range of different weather but in general without extreme climactic variation, and within the United Kingdom the weather can be very different depending on where you are.

The weather in the south east is generally warmer and dryer than that in the north and west.

The climate in the part of the UK in which Pant y Calen sits could be described as changeable or unpredictable, often the site may experience a range of weather systems in just one day with wind driven rain and sunny warm weather being experienced in a twenty-four-hour period.

To gain a perspective of the climate that Pant y Celyn, the data that I have chosen to use is recorded at the Pembrey Sands Weather Station, Pembrey Sands is approximately fourteen miles west of the site and is in my opinion the best situated to represent the climate of the area.

4.1 Temperature.

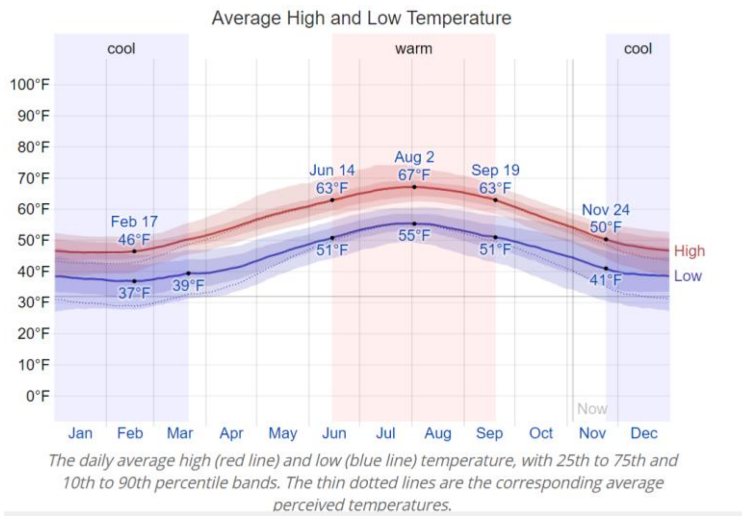

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Figure 16 Average temperature at Pembrey sands.

[17] English Heritage (2014). *Building Environment*. London: Ashgate publishing Limited. 5.

As can be seen in figure 11, temperatures that Pant y Celyn may experience over a year range from a low of 37 Degrees Fahrenheit in winter to highs of 67 degrees Fahrenheit in summer.

The warm season being short at 3.1 months from June to September, and the cold season also being short at 3.9 months between November and March.

4.2 Rainfall.

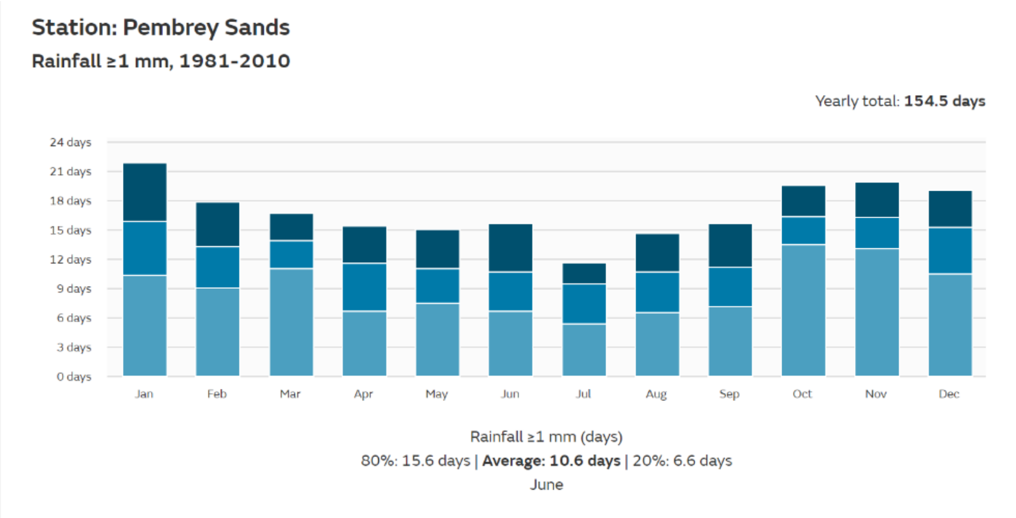


Figure 17 Average days of rainfall at Pembrey sands.

Figure Twelve shows average days of rain data obtained from the Pembray Sands weather station between 1981 and 2010, which is the closest weather station to Pant y Celyn.

The data shows that on average the station recorded 154.5 days of rain per year between 1981 and 2010,

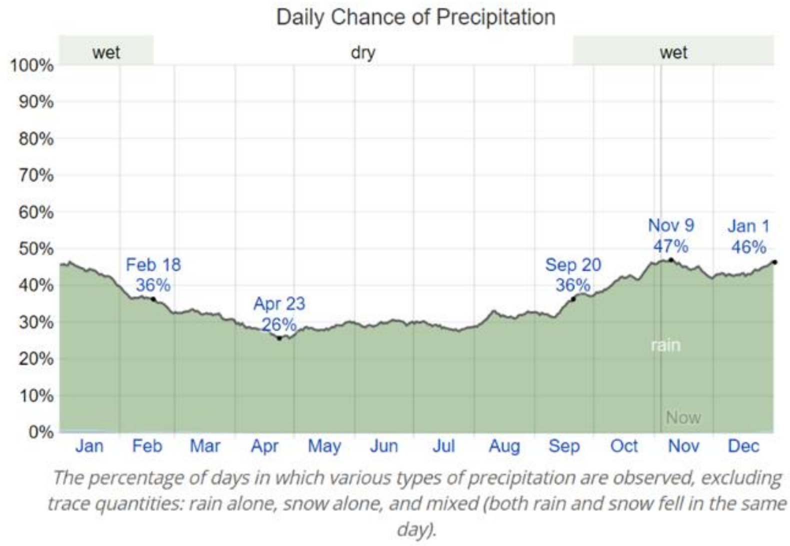


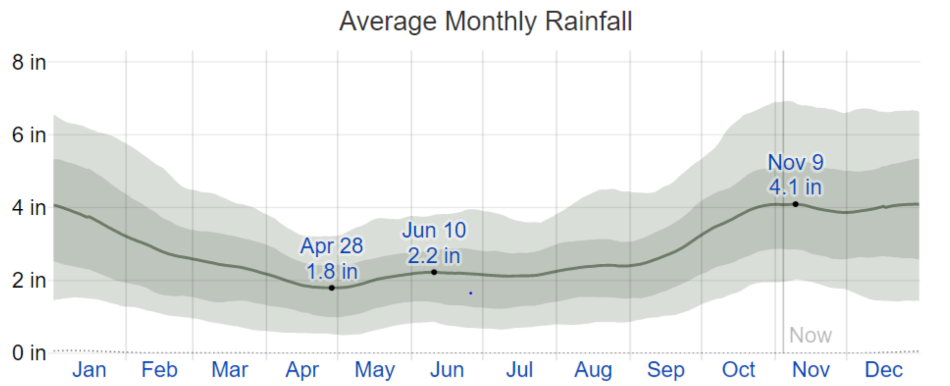
Figure 18 Daily chance of precipitation at Pembrey Sands weather station.

Figure seven displays the daily chance of precipitation at Pembrey Sands weather station, as can be seen from the above data, the chance that Panty y Celyn will experience some form of wet weather, in this graph a “wet day” is one with at least 0.04 inches of liquid or liquid equivalent precipitation, as can be seen the chance of wet days at Pembrey Sands varies significantly throughout the year.

The wetter season lasts approximately 4.9 months, from September through to February with a greater than 36% chance of precipitation.

The chance of wet days peaks in November with a 47% chance of rain in any given day.

The dryer season lasts approximately 7.1 months from February through to September with the smallest chance of precipitation being 26% in April.



The average rainfall (solid line) accumulated over the course of a sliding 31-day period centered on the day in question, with 25th to 75th and 10th to 90th percentile bands. The thin dotted line is the corresponding average liquid-equivalent snowfall.

Figure 19 Average monthly rainfall at Pembrey Sands.

To show the variation within the months themselves and not just monthly totals, you can see the accumulated rainfall over a thirty-one-day scale.

As can be seen even in the dryer months it is common to experience days containing more than four inches of rain.[18]

The amount of rain fall experienced in an area will be of significance when looking at how a mortar needs to function and how detail may be incorporated into the construction of a vernacular building to cope with wetter conditions that it experiences, details such as longer over hangs on eaves to shed water away from building fabric that may be built from relatively soft natural materials like sandstone, cob and timber.

4.3 Wind Driven rain.

Wind driven rain, simply put is the amount of rain driven into a building or building fabric by wind action, in Wales walls that face in a south and west direction are most likely to be affected by wind driven rain. The severity of the impact of wind driven rain will alter depending on the building location and its exposure.

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[18] weather spark/Met Office. (2019). *Average weather at Pembrey Sands.* Available: https://weatherspark.com/y/147735/Average-Weather-at-Pembrey-Sands-United-Kingdom-Year-Round. Last accessed 3rd Nov 2019.

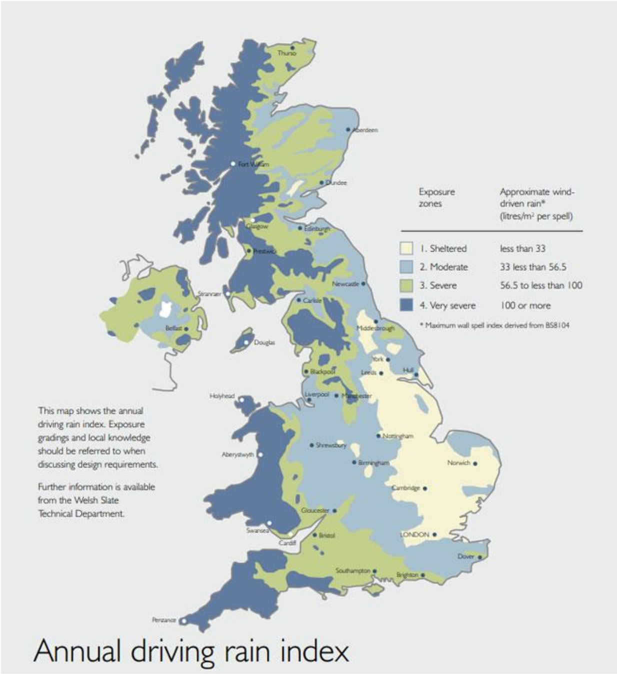

Figure 20 wind driven rain index map (the slatecompany.co.uk)

As can be seen in Figure nine Wales is in the “very severe” category.

In theory as rain and wind are not constant it should be unlikely that moisture driven into building fabric should penetrate any deeper than a few millimetres into traditionally built solid wall buildings constructed of materials such as stone or brick.

Providing that the walls exposed to wind driven rain are in a good condition and able to function in the way they were intended by being able to manage moisture through the process of evaporation during dry periods with the movement of air across the building fabric, be that a mortar or plaster.

When discussing this with clients I often use the analogy of drying clothes on a washing line, for clothes to dry it doesn’t necessarily need to be a warm sunny day, it is often the case that the best conditions for drying are windy and as it’s the movement of wind across the surface of material that aids the drying process.

It is when traditional building fabric is hindered in this process by non-breathable materials such as cement renders, incorrect pointing materials and non-vapour permeable paint finishes that moisture levels build up in the wall’s construction fabric and core.

This build-up of moisture combined with the effects of wind driven rain leads to moisture saturation of the wall, with liquid moisture being able to travel through the thickest of masonry.[19]

To get a picture of what the Climate was like when Pant Y Celyn was built some point between the end of the 18th century and the begging of the 19th century, historic weather data recorded at the time is useful.

The only data I could find relating to weather conditions at the time is from the England and Wales Precipitation (EWP) record, originally published in the journal British of Rainfall in 1931, updated and revised in the 1970s and 80s by climatologists, Janice Lough, Tom Wigley and Phil Jones.

Although this data is a little confusing and difficult to interpret and could be considered unreliable due to the fact that prior to 1820 only one weather station in each area covered was used under the data set from what I can gather, the first ten years of the 19th Century contains reference to long dry summers and warmer, dryer winters, which are ideal conditions for construction. [20]

>1800 - A dry summer.

>1802 - A dry year.

>1807 - A dry year & a dry summer.

>1818 - A long, dry & hot summer. (see below)

>1825 - A dry summer. A notable hot spell in July.

>1826 - A warm summer. (see below)

>1827 - A dry summer.

>1835 - A dry summer.

>1840 - A dry year; a dry summer.

[19] English Heritage (2014). *Building Environment*. London: Ashgate publishing Limited. p76.
[20] Lough, Janice; Wigley Tom and Jones, Phil; “Spatial patterns of precipitation in England and Wales and a revised homogeneous England and Wales precipitation series”; in *Journal of Climatology*; Volume 4, pp. 1-25 (1984)

5 Geology of the area.

The geology of the area will be a significant factor when considering the types of materials available for the construction of Pant Y Celyn, as the building is built from stone and earth with some inclusion of lime as a binder.

Before the end of the 18th century and the spread and influence of railways and canals across the United Kingdom, vernacular buildings like Pant y Celyn relied solely on materials that were available in the surrounding area for their construction and maintenance.

The appearance of vernacular buildings up and down the country will be heavily influenced by the type of building stone available and the availability of aggregates and timber for the production of mortars and the constructing roof structures.

As many traditional mortars used lime or clay rich subsoils as the principle binder to mix with an aggregate for the laying of locally sourced building stone in the construction walls, the availability of limestone, clay rich soils and a suitable type of stone to be used in building was of the utmost importance, in areas of the UK where limestone and building stone were unavailable or scarce, these materials would have to be brought to that area which would inevitably raise the costs of those materials thus having an impact on the style of construction that will have been adopted by that area.[21]

For example, in the East of wales, the poor selection of suitable building stone led to the use of timber as the main material used in construction, compared to the South and West of Wales where stone has been widely used as the principle construction material.[22]

To ascertain the materials used in the building of Pant y Celyn I feel it necessary to study the types of Limestone and suitable building stone that can be found near to site.

[21] English Heritage. (2011). Materials & Sources. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p10-15.
[22] Smith, P. (1975). Construction and Decoration. In: *Houses of the welsh countryside.* 2nd ed. Cardiff: Royal commission on the Ancient and Historical Monuments in Wales. p 267.

The geology of the Gower and surrounding area contain rock types varying in age from the Silurian (400 million years old), Devonian (360 million years old), Upper Carboniferous (290 million years old) and Triassic (200 million years old).[23]

With Small sections of Silurian Period Mudstone, siltstone and Sandstones formed around 400million years ago in an area dominated by rivers forming deposits of fine silts and clays from floods.

The Devonian strata Red Sandstones found in the Gower and in the areas around Gower to the East and West, were formed around 360 million years ago, when the British Isles lay somewhere near the Equator and had a tropical climate, with deposits formed by Fluvial action and Alluvial Fans.

Carboniferous Limestone makes up most of the Gower, its sedimentary layers being laid down some 300 million years ago in warm shallow seas rich with corals and small Molluscs and Coruscations.

5.1 Limestone.

In the south of wales, limestone is classified into two sperate types, Carboniferous and Permian (Magnesian) each being formed at different times in the earth's history.

Limestone is a sedimentary rock that is formed by the accumulation of sediment layers formed on the sea floor and occasionally in freshwater pools.

Ocean dwelling organisms such as oysters, clams, mussels and corals use Calcium carbonate found in sea water to create their shells and skeletal structures, as these organisms die, their shells and bones are broken down by tidal action and then settle on the sea floor where this material is then compressed over millions of years. this sediment material is rich in Calcium Carbonate ($CaCo_3$) with over fifty per cent Carbonate material which may be **Organic, Chemical or Detrital** in origin.

There are three main components in limestone.

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[23] T.R Owen (1973). *Geology Explained in South Wales*. 2nd ed. Devon: David & Charles (Holdings). p 93-96.

- Calcite
- Dolomite.
- Impurities. (silica & alumina)

Calcite.

Calcite is composed of a basic structure of one atom of Calcium, one atom of carbon and three atoms of oxygen ($CaCo_3$) and forms as crystals of varying rhombs.

Dolomite.

Dolomite is a carbonate mineral that can often be found in forms of calcite, when liquids rich in Magnesium Carbonate ($MgCo_3$) filter through a limestone, when this occurs the $CaCo_3$ of the calcite takes up the $MgCo_3$ which then forms dolomite ((CA Mg (CO_3)2).

Impurity's.

Impurities are added to limestones in the form of clay, silts, muds and grains of sand that would have been eroded on land and then washed out to sea by rivers and floods and then mixed with calcium rich sediments.

To illustrate this, we can draw a triangular graph.

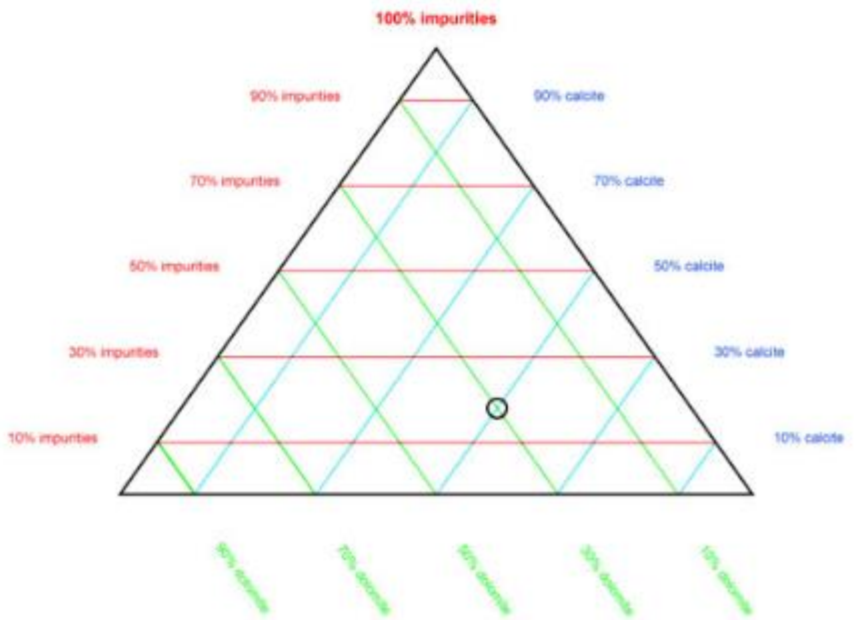

Figure 21 Composition of lime stone graph. British Geological society.

As can be seen in figure sixteen the points of the triangle represent one hundred per cent of a particular component and the opposite line is zero per cent of the component.

For example, a rock with fifty per cent calcite, thirty per cent dolomite and twenty per cent is shown on the graph.

All limestones consist of more than fifty per cent calcium carbonate, with true lime stones consisting of ninety per cent calcite.

The Carboniferous limestone that can be found on the Gower, Pembrokeshire coast and further in land in Carmarthenshire generally have less than ten percent impurities.

5.1.1 Carboniferous limestone.

Carboniferous limestone is a collective term for several limestones that are found across the UK formed between 290 and 354 million years ago.

Generally, there are three classifications of Carboniferous limestone according to how they have been formed.

- Shelf
- Basin
- Reef

Shelf limestone is hard, pale in colour and is made up of fragments of shells and the skeletal remains of marine organisms and are bonded together calcite cement and were generally laid down in shallow seas.

Basin Limestone are usually darker in colour and are more thinly bedded than that of shelf limestone, they usually contain layers of shale and mudstone which were originally deposited as muds. Basin limestones have fewer fossils than that of Basin limestones and are formed in much deeper waters.

Reef limestone tends to be white to pale grey in colour and contain larger amounts of fossils both basin and shelf formed stone. They occur in isolated patches usually between basin and shelf formed limestones and were formed in shallow tropical seas much like coral reefs today.[24]

The limestone to the south and north of Pant y Celyn is carboniferous in formation and is of a very high purity, ranging from 97-98% pure.

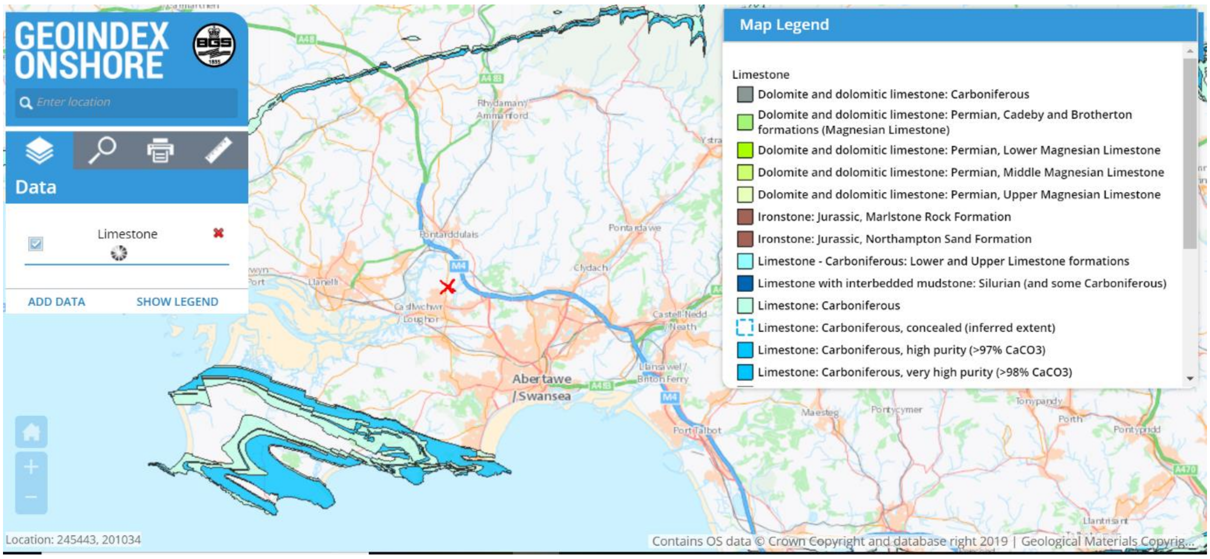

Figure 22 Geo Shore Index Showing Local Limestone.

This means mortars made from the local limestone would be totally reliant on carbonation to achieve their full strength and have no hydraulic set without the aid of a pozzolan.

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[17]British Geological Survey. (). *The composition of limestone.* Available: https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/limestoneLandscapes/whatIsLimestone/composition.html. Last accessed 7th Nov 2019.

http://www.bgs.ac.uk/makeamap/

Figure 23Make a map, showing Carboniferous Sedimentary rock.

As well as the Carboniferous limestones found along the Gower coastline and in land towards Carmarthenshire, there are also types of Carboniferous sandstones that are found in the non-marine upper carboniferous strata.

The upper Carboniferous strata is distributed across five separate areas around the UK, those being:

- The Culm Trough in South West England.
- The Kent coal field.
- The South Wales Coal field
- The North English Midlands.
- The Midland Valley of Scotland.[25]

[25] British Geological Survey. (). *Discovering Geology.* Available: https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html. Last accessed 7th Nov 2019.

The Geological society. (). *Upper Carboniferous (Pennsylvanian).* Available: https://www.geolsoc.org.uk/Groups-and-Networks/Commissions/Stratigraphy-Commission/Brief-Summary-of-British-Stratigraphy/Upper-Carboniferous-Pennsylvanian. Last accessed 7th Nov 2019.

5.1.2 Sandstone

To the North of the Gower where Pant y Celyn is situated in the town of Pontarddulias, the geology changes considerably.

The area being designated as the South wales Upper Coal Measure Formation, its sedimentary bedrock consisting of Mudstone, Siltstone, Sandstone, Ironstone and Coal, was laid down around the same period as the Carboniferous Limestone of the Gower but in an area that was predominantly covered swamps, estuaries and deltas.

The south wales coal measure group consists of a thick layer of sandstones consisting of grains between 0.05mm – 2mm known as 'Twrch' and 'Pennant' sitting on top of Carboniferous limestone with large quantities of Bishopston Mudstone on top.

Mudstones are made up of particles of clays less than 0.05mm deposited in environments such as tidal flats, estuary's, lakes, this sediment is compressed by deposited layers above and forms Shale.[26]

6 Soils and map data from the area.

The use as earth as a material for building can be found all over the world dating back thousands of years.

In the United Kingdom, the use of earth as a material for the bedding of stone in traditional buildings can be traced back Neolithic times.[27]

As the availability of aggregates for the use in mortars varied around the country, up until the beginning of the nineteenth century the freely available material that could be utilised by the builders of vernacular buildings was earth, this earth was often mixed with lime to form a workable mortar or plaster.

As the type of soil, sands and aggregates are of influence with regards there use in the making of traditional mortars I feel its beneficial to look at the information available to help

[26] British Geological Survey. (). *Sedimentary Rocks.* Available: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=PES. Last accessed 5th Feb 2020.
[27] Nigel Copsey (2019). *Hot Mixed Limes and Traditional Mortars*. Wiltshire: The Crowood Press Ltd. p16.

build a picture as to the types of soil and aggregate that will have been available within the area in which Pant y Celyn resides.

6.1 Soil formation

The formation of a new soil depends on the presence of new soil material these materials are obtained in two main ways either by,

Denudation - the scraping clean of a surface by action of wind, water or ice.

Deposition - where materials from erosion elsewhere - for example river gravels, rock-falls or blowing sand - or the formation of new rocks formed by uplift of the ocean bed or volcanic action.

With this in mind there are many different materials that go into the makeup of earth and soils which all have varying characteristics and quality's that will in turn have be a factor in its use in mortars and plasters.

Examples:

- Rocks - Sandstone, siltstone, mudstone, limestone, volcanic lavas or dusts
- Gravels - river and sea deposits
- Scree - fallen rocks
- Alluvium – sands, silts, clays from marine, estuarine or freshwater rivers and lakes
- Boulder clay - can be very variable deposits laid down by scraping ice
- Loess - blown silts and clays are common inland on the continents
- Blown sand - forming dunes or plains
- Manmade materials – e.g. quarry or mining waste

Soils are also formed by the formation and decay of Organic matter and by **paedogenic processes** - the leaching and evaporating effects of water and the biochemical actions of bacteria and other living things.[28]

As the site in which Pant Y Celyn sits is in close proximity to the Loughor estuary, it could be assumed that the soil type at site would be of an Alluvial nature made up of high quantities of sand ($>20_{um}$), silts ($>63_{um} <20_{um}$) and fines ($<63_{um}$).[29]

From ordinance survey map data published in 1888, the presence of a gravel pit is shown to be just over five hundred feet from the field in which Pant Y Celyn sits, the availability gravel to be used in the production of mortar would be of a great advantage to the vernacular builder as, as discussed previously, the availability and cost of transportation of building materials was a major factor in how traditional buildings were constructed.

[28] British Society of Soil Science. (). *Soil Forming Factors and Processes.* Available: https://www.soils.org.uk/soil-forming-factors-and-processes. Last accessed 26th Jan 2020.

[29] Cemex. (). *Educational Guide to Aggregates.* Available: https://www.cemex.co.uk/documents/45807659/45840198/mortar-aggregates.pdf/47b32d0f-7a4a-f1f9-4551-8bbe39fbeb90. Last accessed 10th feb 2020.

Figure 24 Gravel pit location to Pant y Celyn.

6.1.1 Gravel formation.

Gravel deposits are a common geological feature formed as a result of the weathering and erosion of rock. The action of rivers and waves will usually mass gravel into large accumulations and can occasionally lead to them becoming covered by soils and silts thus becoming lithified (turned to stone) in to sedimentary rock such as sandstone conglomerates.

In South Wales sand and gravel deposits lie on top of the bedrock geology (superficial) and in most cases concentrated in river valleys where they are being deposited by ice on the margins of glaciers (glaciogenic) or by glacial melt water flowing from glaciers (glaciofluvial).

Sand and gravel may also be found on riverbanks in areas that have sections below the level of floodplains (sub alluvial).[30]

In the area that Pant Y Celyn sits there is large amounts of superficial sand and gravel deposited

Gravel would be a good source of aggregate for vernacular builders of the past as is easily identifiable and relatively easy to process, using gravel as an aggregate is mentioned by Vitruvius in the "Ten Books of Architecture".[31]

Figure 31 Gravel pit as shown on early Ordinate survey Map.

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[30] British Geological Survey. (2019). *Geo Shore Index.* Available:

https://mapapps2.bgs.ac.uk/geoindex/home.html. Last accessed 15th Feb 2020.

[31] Vitruvius, M. (1914). Book Two. In: Morris Hicky Morgan *The Ten Books on Architecture.* New York: Dover Publications. P 38-48.

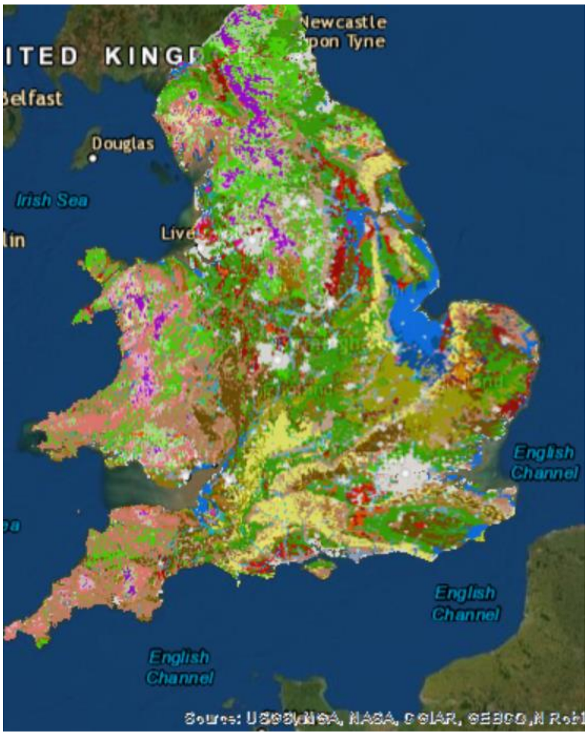

Figure 25 UK soil observatory map data.

From data gathered from the UK Soil Observatory it can be determined that the soil type at Pant Y Celyn could be of mixture of two differing types.

As seen in figure twenty six the site in which Pant Y Celyn sits is almost on the boundary of two types of soil associations, with the identified gravel pit sitting in the Brickfield association.

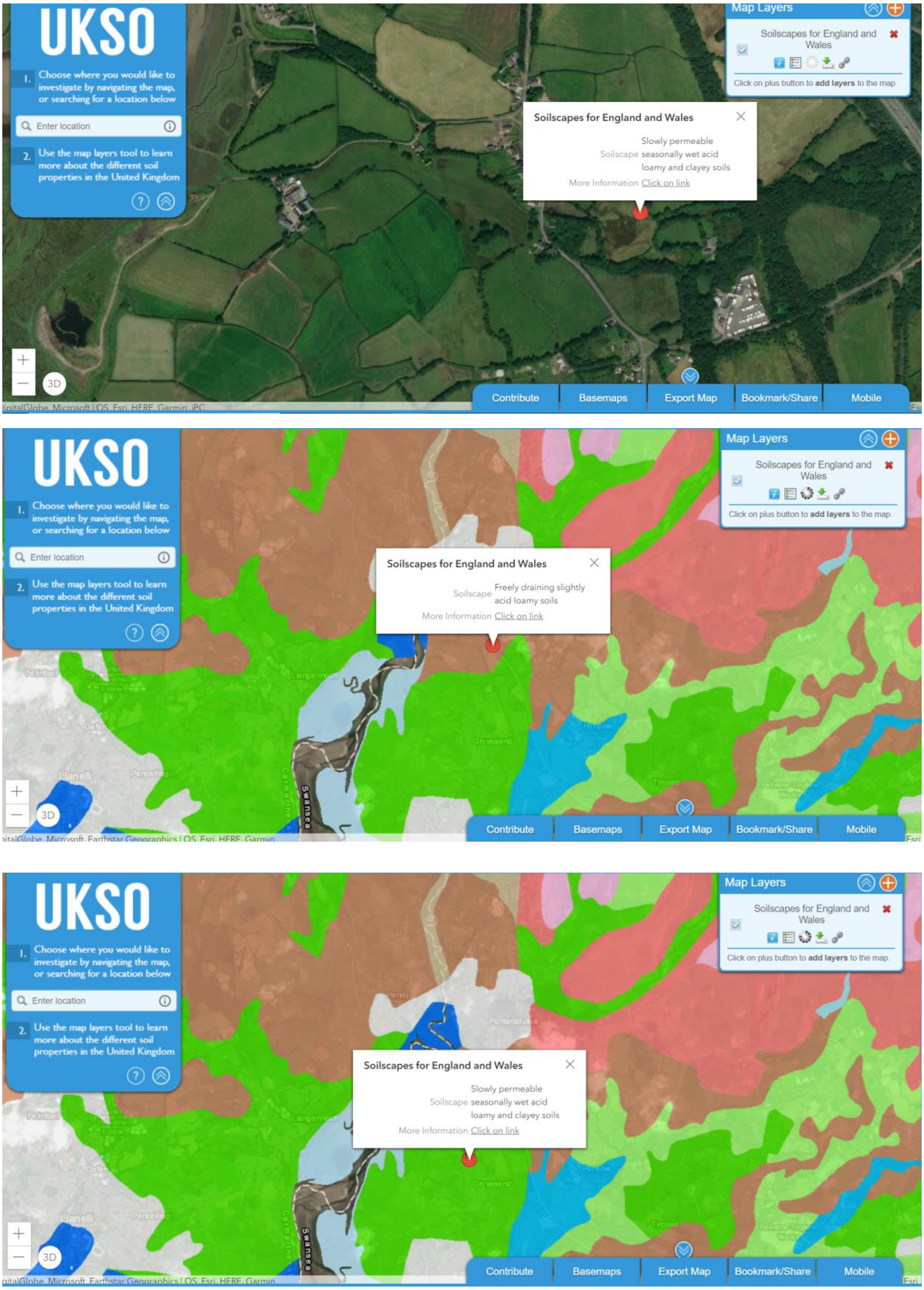

Figure 26 UK Soil Observatory Soilscapes map data.

With the north half of the field that the building is located in being part of the Neath association and the southern part of the site being part of the Brickfield 2 association.[32]

Soil samples taken from the field in which Pant Y Celyn sits and from the assumed location of the gravel pit (as shown in figure 24) from visual examination seem to correspond with the description of the soils that are described below.

6.1.2 Brickfield 2 0713f

This association consists of loamy soils comprised of mainly carboniferous Shale and sandstone found in the undulating Till planes (the flat plane that is formed when a sheet of ice becomes detached from the main body of a glacier which then melts thus depositing the sediment that it carried)and Drumlins (formed by the action of glacial ice acting on the unconsolidated material beneath it) of the South Wales Valleys that stretching through the dales in the North of England and Southern Scotland with peaty or alluvial hollows scattered among them.

6.1.3 Neath 0541h

The Neath soils consist of typical brown earths, and are described as being permeable and well drained, with brown, clay loam upper sections containing fine sandstone and siltstone fragments which increase in number downwards, as the soils pass into rubbly Head or fractured bedrock. In south Wales, the Neath association is mapped principally on the Coal Measures, where it occupies gentle or moderate slopes below 170 m

[32] Cranfield University 2020. *The Soils Guide.* Available: www.landis.org.uk. Cranfield University, UK. Last accessed 30/01/2020

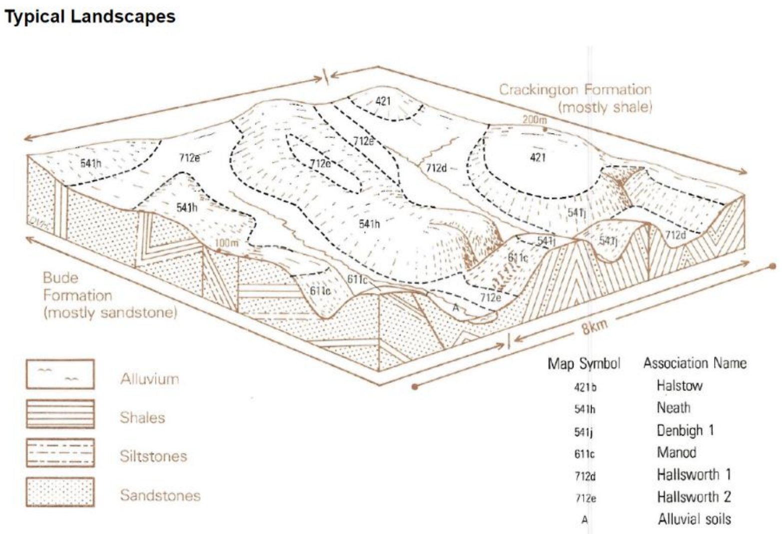

Figure 27 Typical land formation of the Neath Association. The Soil Society.

7 The building fabric of Pant y Celyn.

7.1 Stone.

At the present time the materials that can be easily identified from the ruins of Pant Y Celyn are the components that the walls have been constructed from as other than the presence of a few broken Slate roofing tiles scattered on the ground, other materials such as roof timbers, window frames and ceiling joists have either rotted away or have possibly be salvaged for use elsewhere thus only allowing us to assume what these materials once may have been.

Figure 28 wall construction at Pant Y celin. Image J Moriarty.

From visual inspection the type of stone used predominantly in the construction of the building is the local sandstone, constructed mainly from rounded river rubble, known locally as “Popyl” stone with the inclusion of some flatter, seemingly semi- dressed quarried sandstone,mudstone and harder quartz Conglomerates.

Figure 29 Quartz conglomerates and Sandstone of Pant Y Celyn.

7.2 quarried stone.

From archive research it has been possible to identify the location of two possible sources of quarried sandstone from which to have built the property. As the nature of the building would suggest, building materials would in all probability have been sourced as close to site as possible, with factors such as the cost and time of transportation of heavy, bulky materials being of significance.

As can be seen in figure thirty, the two quarries identified are within two miles of the site.

It is also in my opinion safe to assume that as Pant Y Celyn was once a farm workers cottage and was in all probability built by the workers that worked the land for the land owners, that much of the stone would have been salvaged from the fields that were ploughed by those workers as a free source of building materials.

Another type of building stone used locally is known as Pennant or Blue Pennant, this stone is derived from a sequence of sedimentary rock designated under the South Wales Coalfield or the Pennant Sandstone formation.

Pennant Sandstone in its freshly quarried state is dark grey, almost green in colour, this colour is owing to the fragments of shale and carbonaceous material that they contain[33] but in time the stone has a tendency to turn a brown or yellow colour. and like most sandstone is a sedimentary rock composed of particles of silicate mineral grains that are susceptible to moisture and salts.

[33] Howe, J A. (2001). Sandstones and Grits. In: Donhead Publishing. *The Geology of Building Stones*. Dorset: Donhead . p126-127.

Figure 30 Location of two quarries local to Pant Y Celyn.

Since the time of the Roman occupation of Wales and in my opinion in all probability, before that time, Pennant Sandstone has been used in masonry, with evidence of its use as a building material at the Roman fort Gelligaer, near the town of Caerphilly and more locally at the costal fort at Loughor.[34]

With the arrival of the railways during the industrial revolution and the availability of more efficient forms of transport, this type of local stone became the choice of building stone used in many of the traditional stone-built buildings across south wales, from the chapels and miners terraces of the South Wales valleys to grander post industrial revolution buildings in the towns and cities of Cardiff and Swansea.

Figure 31 Image of Miners terrace. Wales online.

From visual inspection the bedding stone seems to have been laid in courses, with the rounder larger stone being capped with the smaller flatter stones after a few courses.

I believe this style of construction could have been the result of, the way in which it was constructed by the farm workers that worked the land on the Lewis Weston Dillwyn estate,

[34] Peat, C Iorweth. (1940). Building materials. In: Oxford University press, Gwasg Gomer. *The Welsh House*. 2nd ed. Lampeter: Llanerch Publishers. p 26.

this work would in probability have been undertaken during the relatively small amount of free time available to the builder. I believe it possible that, during the period between spring and autumn that would have been considered the ideal time to start or carry out construction, that the only free time available to farm workers would be on Sundays or in the evening after their daily work had been carried out.

Taking into account the relatively small size of the building and having had experience in the laying of sloid stone walls, I'm of the opinion that with a small amount of labour it would be possible to construct two – three courses utilizing the larger more rounded river and field stone, then using the smaller flatter stone as a way of flattening off the course in preparation for the next courses of rubble stone, this technique would also act as a form protection from the potential ingress of water into the core of the wall which in turn would aid in the setting and curing of bedding and core mortars, with the flat stones laid on top acting as a barrier.

Figure 32 Semi coursed construction of Pant Y Celin. J moriarty.

7.3 Mortar.

As much of the focus of this piece of work is concentrated on the mortar at Pant y Celyn, I feel it is pertinent to look at the history of traditional mortar production, the processes it involves and advancements overtime.

Mortar is essentially the material that is used to fill the gaps between whatever type of masonry that is to be used in the construction of buildings, they aid in the spreading of load and act as a means of shedding moisture by absorbing and releasing moisture through evaporation ideally having an open pore structure to facilitate this.

Mortar is in most cases a binder mixed with an aggregate and water, applied as a form of paste to enable the efficient stacking of construction masonry which over a period of time will set.

As with other vernacular building materials, the type of mortar produced for construction will in most cases be heavily influenced by the local materials it is made from, with locally sourced aggregates and other materials used in the preparation of mortars being of the same colours and textures of local raw building materials, aiding in the way in which the building blends into is surroundings and in some cases the way in which the building copes with the local climate.

Over the last two hundred years the development of harder, quicker setting mortars has led to the common use of Ordinary Portland Cement (OPC) as the material of choice for making mortars in the UK, mortars made from OPC are very good when used with the suitable materials but when used as repair mortar in traditional solid wall buildings constructed from often soft bedding stones and earth/lime mortars they have a detrimental effect, causing moisture to become trapped in building fabric, accelerating its decay.

7.3.1 History of mortars

One of the earliest illustrations of mortar production and its use is an Egyptian Mural thought to date from 1950 BCE.

Early written records of mortar production can be traced back to Classical antiquity in the writings of **Marcus Porcius Cato** (234-149 BCE), **Pliny the Younger** (62-113 CE) and in what may be the most written about of sources when discussing early mortar production, the writings of the Roman architect **Marcus Vitruvius Pollio** (27BCE – 14CE).[35]

For thousands of years, many different materials have been used in the development of mortar depending on where in the world these mortars were developed and to be used.

The most early forms of construction have in many instances used clay rich soils mixed with various quantities of aggregates, water and natural sources of fibre such as straw, dung, flax and animal hair to construct buildings that have been formed by way of forming temporary shuttering and then compacting the earthen material between the forms, gradually gaining height as the previously laid sections dry and harden or by using the same earthen material to form bricks, blocks and tile to be laid bonded together by an earth mortar.

In the United Kingdom, earth mortars have been used in construction as far back as Neolithic times.[36]

In these instances, the natural clay content of soils has been used as the **binder** that holds the materials together.

A binder is, in essence, any material that holds or draws other materials together to form a cohesive body.

The use of mortars for various styles of construction was developed and refined in much of the Western world by the Romans, who developed mortars, mixed from quantities of aggregate mixed with lime as a binder, in the construction of defensive positions and buildings of high status.

The Romans were responsible for the development of the first Hydraulic lime mortars, these mortars were mixed with varying amount of pozzolanic material that allowed these mortars to set to grater strengths and under water thus allowing the construction of stronger larger buildings, docks, and costal defences.

[35] English Heritage. (2011). Mortars Renders and Plasters: A Historical perspective. In: *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. 5.

[36] Copsey, N. (2019). Earth and Earth Lime Mortars. In: *Hot Mixed Limes and Traditional Mortars*. Wiltshire: The Crowood Press Ltd. p 16.

Pozzolans are materials that contain reactive alumina and silica which have been heated to relatively high temperatures, this can happen naturally in the form of volcanic ash or artificially in kilns in the form of clay bricks and pan tiles, these materials in themselves have little to no cementitious ability but when mixed with water and calcium hydroxide will form calcium silicate hydrates and calcium aluminate hydrates giving lime mortars a hydraulic set.[37]

After the fall of the Roman empire and the retreat from the British Isles, much of the knowledge of mortar preparation was lost and throughout the dark ages little is known about how mortars were being produced and used as we have no written evidence.

It isn't until the Norman conquest of the British Isles that brought with it a resurgence in building with stone and lime based mortars that we start see major construction projects such as the many castles, abbeys and cathedrals that can be found today in most parts of the UK that, although having endured many decades of neglect and the harsh maritime climate of the Uk, are still standing to this day,[38] it would be easy to assume that these early builders were always masters of their craft as these grate stone monuments that have stood the rigors of time would suggest but as in construction today failures were in all probability common, one can only assume that for every example of grand medieval construction still standing today there must have been many examples that did not stand the test of time, with failures caused by poor building techniques, material preparation or selection.

Mortar preparation and use seems to have changed little over the next six hundred years or so, with earthy, lime rich mortars being widely used throughout the British Ilse's

During the 1700's advancement was made in the science of mortars and the development of mortars with hydraulic properties, while endeavouring to construct larger, stronger and in less time.

In 1750 the architect and engineer John Smeaton was given the task of building the Eddystone Lighthouse.

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[37] Cowper, A D. (1998). Pozzolanas. In: Donhead Publishing *Lime and Lime Mortars*. 2nd ed. Dorset: Donhead. p 46-50.

[38]English Heritage. (2011). Mortars Renders and Plasters: A Historical perspective. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p 6-9.

This commission led him to conduct investigation into the properties of different limestones that had the necessary impurities to produce mortars that had different levels of hydraulic set, in particular the properties of Blue Lias limestones found in the east and west of England and also in South Wales.

For the first time the hydraulicity of mortars was directly linked to the presence of reactive clay materials found in types of limestone and it became possible ascertain which types of limestone would yield limes with varying amounts of hydraulic set.

Following on from the work carried out by Smeaton, the development of so-called Natural cements by James Parker who used clay rich limestone to formulate binders much like strong hydraulic limes but with much grater percentages of silica, alumina and iron oxide to calcium carbonate than limestone used to manufacture hydraulic limes.

Later in the 19th century Joseph Aspdin developed Portland cement, which at first was patented as an 'artificial stone' after its supposed similarity's to Portland stone.

Cements were classified into three phases and typologies:

- **Proto – Portland Cement.**

Calcined limestone and clay, with little reaction between calcium oxide and silica in the kiln due to low temperature**.**

- **Meso – Portland Cement.**

A heterogeneous mixture containing Belite (dicalcium silicate) and small amounts of Alite (tricalcium silicate).

These cements were the pre-cursor to what we know today as ordinary Portland cement.

- **True Portland Cement.**

Characterised by high quantities of Alite

Ordinary Portland cement was fired at much greater temperatures than that of its forebears and due to higher kiln temperatures contained high quantities of tricalcium silicate, it's the reaction that takes place when in the presence of water that gives cement its rapid set.

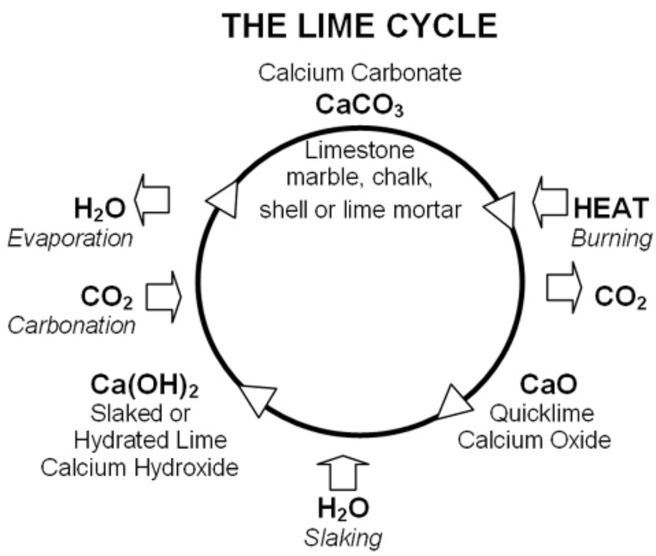
7.3.2 Lime carbonation.

Lime as a binder is produced first by crushing and then heating limestone which is rich in Calcium Carbonate in a kiln at temperatures in excess of 800 degrees Celsius, this burnt material undergoes a chemical change with the carbon dioxide and water that the limestone contains being driven off during the burning process resulting in a material known as quicklime (calcium oxide).

Traditional lime mortars set and harden through the process of carbonation, this is the process whereby the carbon dioxide driven of during the burning of crushed limestone is reabsorbed by the mortars pore structure from the atmosphere and in essence turns back to limestone.

7.3.3 The Lime Cycle.

To illustrate this process, we can look at what is called the Lime Cycle, this diagram shows the process from the quarrying of limestone through to the mortar's carbonation.



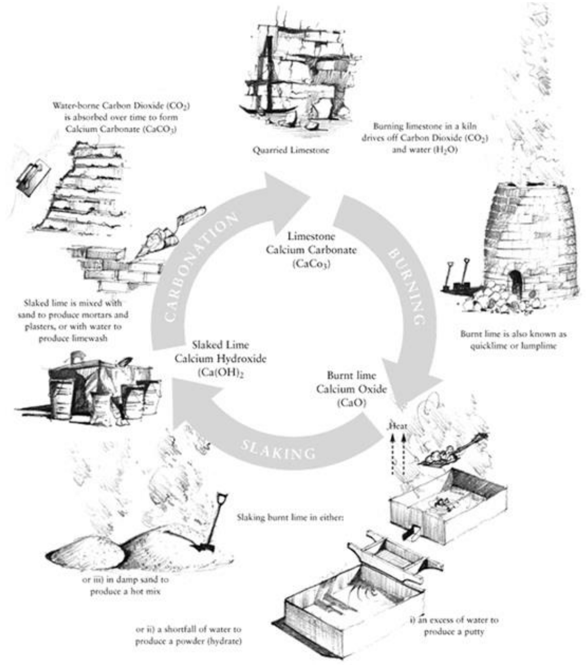


Figure 33 The Lime Cycle, image: Building limes forum.

As can be seen in figure 24, limestone (C_acCO_3) is broken down , heated to around 950 degrees Celsius which drives out the carbon dioxide (CO_2) and water (H_2O), the resulting material being quicklime (CAO), adding water to this material is known as the slaking process, during this process an exothermic reaction takes places causing the quicklime to heat.

It is at this stage many early traditional mortars were formed by adding gauged quantities of aggregates or earth to the quicklime and allowing the moisture in these materials to act as a catalyst to start the exothermic reaction and form a hot and very sticky mortar known as hot mixing.

This quick lime can be saturated in an abundance of water to produce calcium hydroxide ($Ca(OH_2)$)   a thick white putty like material that can be used in two ways as a putty, mixed with aggregates to produce mortars and plasters or mixed with just the right amount of water to form a powder known as hydrated lime.

As previously mentioned, the mortars that are produced in this fashion have no chemical or initial set and thus rely totally on carbonation to achieve their full strength.

7.4 Hydraulic mortars.

As discussed in the history of mortars, the desire to achieve harder, faster stetting mortars with a greater crushable strength and ability to set under water led to the development of mortars produced by adding pozzolanic materials, such as volcanic ash and crushed burnt clay based materials such as bricks and pan tiles by the Romans, as documented in the works of Vitruvius which allowed the roman builders to construct larger fortifications, grand public buildings and jetties.

This adding of impurities that gives lime mortars a hydraulic set can also occur naturally in certain limestone formations which have specific quantities of silica and alumina present.

Depending on how much or how little of these materials are present naturally in the limestone, will determine the amount of hydraulic set that a mortar made from such limestone will achieve.

Lime's produced by burning limestone with naturally occurring impurities are called Natural Hydraulic Lime (NHL's).

These hydraulic limes are broken down into three subcategories, depending on the percentage of impurities present.

- **Feebly Hydraulic = less than 15 percent (usually between 5% -10%) NHL 2**
- **Moderately Hydraulic = 15% - 25% NHL 3.5**
- **Eminently Hydraulic = 25% - 30% NHL 5**

TABLE 5-1
HYDRAULIC LIMES

No.	Item	Feebly hydraulic lime	Moderately hydraulic lime	Eminently hydraulic lime
1.	Clay content	5 to 10%	11 to 20%	21 to 30%
2.	Slaking action	Slakes after few minutes	Slakes after one or two hours.	Slakes with difficulty.
3.	Setting action	Sets in water in 3 weeks or so.	Sets in water in one week or so.	Sets in water in a day or so.
4.	Hydraulicity	Feeble	Moderate	Eminent
5.	Uses	The mortar produced by this lime is reasonably strong and hence it can be used for ordinary masonry work.	The mortar produced by this lime is strong and hence it can be used for superior type of masonry work.	The mortar produced by this lime is similar the ordinary cement and hence it can be used for damp places.

Figure 34 Properties and performance of Hydraulic lime.

Hydraulic limes have changed considerably since the time of their development by the likes of Smeaton who as discussed developed and refined hydraulic mortars in the 1700s while searching for a suitable mortar for the reconstruction of the Eddystone light house.

The compressive strengths of these mortars are far greater than those produced using quicklime (Calcium Oxide) or lime putty's (Calcium Hydroxide), with breathability decreasing with the increase in impurities present in the binder.

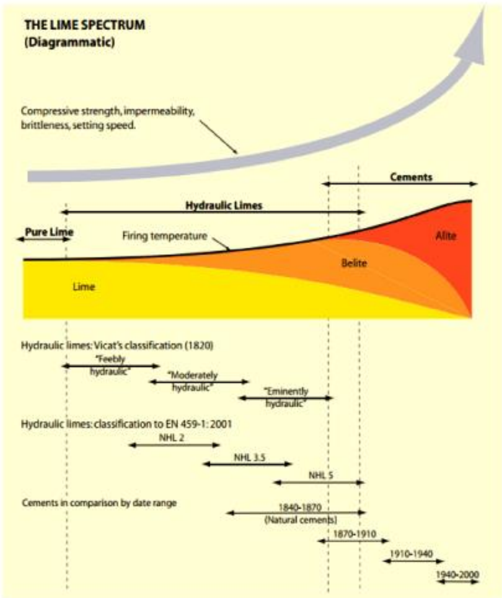


Figure 36 The lime spectrum, Mortars, Renders and Plasters.

As can be seen I figure 32, the correlation between compressive strength, permeability, flexural strength and setting speed will depend on the firing temperature and the purity of the limestone that is burnt, with pure lime stone between 100% and 94%being of greater porosity and flexibility than that of limestone with high amounts of reactive clay.

7.4.1 Compressive strength.

Current British Standard (BS EN 459-1 2015) for measuring compressive strength of hydraulic lime mortars is based on the minimum compressive strength achieved over twenty-eight days and are shown in the unit of Mpa (megapascals).

BS EN 459-1:2015
EN 459-1:2015 (E)

Table 17 — Compressive strength of natural hydraulic lime given as characteristic values

Type of natural hydraulic lime	Compressive strength MPa	
	7 d	28 d
NHL 2	—	≥ 2 to ≤ 7
NHL 3,5	—	≥ 3,5 to ≤ 10
NHL 5	≥ 2	≥ 5 to ≤ 15

Figure 37 Compressive Strength of hydraulic lime mortars after 28 days, British Standard BS EN 459.

The way in which modern hydraulic limes are often referred to as being of one of three classifications, **NHL 2 feebly hydraulic, NHL 3.5 moderately hydraulic** and **NHL 5 eminently hydraulic,** could give the wrong impression as to the true compressive strength that they will achieve.

Modern hydraulic limes are considerably stronger than their historic counterparts, with modern so called **feebly** hydraulic NHL 2's being more consistent in terms of compressive strength with that of traditional **moderately** hydraulic limes, with this in mind the difference will also equate to the materials porosity and flexural strength.

The problem with the testing of hydraulic lime mortars over twenty-eight days is that hydraulic lime mortars take a lot longer to reach their full strength than that of the twenty-eight-day test period, in some instances taking years to fully carbonate and set to their maximum strength.

The 1966 British Standard for limes shows that a feebly hydraulic lime which at the time was classed as "Semi Hydraulic" could be expected to achieve somewhere in the range of 0.7 - 2Mpa after the 28 day test period, this is comparable to a cured air lime (hot mix, lime putty) which could take up three months to gain a compressive strength similar to that of its feebly hydraulic counterpart.

Comparing this to a modern feebly hydraulic NHL 2 which is expected to reach between 2 – 7Mpa in the 28 day test period but in all probability will carry on gaining in compressive strength for up two years. [39]

These tests could lead to the conclusion that an NHL3.5 would be of average compressive strength and be suitable to be used as a binder for mortars that require a mid-range of porosity and flexural strength, when in fact after the twenty – eight day period described in the compressive strength test these mortars are actually reaching compressive strength comparable or exceeding with that expected of an NHL5, with NHL 5's reaching compressive strengths associated with modern cement.[40]

In my experience the significance of compressive strength when assessing traditional mortars used and in the production of a repair mortar for use what could be considered low status vernacular construction is often over emphasised, with many traditional earth lime mortars that I have handled being of a compressive of much less than that of the mortars that have been specified and produced as suitable repair mortars.

8 Hydraulic lime current thinking.

Over the last thirty years, modern hydraulic limes have been widely used in the conservation and restoration works carried out on traditional buildings across the United Kingdom, throughout Northern Europe and North America.

These modern hydraulic limes have been used widely as a replacement of cementitious mortars and plasters commonly used throughout the twentieth century as almost a panacea to make up for the knowledge loss regarding the production and uses of traditional mortars.

Examples such as restoration works carried out in the late nineteen seventy's on Wells cathedral acted as a catalyst in the search for more durable lime mortars, where non hydraulic lime mortars were developed for the use repointing and the consolidation of and conservation of fragile limestone sculptures, these mortars utilized the use of

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[39] Copsey, N. (2019). Traditional hot mixed lime mortars for conservation and repair. *Journal of Building Survey, Appraisal & Valuation.* 8 (1), P 4.

[40] English Heritage. (2011). Treatment and Repair. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. 251.

pozzolans to achieve some degree of hydraulicity but in areas of great exposure proved to be unsuitable, this search for more durable lime binders led to a shift towards Hydraulic lime imported from Europe, mortars produced using these modern hydraulic limes were faster setting and more resilient than that of their non hydraulic counterparts but over the next two decades, the users of these modern Hydraulic limes began to fear that modern Hydraulic limes were too strong and hard for many of the applications that they were being used.

The fact that modern hydraulic limes are still classified as being either **feebly**, **moderately or eminently** hydraulic by manufacturers and suppliers has led to a great deal of misuse, as earlier produced hydraulic limes had very different compressive strengths and were used very differently to how they are today, with traditional **feebly** hydraulic limes sometimes called "semi hydraulic" lime only obtaining a maximum compressive strength comparable to the minimum compressive strength of modern NHL2.[41]

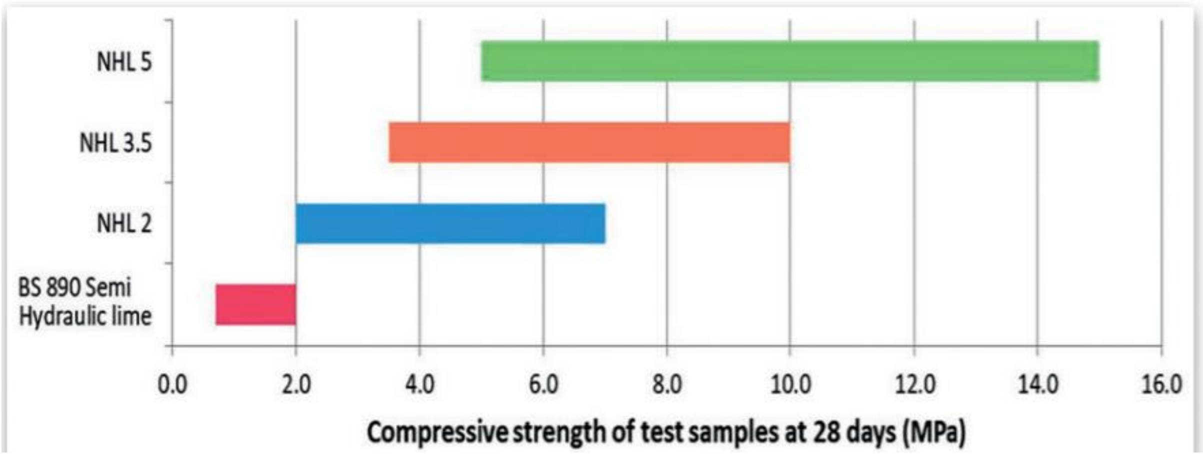

Figure 38 Compressive strength of modern hydraulic limes compared with an early "Feebly Hydraulic lime".

In my experience over the last seven years, it is often the case that NHL3.5 and NHL5 are being grossly misused, for example I was recently shown a specification for the dismantling

[41] Henry, A. (2019). *the new lime revival.* Available: https://historicengland.org.uk/content/docs/research/ctx154-henry-hot-mixed-mortarspdf/. Last accessed 10th feb 2020

and rebuilding of a traditional Flemish bond Dwarf brick wall, the mortar that was originally used its construction was of a very soft, coarse grained lime rich consistency that was very easily removed from the very soft, uneven, and irregular shaped handmade bricks, these bricks were to be reused and relayed with a mortar that is to be produced using an NHL5.

The fact that this wall was able to be saved and rebuilt is owing to the soft and flexible nature of the original mortar, this mortar could be very easily removed, thus allowing a large percentage of the original bricks, to be salvaged and reused.

The use of a modern NHL5 as a binder for the relaying of the wall will in all probability lead to issues in later years with the brick becoming the sacrificial element of the structure as opposed to the mortar used in its laying and pointing, when that time comes and the decision is made to rebuild the wall, the bricks will in all likelihood not be able to be cleaned of their new extremely hard mortar and thus will have been recycled for the last time.

9 Mortar testing and analysis.

To understand the composition of mortars there are a wide variety of ways in which analysis can be carried out that range in complexity, from the very simple visual analysis that can divulge useful information such as whether a mortar is made from a blend of aggregates or of earth with the inclusion of animal hair or other natural fibre such as straw, through to the sometimes complex and often expensive chemical analysis that all too often requires samples to be sent away to specialist labs.

Mortar analysis may be carried out for a number of different reasons, such as to

- Establish the composition of a mortar to assess its age and constituent parts.
- Determine causes of deterioration or failure of a mortar.
- To facilitate and aid the production of a suitable repair mortar.

The need for testing and analysis should be determined by the required outcome, the significance of the building and the nature of the work intended to be carried out, for example it, in most cases will not be required to undertake costly lab based testing methods such as **X-ray diffraction** or **Scanning electron microscopy** to undertake remedial works such as patch repairs or the tidying up masonry pointing on modest or low significance building.

The most critical part of any mortar analysis is the initial visual assessment of the mortar and the building or site as a whole and understanding them in context and how they may play a part in the significance or in the aesthetic of a building. Identifying if the mortar in question is the original used in the construction of a building or is it a later addition, the location and reason of failed mortars, will all aid in the process of selecting a replacement.

In all instances it is best practice to select the least intrusive and destructive method that will give the necessary results required.

When selecting tests to be carried out on traditional mortars or on any part of a buildings fabric the following factors should be kept in mind.

- **Age of the materials.**

Many historic buildings will have building fabric that has been included over the evolution of a building and may need to be assessed and distinguished chronologically.

- **Use of the material in question.**

Is the material to be tested appropriate for the development of replacement materials, eg taking samples of bedding mortar to develop a mortar for the pointing of masonry. In many cases these were very different in how they are produced and how they function.

- **Number of samples required.**

It may be necessary to take multiple samples from an area or through multiple layers of building fabric., in this case the number of samples to be taken will be limited due to the fragile nature of the building with maximum benefit being made of those samples.

- **Sample size.**

Different methods of testing and analysis may require different size samples.

- **Location of the sample.**

The location from where a sample is taken can have an effect on the condition and quality of information it will yield, for example, samples taken from close to ground level may be more contaminated than those taken from higher up a buildings elevation by such things as salts or algae.

9.1 Types of testing and analysis.

Wet Chemical Analysis.

This is the reaction of a mortar sample with various chemical reagents that can establish the presence and volume of different mortar components. The most common form of wet chemical analysis is an acid dissolution to determine the amount of binder, the degree of hydraulicity of binders and the ratio of binder to aggregate.

The obvious drawback with this method is that if the mortar contains any aggregate consisting of calcium carbonate such as limestone or marble or organic material such as hair or other natural fibres, these materials will in all probability be lost and dissolved by the acid.

Scanning Electron Microscopy (SEM).

Scanning electron microscopy is a form of petrographic analysis that magnifies samples by up to 2000X magnification, mortars are typically examined in very thin polished sections using backscattered electron imaging, this gives a black and white image in which different minerals and materials can be distinguished on the basis of their composition, identifying individual pores and crystals.

These images can be analysed digitally to give estimations of the porosity of a sample.

X-Ray Diffraction.

X-ray diffraction can be used to highlight crystalline materials, such as mineral composition of binders, pozzolans, aggregates and products of weathering.

This is best adopted to highlight the presence of minerals as opposed to quantity.

9.2 Aggregate Grading and Particle Distribution.

The way in which a mortar will perform, and function is highly dependent on the on the size, shape and distribution of the particles that make up that aggregate, these factors will contribute significantly to the workability, permeability and strength of a mortar.[42]

A well graded aggregate will be made up of a broad range of particle sizes with the smaller particles filling up the voids between the larger particles but leaving enough space for the particles that of binder that will bring the mortar together into a workable paste.

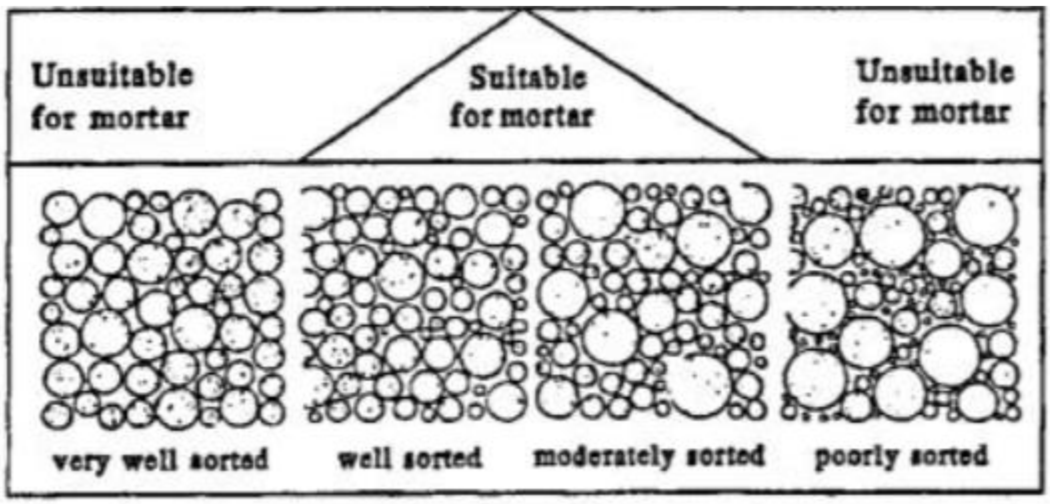

Figure 39 Aggregate distribution in mortars, Historic Environment Scotland (TAN19).

A well graded aggregate will be critical in the compressive strength achieved by a mortar in how an aggregates range in size and shape of particles have the ability to interlock together.

[42] English Heritage. (2011). Treatment and Repair. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p 256-258. & Historic Environment Scotland. (1999). Methods of analysis of Mortars and Aggregates. *A guide to the availability and suitability of aggregates for use in mortars to match those used in historic buildings in Scotland.* 19 (3), P 18.

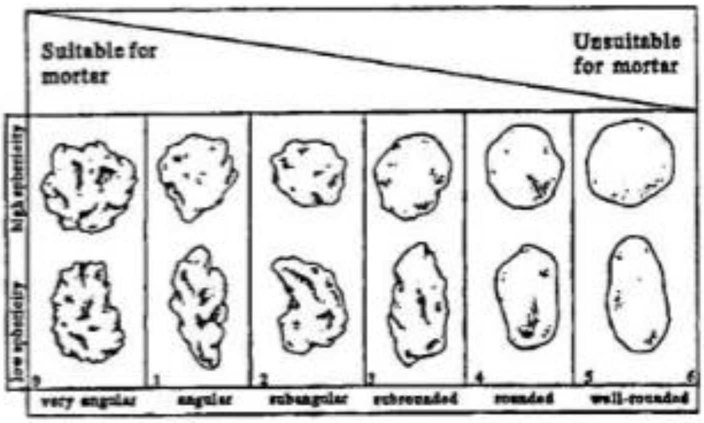

Figure 40 Shape of Aggregate Particles. Historic Environment Scotland (TAN 19).

The shape of aggregate particles will be influential in how workable a mortar will be, with more rounded particles having the ability to roll around each other and therefore able to be compacted more tightly than that of sharp or angular aggregate particles.

Workability is a key feature of a good mortar, often in my experience, mortars made with more angular particles take a lot longer to mix and often feel "dead" or lacking in plasticity as the binder will coat rounder particles easier, when using more angular grained aggregates to produce mortars, there is often the temptation to add more water to achieve a workable material, this is will increase the shrinkage experienced as the water leaves the mortar.

Mortars made from aggregates with angular particles will however be grater in compressive strength due to the fact that these particles are able to interlock more efficiently with more friction between particles.

9.3 Particle Size Distribution.

Particle size distribution relates to the overall spectrum of grain size in an aggregate or mortar, the particle size of and distribution in a mortar will be integral to the compressive strength, workability, porosity and permeability that it will be able to achieve.

A well graded aggregate will have a broad range of particle sizes varying between 5mm and 63 microns ($_{um}$) with no more than 30% of the total mass being of one size, ideally with the largest quantity of grain size being in the middle of that range.

Particle size distribution of aggregates is determined by using a set of British Standard (BS 410-1 2000) sieves to sort and collect the different size particles within that aggregate.

Figure 41 British Standard Sieves, Joe Moriarty.

The material retained in each section of the sieve being weighed, recorded and expressed as a percentage of the total mass of the sample.

The current British Standard for aggregates is BS EN 1319:2002 defines “fine” aggregate particles as those passing through a 4mm sieve and “fines” being those that pass through a 0.063 mm (63 microns $_{um}$).

The range of particle size will play a fundamental role in the porosity and permeability of a mortar with well graded aggregates creating a mortar with better porosity.

Porosity is relative to the ratio of voids to solid matter that a material has, permeability is the ability of that material to transfer fluids which is dependent on the degree of connectivity between those voids.

A good mortar will have a balance of porosity and permeability achieved by having wide range of pore sizes linking together to assist the free transfer of liquids and vapour.

Mortars containing high concentrations of fines (under 63_{um}) are likely to be more porous than those containing a well graded aggregate.

Fine micro pores take in moisture through capillary action and hold on to moisture longer than that of larger pores which means mortars with this type of pore structure will stay wetter for longer with it being more difficult for the action of air blowing across the surface of the material to draw out moisture.[43]

The pore structure will also be significant in how a mortar deals with freeze thaw action with larger pore structure being able to accommodate ice crystals without disrupting the material and causing failures.[44]

10 Methodology.

Having decided to carry out the rebuilding of Pant y Celyn, it was evident from its current precarious condition that a suitable mortar would need to be produced for the of bedding masonry and wall core material.

To carry out this task it was decided to combine both qualitative and quantitive research to build a picture of Pant y Celyn's history, significance, building fabric and construction.

Current thinking as to best practice with regard to the repair and restoration of historic buildings as set out by CADW states that repair or intervention should have a minimum impact on the significance and character of a building and that when designing repairs they should allow for the maximum retention of significant original fabric. [45]

With this in mind firstly it was decided to find out as much information as possible with regards the history of the area in which it was built, the original owners of the building, the evolution of the building and the materials that have gone into its construction.

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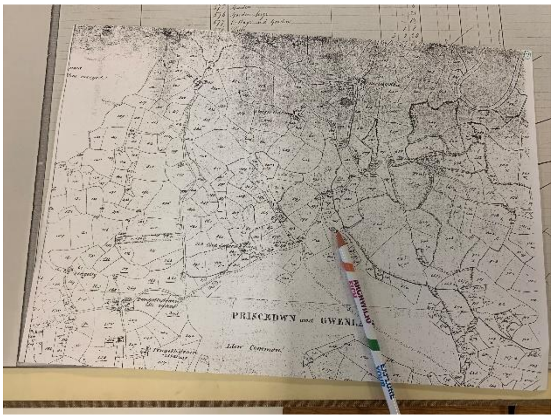
[43] Wiggins, D. (2019). *Functional Behaviour of Traditional Lime Mortar.* Available: https://www.curtins.com/wp-content/uploads/2018/06/Functional-Behaviour-of-Traditional-Lime-Mortar_RIBA-June-2018.pdf. Last accessed 15th Feb 2020.

[44] English Heritage. (2011). Treatment and Repair. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited. p 242-267.

[45] CADW. (2019). *Conservation Principles in Action.* Available: https://cadw.gov.wales/advice-support/conservation-principles/conservation-principles-action. Last accessed 15th Feb 2020.

These factors all helping to ascertain the potential significance of the building.

Information held in the Swansea City archives in their collection of Tithes and data regarding field numbers, made it possible to identify the landowner, tenant of the site and approximate age of the building.



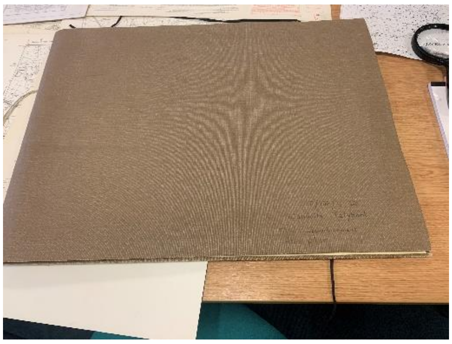


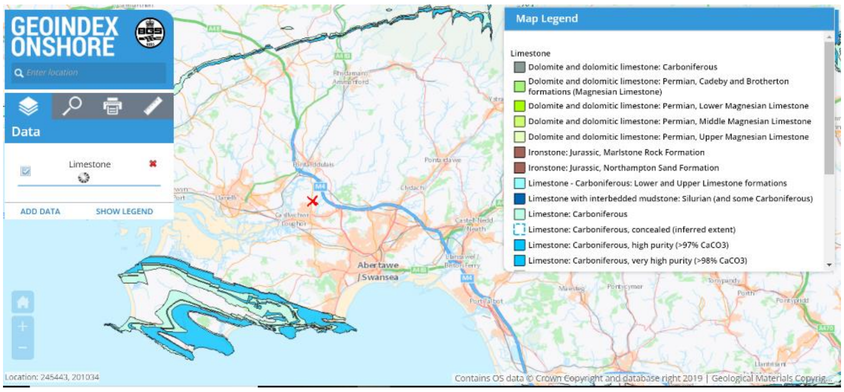
Figure 42 Tithe and Field Number Material at Swansea City Archives, Joe Moriarty.

Having identified the landowner and tenant of the site, the next step I decided was to build a picture of what the building once may have looked like, how it was constructed and what it was constructed from.

Through the process of conducting my literature review I was able to form an opinion as to the possible style of and methods used in the construction of other vernacular buildings in the area surrounding Pant y Celyn that were built at around the same time.

Other aspects looked at through the course of the literature review were the availability of construction materials found in the locality of Pant y Celyn.

From data obtained from sources such as the British Geological Survey and Soilscape maps, useful information as to the geology and soil type of the area, which when taking into account the age, identifiable materials that remain at sight and the nature of the buildings intended use, would have been significant factors in how the building was constructed.



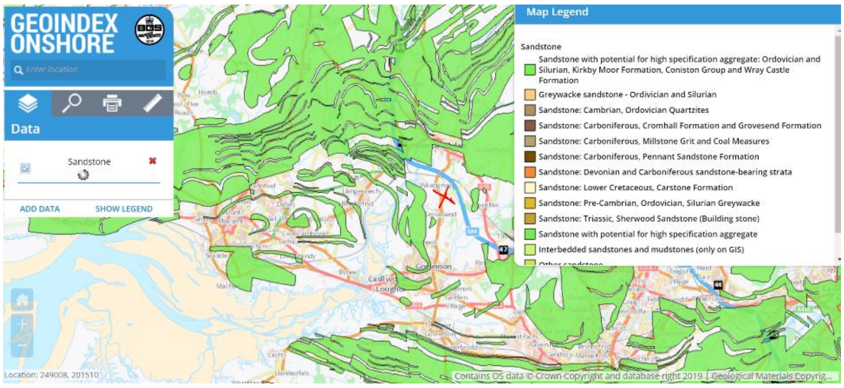


Figure 43 British Geological Society, Geoindex Onshore.

When we consider the vernacular nature of low status buildings of this time the above information is key when one considers introducing new materials into a site, as any new materials should be as close to the original as possible and not detract from the buildings character.

Using this data, I was able to then look for sources of construction materials that were local to Pant Y Celyn, using Ordinance Survey maps published in 1880. These maps provide the location of three elements that could in my opinion have been played a role in the construction of Pant Y Celyn,

- A local source of building stone.
- Gravel pits.
- Lime Kilns. (see figures 24 & 30)

With this new data, the next step was to take samples of the mortar and also soil from the site and the location of what was once a designated gravel pit.

The location of the gravel pit was found by using the road that is shown to run parallel to the pit as a guide. (see figure 24)

Figure 44 Soil Sample Hole, Joe Moriarty.

Soil samples taken from an approximate depth of 38cm, samples then dried.

Figure 45 Dying Soil Sample, Joe Moriarty. *Figure 46 Mortar Samples, South, Joe Moriarty.*

Bedding and core mortar samples taken from south elevation within the same course, as other areas of the building not easily accessible due to ivy growth and the unstable nature of the building.

My original intention was to send the mortar samples to be tested at the Scottish Lime Centre for analysis.

The test offered by the Scottish Lime Centre are displayed in the following table.

Method of analysis		Wet Chemistry Analysis (SLCT 'Mortar Analysis by Acid Digestion')	Petrographic Analysis by Optical Microscopy	Analysis by British Standard 4551	X-Ray Diffraction (XRD)	X-Ray Fluorescence (XRF)	Physical Testing
Suitability for binder type	Lime	*	*		*	*	*
	Cement		*	*	*	*	*
	Clay / earth		*		*	*	*
Results available	Visual description	*	*	*	*	*	*
	Original mix proportions	*	*	*			
	Visual identification of binder type	*	*	*	*	*	
	Mineralogical identification of binder type				*		
	Chemical identification of binder type					*	
	Aggregate characterisation	*	*	*			
	Aggregate grading	*					
	Aggregate match[1]	*					
	Mortar mix to match existing[2]	*					
	Physical characteristics						*

Figure 47 Scottish Lime Centre Mortar Analysis.

A quote for the desired analysis was received and was far in excess of my budget.

The decision was made to see if it was possible to re-create any of the tests offered by the Scottish Lime Centre within Cardiff University.

With time being a limiting factor and having already discovered the purity of local limestone from research carried out in my literature review, it was decided that separating the binder from the aggregate and then analysing the aggregate particle size distribution would yield sufficient enough data to be able to possibly re-create a suitable repair mortar at a later date.

Having no lab experience and not having carried out similar tests before assistance was given to me by Dr Magdalini Theodoridou who had carried out the necessary type of testing before.

After discussion, the method selected for the separation of the binder from the aggregate was a dissolution in acetone, this was decided because using a hydrochloric acid would not only remove the binder but also dissolve any organic matter that may be present in the mortar.

To carry out the test, it was necessary to seek permission from the lab supervisor Richard Thomas and to complete a lab induction and health and safety briefing at the concrete and soils lab in the engineering department, Queens building Cardiff.

<u>Process of separating binder from aggregate.</u>

Sample confirmed dry visual analysis.

Bedding Mortar South corner. Gently broken down in pestle and mortar to a manageable test size and put in sample tin 31 and weighed.

Tin 31 sample pre-test weight 100.2 Grams.

Tin 31 passed through riffle to roughly divide sample randomly, weight after passing 53.61 grams, test sample material then saturated in acetone and placed in ultrasound bath for ten minutes to help sperate the binder from aggregate material.

Figure 48 Process of Separation, Aggregate from Binder, Joe Moriarty.

After ten minutes sample removed from ultrasound bath, contents poured into 63_{um} aperture sieve, brushed through then put back in pestle and mortar gently reagitated, re-saturated in acetone then placed back in ultrasound bath for a further ten minutes.

Process repeated Fourteen times, with numbers nine – fourteen the time left in ultrasound bath increased to 15 minutes under advice of Dr Magdalini Theodoridou.

Once the binder has been removed from the aggregate via dissolution (visual identification with only a clean aggregate left on top of 63_{u}m sieve), sample is then placed in an oven and dried at 40 degrees Celsius, below the flash point of acetone, both the binder and aggregate weighed again, weight recorded with the weight of the binder subtracted from the samples original weight.

The same process was carried out on core Mortar sample South corner. Tin 93 pre-test weight 100.9 grams

Passed through riffle – weight after passing 56.36 grams.

Ultrasound bath x 14.

The next stage was to analyse the Particle Size distribution of the aggregate that was removed from the binder by placing the sample in a set of British Standard Sieves ranging from 5mm – 63$_{um,}$ test was carried out in accordance with BS EN 10151-1-1999 Methods of test for mortar for masonry, part 1: Determination of particle size distribution (by sieve analysis).[46]

Figure 49 British Standard Sieve. Moriarty.

Figure 50 Vibration Plate, Joe

The sieve test was also carried out on the two soil samples designated **Site Soil Sample & Gravel Pit Sample** to look for any correlation between the aggregate used in the mortar and the soil samples taken.

The aggregate remaining in each section of the sieve was weighed, recorded and subtracted from the original mass of sample and worked out into a percentage.

[46] BS EN 1015-1-1999
Cardiff University
15 Feb 2020

Figure 51 Particle size Distribution. Joe Moriarty.

It was decided that due to time constraints only the **south bedding mortar** would be analysed and compared with the **site soil** sample and **Gravel pit sample to look** for correlation between samples.

11 Findings.

There are two main sets of results from the process to assess the; aggregate separation from binder and sieve particle size distribution analysis.

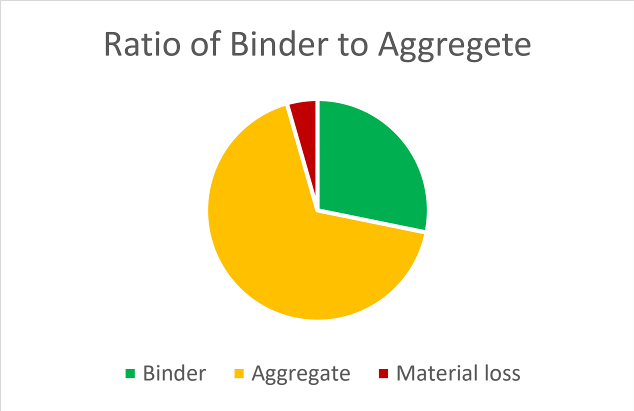
11.1 Separation of Binder from Aggregate

The results below show the separation of the binder from the aggregate first the **South Bedding Mortar** sample and then the **North Bedding Mortar** sample.

11.1.1 South Gable Bedding Mortar

The table below shows the results from the aggregate separation process for the sample **South Bedding mortar**.

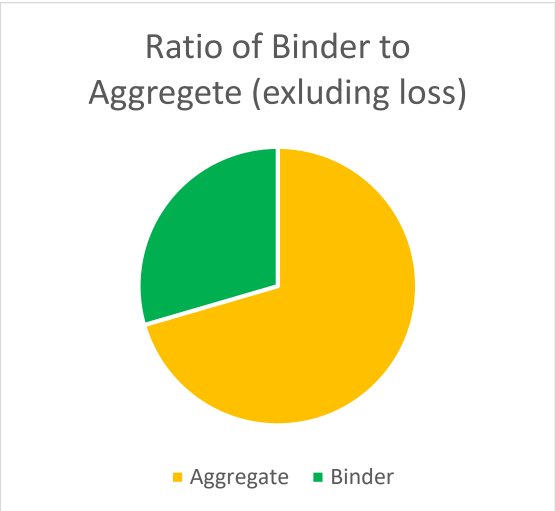
Material	**Weight (g)**	**Percent of sample**
Aggregate	36.11	67.36%
Binder	15.12	28.20%
Material loss	2.38	4.44%
Total	**53.61**	**100.00%**



The sample went through the acetone separation process 14 times and lost 2.38 grams of material in doing so, this accounted for 4.44% of the total 53.61g sample.

Material (excluding lost material)	Weight (g)	Percent of sample
Aggregate	36.11	70.49%
Binder	15.12	29.51%
Total	**51.23**	**100.00%**

When the lost material is excluded there is an approximate ratio of **2.4 : 1**



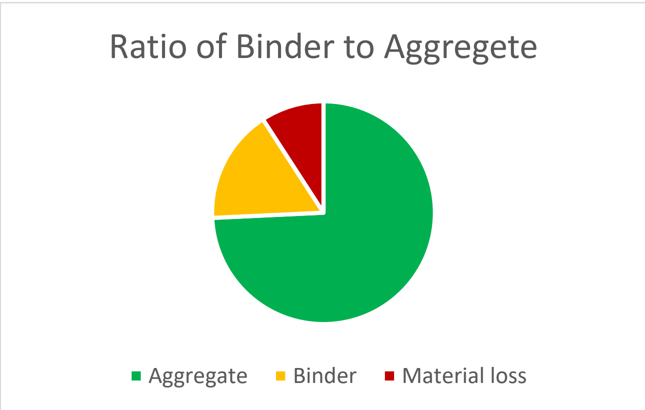
When the lost material is excluded there is an approximate ratio of **2.4 : 1**

Aggregate to Binder Ratio	12.036 : 5.04
Simplified	2.4 : 1

11.1.2 South Gable Core Mortar

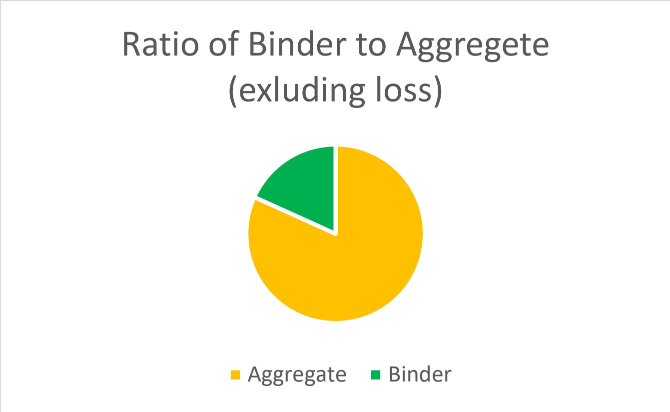
The table below shows the results from the aggregate separation process for the sample from the south gable core mortar.

Material	Weight (g)	Percent of sample
Aggregate	41.85	74.25%
Binder	9.35	16.59%
Material loss	5.16	9.16%
Total	**56.36**	**100.00%**



The sample went through the acetone separation process 14 times and lost 5.16 grams of material in doing so, this accounted for 9.16% of the total 56.36g sample.

Material (excluding lost material)	Weight (g)	Percent of sample
Aggregate	41.85	81.74%
Binder	9.35	18.26%
Total	**51.2**	**100.00%**



When the lost material is excluded there is an approximate ratio of **4 parts aggregate to 1 part binder**.

Aggregate to Binder Ratio	41.85:9.35
Simplified (approx)	4:1

11.2 Sieve Analysis of Particle Size Distribution

The results below show the results of particle separation analysis for 3 samples; South Gable Core Mortar, Site Soil Sample, Gravel Pit Sample.

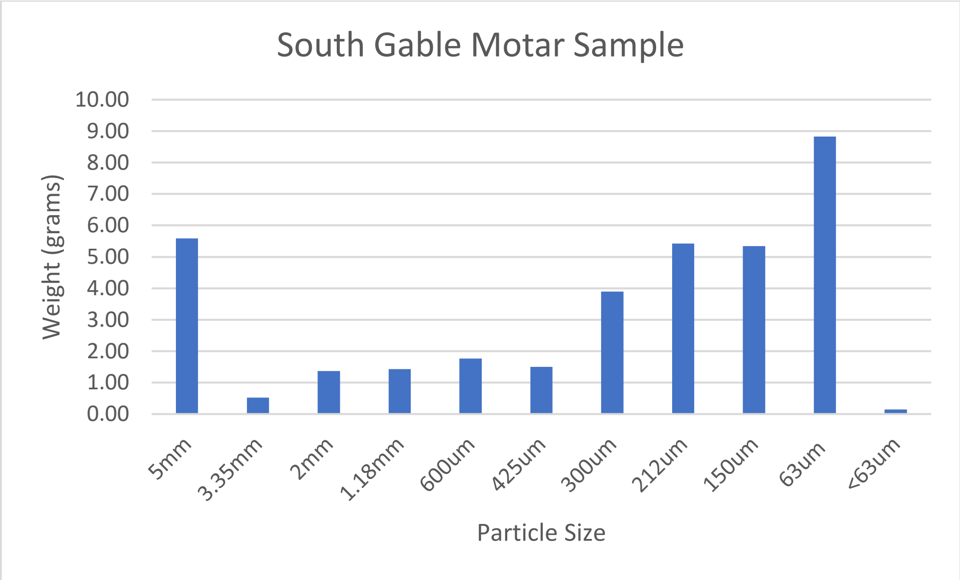
11.2.1 Individual sample results

The 3 samples were all passed through British Standard Sieves and placed on a vibraplate. The results are shown below:

South Gable Core Mortar Sample

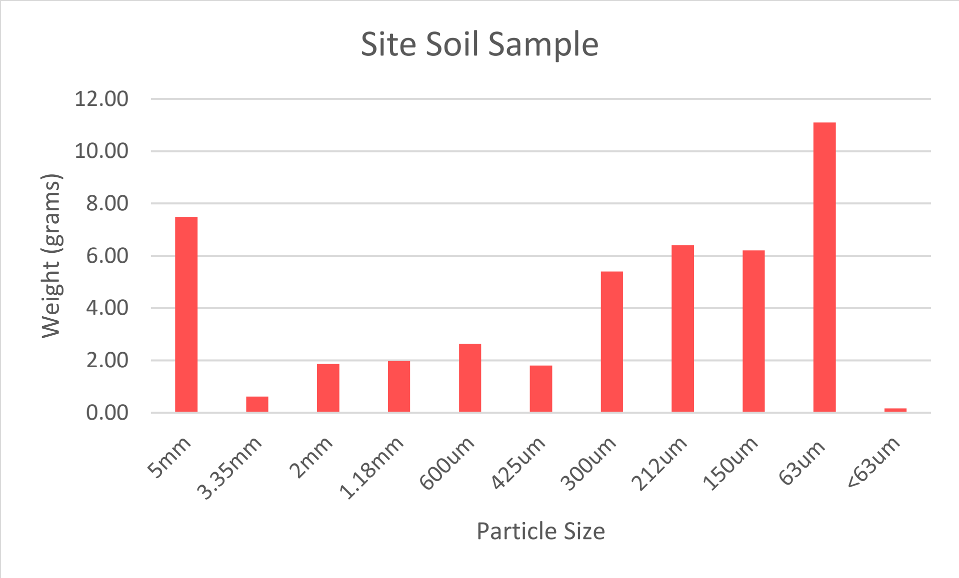
Sieve Size	Weight (grams)	Percentage(%)
5mm	5.59	15.61%
3.35mm	0.52	1.45%
2mm	1.37	3.82%
1.18mm	1.43	3.99%
600um	1.77	4.94%

425um	1.50	4.19%
300um	3.90	10.89%
212um	5.42	15.13%
150um	5.34	14.91%
63um	8.83	24.65%
<63um	0.15	0.42%
Total	**35.82**	**100.00%**



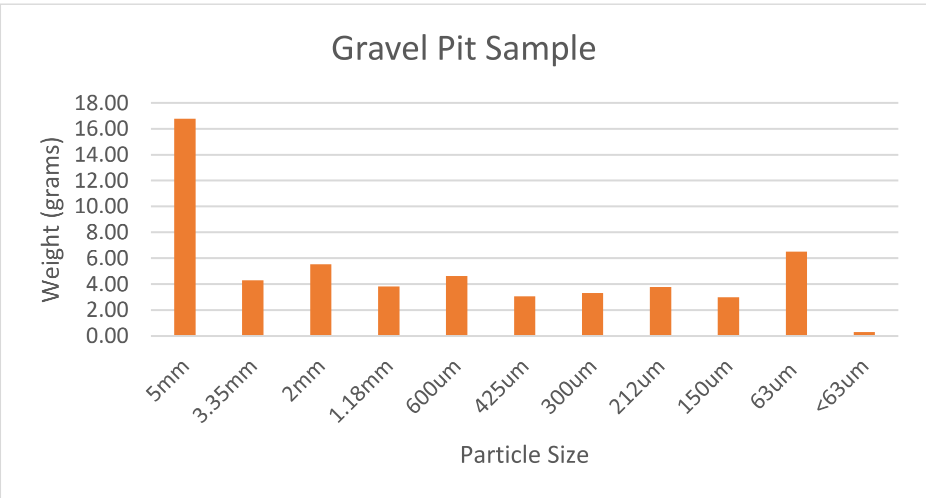
Site Soil Sample

Sieve Size	Weight (grams)	Percentage(%)
5mm	7.49	16.40%
3.35mm	0.62	1.36%
2mm	1.87	4.10%
1.18mm	1.98	4.34%
600um	2.63	5.76%
425um	1.80	3.94%
300um	5.40	11.83%
212um	6.40	14.02%
150um	6.20	13.58%
63um	11.10	24.31%
<63um	0.17	0.37%
Total	**45.66**	**100.00%**



Gravel Pit Sample

Sieve Size	Weight (grams)	Percentage(%)
5mm	16.78	30.49%
3.35mm	4.28	7.78%
2mm	5.52	10.03%
1.18mm	3.83	6.96%
600um	4.64	8.43%
425um	3.06	5.56%
300um	3.32	6.03%
212um	3.79	6.89%
150um	2.99	5.43%
63um	6.52	11.85%
<63um	0.31	0.56%
Total	55.04	100.00%



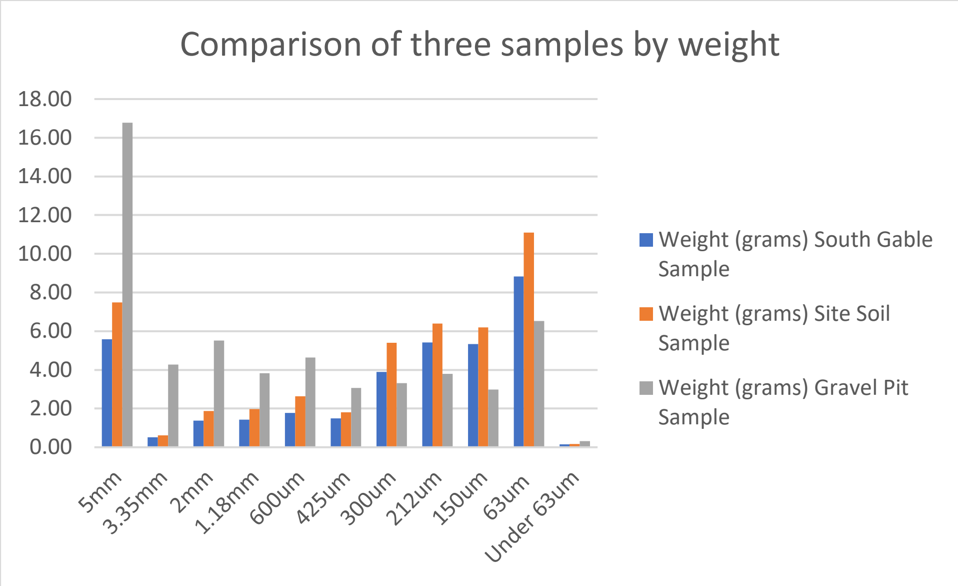
Weight (grams)			Percentage			Difference (Gable to Soil)	Difference (Gable to Gravel)
South Gable Sample	Site Soil Sample	Gravel Pit Sample	South Gable Sample	Site Soil Sample	Gravel Pit Sample		
5.59	7.49	16.78	15.61%	16.40%	30.49%	-0.80%	-14.88%
0.52	0.62	4.28	1.45%	1.36%	7.78%	0.09%	-6.32%
1.37	1.87	5.52	3.82%	4.10%	10.03%	-0.27%	-6.20%
1.43	1.98	3.83	3.99%	4.34%	6.96%	-0.34%	-2.97%
1.77	2.63	4.64	4.94%	5.76%	8.43%	-0.82%	-3.49%
1.50	1.80	3.06	4.19%	3.94%	5.56%	0.25%	-1.37%
3.90	5.40	3.32	10.89%	11.83%	6.03%	-0.94%	4.86%
5.42	6.40	3.79	15.13%	14.02%	6.89%	1.11%	8.25%
5.34	6.20	2.99	14.91%	13.58%	5.43%	1.33%	9.48%
8.83	11.10	6.52	24.65%	24.31%	11.85%	0.34%	12.81%
0.15	0.17	0.31	0.42%	0.37%	0.56%	0.05%	-0.14%
35.82	**45.66**	**55.04**	**100.00%**	**100.00%**	**100.00%**		

These individual results show a clear correlation of particle size distribution between the South Gable Core Mortar sample and the Site Soil Sample. Both these samples have a low proportion of particle above 300um and a larger proportion of the sample with particle size smaller than 300um. The Gravel pit sample has a much greater proportion of the sample classified as non-sediment (i.e. greater than 5mm) than the other two samples, and it also has a much more even distribution of particle size.

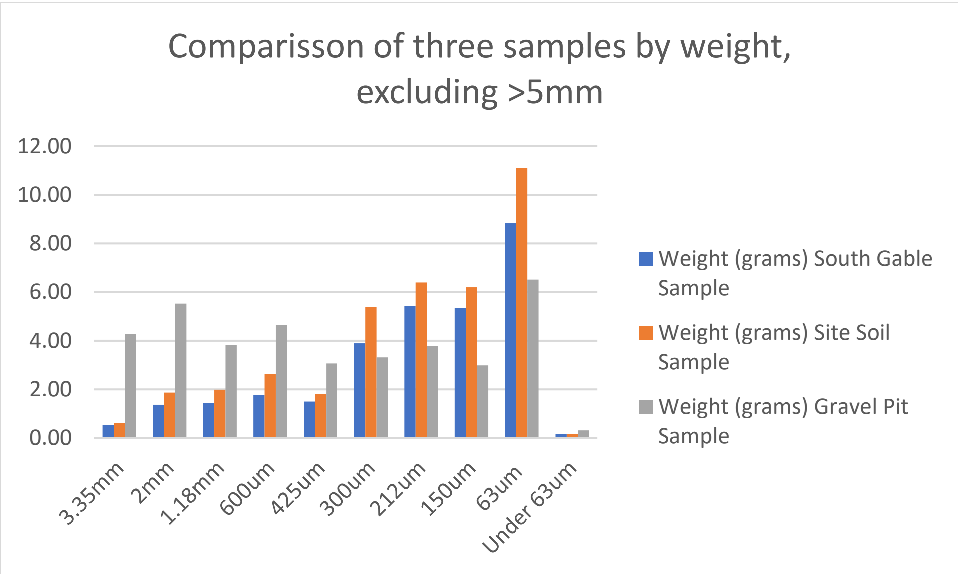
11.2.2 Comparison of Samples

The two soil samples (Site Soil Sample and Gravel Pit Sample) can be compared to the South Gable Bedding Mortar sample.

The graph below shows the distribution of particle size for the 3 samples. There is a clear correlation between the particle size distribution for the South Gable and Site Soil Sample. The Gravel Pit sample shows different distribution of particle sizes.



As the Gravel Pit sample has (as expected) a larger proportion of particles greater than 5mm the samples were then compared excluding this particle size from the data.



Excluding the large particles (greater than 5mm) from the sample data, there is still a clear correlation between the South Gable and Site Soil samples. The Gravel Pit sample is still completely different distribution of particle sizes to the other two samples, with a more even distribution through all sieves sizes than the other two samples, that have the majority of their composition made from particles smaller than 400um.

12 Conclusion

In writing this dissertation, my main objective was through a combination of qualitative and quantitive research, to be able to make suggestion as to a suitable mortar that could be used in the restoration of Pant y Celyn.

Using the buildings location as a starting point, I was able start piecing together information that would slowly build a bigger of the building and the site as a whole.

By firstly establishing an understanding of the local history, then combining that information with data gathered from archive material regarding the ownership of the land and the tenants that lived on and worked the site, It was possible to begin to assess any significance the building may have had in the area.

This type of building at one point would have been of a very common architectural style for the area [47] and would have been viewed as just another example of a small farmworkers cottage with very little difference from any other, but when looking at the building today I am of the opinion that the building is of significance to the area as there are very few buildings of this style still intact that have escaped alteration.

Once the significance has been assessed it was then possible to begin to think about the materials that are likely to have been used in the construction of Pant Y Celyn and the relationship they would have with the land around the site in which it was constructed.

By studying data produced by sources such as the British Geological Society, Ordnance Survey and DEFRA, it was possible to draw conclusions as to the likely nature of building fabric and its availability within the area.

It was also possible to identify potential sources of building materials, such as local disused quarries, Gravel pits, lime kilns and a source of limestone for the production of mortar, having data that gave evidence to the purity of the limestone found locally was extremely useful as this is imperative when trying to formulate or recreate a mortar for use in repair or restoration as it will play a major role in the performance of that mortar.

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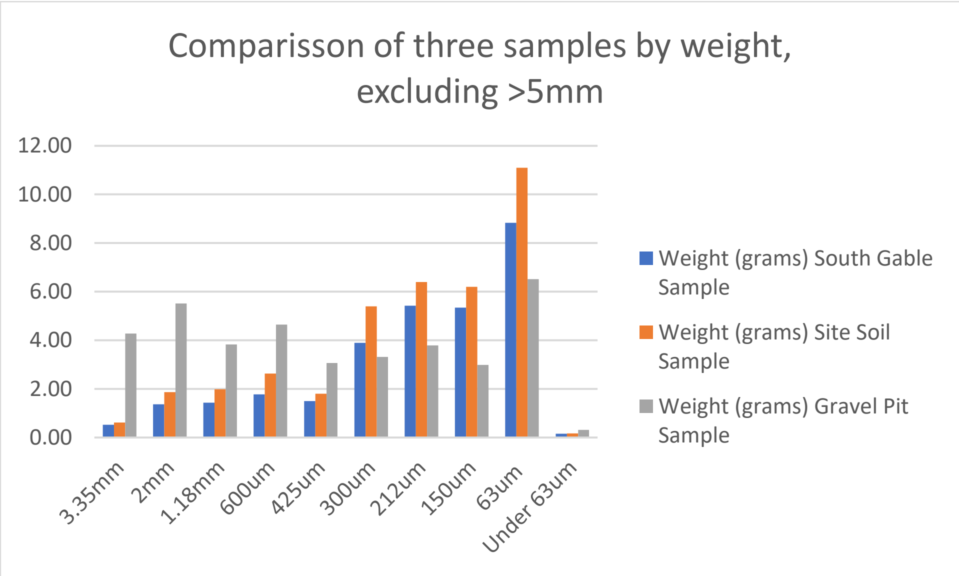
[47]Morris, B (1998). *Old Gower Farmhouses and their Families*. Llandybie: Dinefwr Press. P 135-137.

Having this information regarding the location of sites that possibly would have been utilized by traditional builders as sources of building material was crucial for this paper. It made it possible to take samples from these locations and the building itself and look for any correlation that there might be between those samples.

The results of the tests proved most interesting by showing clear correlation between the **Site Soil Sample** and the mortar sample taken from site, designated **South Bedding Mortar.**



Analysing this data shows that in all probability the earth used in the production of mortar for the building of Pant y Celyn came from the field in which its sits.

Although the presence of a gravel pit within short distance of the site can be identified quite easily today, this may not have been the case at the beginning of the 19th C when this house was built.

From assessment of the particle size distribution of the mortar sample and the sample obtained from the gravel pit it could be concluded that if a repair mortar is to be formulated, then ideally the earth should be taken from the location of the gravel pit as this materials has a far better range of aggregate particle size and a more even distribution of those sizes.

To formulate a mortar, due to the lack of readily available locally produced quicklime, I suggest using Calbux 90 (a high purity quicklime < 90% pure) Quarried in Buxton, that is of a similar purity of limestone found locally.

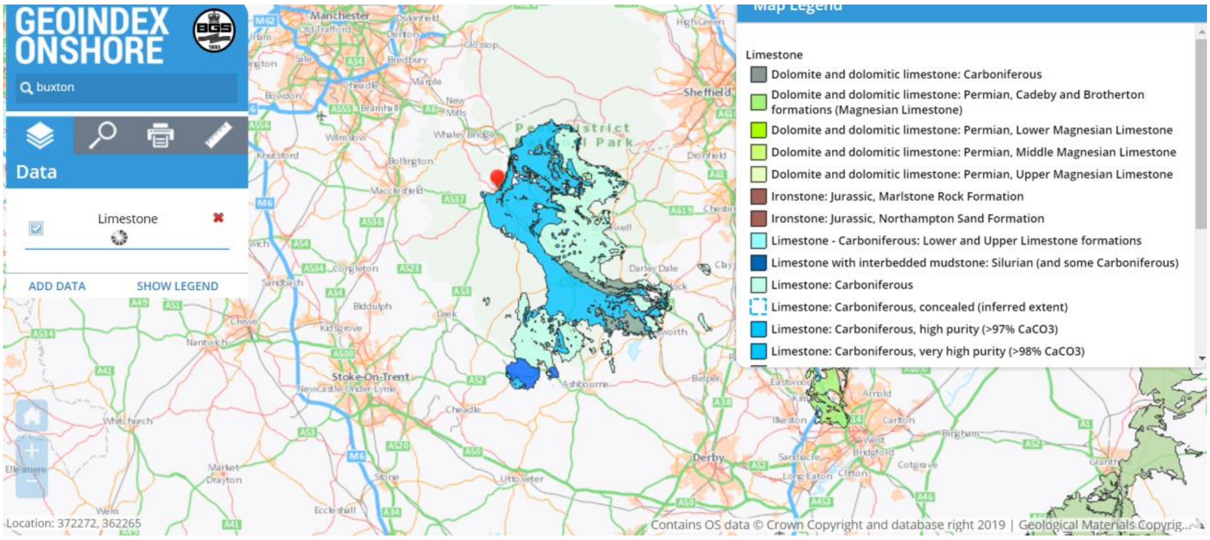


Figure 52 Buxton Limestone. Geoindex Map.

Although examples of vernacular architecture differ greatly depending where they are found and the materials found local to those buildings, I believe the way in which this paper examines available data sets and the comparison of that data with site samples, forms a picture of local building materials that then allows informed decision making when considering materials to be selected for the use in the repair and maintenance of traditional buildings could be utilized by others that require similar outcome.

12.1 Areas of further study

A suggestion of further study would be to build in monitoring systems during the reconstruction of Pant y Celyn, that would record the performance of the newly built sections over the course of its reconstruction and in later years.

In my experience opportunity's to analysis the performance of newly constructed solid walls utilising earthen mortars are fairly uncommon and with current thinking leaning towards the use of more traditionally accurate mortars, would be beneficial as away of furthering our understanding of the capability's and performance of such walls.

13 Bibliography

Ashurst, J (2002). *Mortars, Plasters and Renders in Conservation*. Leominster: Orphans Press Ltd.

Barry C. Burnham, Jeffrey L. Davies (2010). *Roman Frontiers in Wales and The Marches*. london: Royal commission on the Ancient and Historical Monuments in Wales.

Blundell, C (2007). *Precious Inheritance*. Barry, Vale of Glamorgan: Quinto Press.

British Geological Survey. (). *Discovering Geology.* Available: https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html. Last accessed 7th Nov 2019.

British Geological Survey. (). Sedimentary Rocks. Available: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=PES. Last accessed 5th Feb 2020.

British Geological Survey. (). *The composition of limestone.* Available: https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/limestoneLandscapes/whatIsLimestone/composition.html. Last accessed 7th Nov 2019.

British Society of Soil Science. (). *Soil Forming Factors and Processes.* Available: https://www.soils.org.uk/soil-forming-factors-and-processes. Last accessed 26th Jan 2020.

BS EN 1015-1-1999 Cardiff University 15 Feb 2020

CADW. (2019). *Conservation Principles in Action.* Available: https://cadw.gov.wales/advice-support/conservation-principles/conservation-principles-action. Last accessed 15th Feb 2020.

Cardiff University . (2013). BSI Standards Publication. *Guide to the conservation of historic buildings*.

Cardiff University . (2015). BSI Standards Publication. *Definitions, specifications and conformity criteria* . 1

Cranfield University 2020. *The Soils Guide.* Available: www.landis.org.uk. Cranfield University, UK. Last accessed 30/01/2020

Cemex. (). *Educational Guide to Aggregates.* Available: https://www.cemex.co.uk/documents/45807659/45840198/mortar-aggregates.pdf/47b32d0f-7a4a-f1f9-4551-8bbe39fbeb90. Last accessed 10th feb 2020.

Cemex. (). *Educational Guide to Aggregates.* Available: https://www.cemex.co.uk/documents/45807659/45840198/mortar-aggregates.pdf/47b32d0f-7a4a-f1f9-4551-8bbe39fbeb90. Last accessed 10th feb 2020.[1]

British Geological Survey. (2019). *Geo Shore Index.* Available: https://mapapps2.bgs.ac.uk/geoindex/home.html. Last accessed 15th Feb 2020.

Coflein. (). *Burrows Lodge.* Available: https://www.coflein.gov.uk/en/site/18149/details/burrows-lodge. Last accessed 7th Nov 2019.

Coflein. (2019). *Castell Ddu.* Available: https://coflein.gov.uk/en/site/303962/details/talybont-castle-hughs-castlecastell-du#archive. Last accessed 28th OCT 2019.

Coflein. (). *StTeilos.* Available: https://www.coflein.gov.uk/en/site/94698/images/. Last accessed 28th OCT 2019.

Copsey, N. (2019). Earth and Earth Lime Mortars. In: *Hot Mixed Limes and Traditional Mortars*. Wiltshire: The Crowood Press Ltd

Copsey, N. (2019). Traditional hot mixed lime mortars for conservation and repair. *Journal of Building Survey, Appraisal & Valuation.* 8 (1)

Cowper, A D. (1998). Pozzolanas. In: Donhead Publishing *Lime and Lime Mortars*. 2nd ed. Dorset: Donhead.

Davies, G (2017). *Pontarddulais Tinplate 1866-1961*. Pontarddulais: The University of the third age.

English Heritage. (2011). Materials & History of Use. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited.

English Heritage. (2011). Materials & Sources. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited.

English Heritage. (2011). Mortars Renders and Plasters: A Historical perspective. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited.

English Heritage. (2011). Treatment and Repair. In: Bill Martin and Chris Wood *Mortars, Renders and Plasters*. Farnham: Ashgate publishing Limited.

English Heritage (2014). *Building Environment*. London: Ashgate publishing Limited. 5.

Emlyn Thomas. (1987). The Dillwyn Family. *Llwchwr Society.* 12 (6).

Frew, C. (2005). Mortar Specification by Design . *The Journal of the Building Limes Forum*. 12 (1)

Gerald Davis, Maybery Evans, Huw Jones (2017). *Pontarddulais Tinplate 1866-1961*. Swansea: Macmillan Distribution MDL.

Gwynne, A. (2016). Upgrading traditional buildings and using lime and modern applications. *Firest of Dean District Council, upgrade traditional buildings using lime and modern applications*. 2

Historic Environment Scotland. (1999). Methods of analysis of Mortars and Aggregates. *A guide to the availability and suitability of aggregates for use in mortars to match those used in historic buildings in Scotland.* 19 (3).

Henry, A. (2018). Hot mixed Mortars: the new lime revival. *Context*. 154 (1).

Henry, A. (2019). *the new lime revival.* Available: https://historicengland.org.uk/content/docs/research/ctx154-henry-hot-mixed-mortarspdf/. Last accessed 10th feb 2020

Holmes, S and Wingate, M (2006). *Building with Lime* . Rugby: yidg publishing .

Howe, J A. (2001). Sandstones and Grits. In: Donhead Publishing. *The Geology of Building Stones*. Dorset: Donhead.

Iorwerth C. Peat (1940). *The Welsh House A Study in Folk Culture*. Felinfach: Llanerch Publishers. P 10 - 31.

L.J.Vicat (1997). *Mortars and Cements*. London: Donhead Publishing Ltd.

Lough, Janice; Wigley Tom and Jones, Phil; “Spatial patterns of precipitation in England and Wales and a revised homogeneous England and Wales precipitation series”; in *Journal of Climatology*; Volume 4.

Morris, B (1998). *Old Gower Farmhouses and their Families*. Llandybie: Dinefwr Press.

National Museum Wales. (). *St Teilos.* Available: https://museum.wales/stfagans/buildings/st_teilos_church/. Last accessed 28th OCT 2019.

Nigel Copsey (2019). *Hot Mixed Limes and Traditional Mortars*. Wiltshire: The Crowood Press Ltd.

Oxley, R (2006). *Survey and Repair of Traditional Buildings, A Sustainable Approach*. 2nd ed. United Kingdom: Donhead Publishing Ltd.

Pasley, CW (1838). *Observations on lime*. London: John Weale.

Patrick McAfee (2009). *Lime Works using lime in traditional and new buildings*. Dublin: The Building Limes Forum of Irland.

Peat, C Iorweth. (1940). Building materials. In: Oxford University press, Gwasg Gomer. *The Welsh House*. 2nd ed. Lampeter: Llanerch Publishers.

Pontarddulais town council. (2019). *Potted history of Pontarddulais.* Available: http://www.pontarddulaistowncouncil.gov.uk/Pontarddulais-Tc/potted_history_of_pontarddulais-7023.aspx. Last accessed 28th OCT 2019.

Powell, G (2000). *Survey of Gower 1764*. Wales: The Gower Society

Smith, P. (1975). Construction and Decoration. In: *Houses of the welsh countryside.*. 2nd ed. Cardiff: Royal commission on the Ancient and Historical Monuments in Wales.

The Geological society. (). *Upper Carboniferous (Pennsylvanian).* Available: https://www.geolsoc.org.uk/Groups-and-Networks/Commissions/Stratigraphy-Commission/Brief-Summary-of-British-Stratigraphy/Upper-Carboniferous-Pennsylvanian. Last accessed 7th Nov 2019.

The Gower Society. (2003). Vernacular Gower... In: *Vernacular Gower*. Carmarthenshire: Dinefwr Press.

The History of Pontarddulais (1985). E Lewis Evans, Translated by I Griffiths.

T.R Owen (1973). *Geology Explained in South Wales*. 2nd ed. Devon: David & Charles (Holdings).

Vicat, L J. (1837). On the Theory of. In: Donhead Publishing *Mortars and cements*. London: John Weale.

Vitruvius, M. (1914). Book Two. In: Morris Hicky Morgan *The Ten Books on Architecture.* New York: Dover Publications.

Watt, D (2011). *Surveying Historic Buildings*. 2nd ed. United Kingdom: Donhead Publishing Ltd.

Weather spark/Met Office. (2019). *Average weather at Pembrey Sands.* Available: https://weatherspark.com/y/147735/Average-Weather-at-Pembrey-Sands-United-Kingdom-Year-Round. Last accessed 3rd Nov 2019.

Wiggins, D. (2019). *Functional Behaviour of Traditional Lime Mortar.* Available: https://www.curtins.com/wp-content/uploads/2018/06/Functional-Behaviour-of-Traditional-Lime-Mortar_RIBA-June-2018.pdf. Last accessed 15th Feb 2020.

Wiliam, E (1988). *Home-made Homes Dwellings of the rural poor in Wales*. 1nd ed. Caerphilly: National Museum of Wales, Cardiff.