Geology Fieldwork Pembroke

By Martin Yeo

Investigation 1: A field investigation into igneous rocks, textures & structures in relation to their mode of origin & cooling histories.

Investigation 2: A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

8/10/2007 TO 12/10/2007

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Introduction

I am conducting two projects along the Pembrokeshire coast in Wales; the 1st project is on igneous rocks and the 2nd on orogenic events influencing Pembroke. This section provides maps and aerial photography for the area and all the smaller localities subject to my study.

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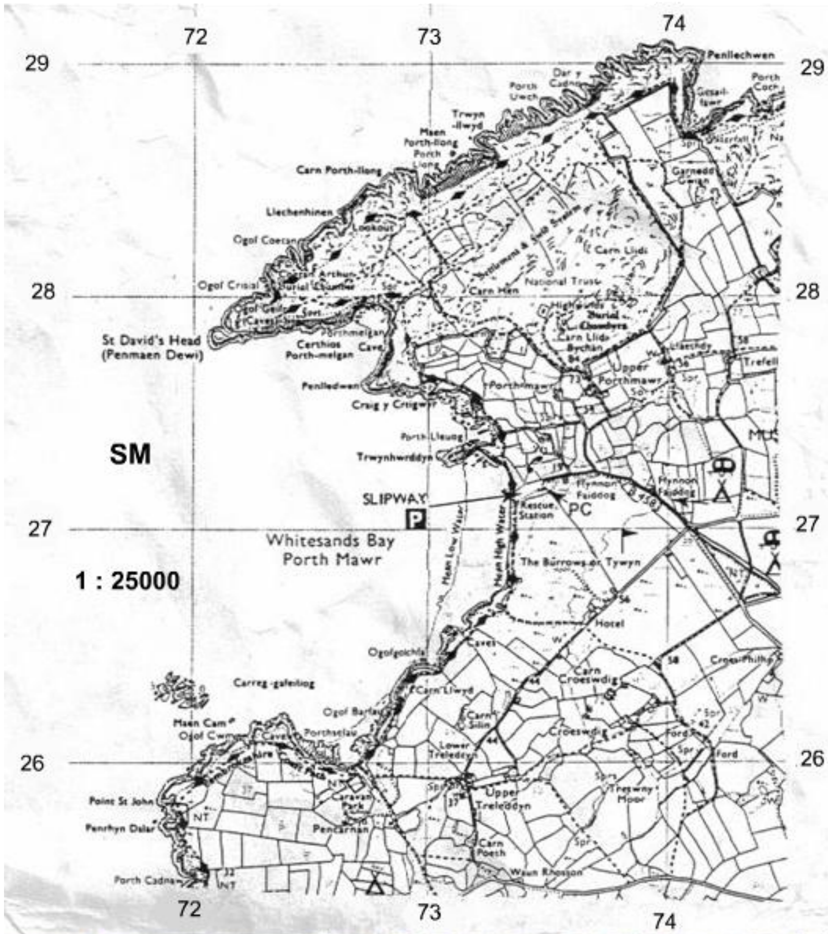
Introduction

St David's Head and Whitesands Bay



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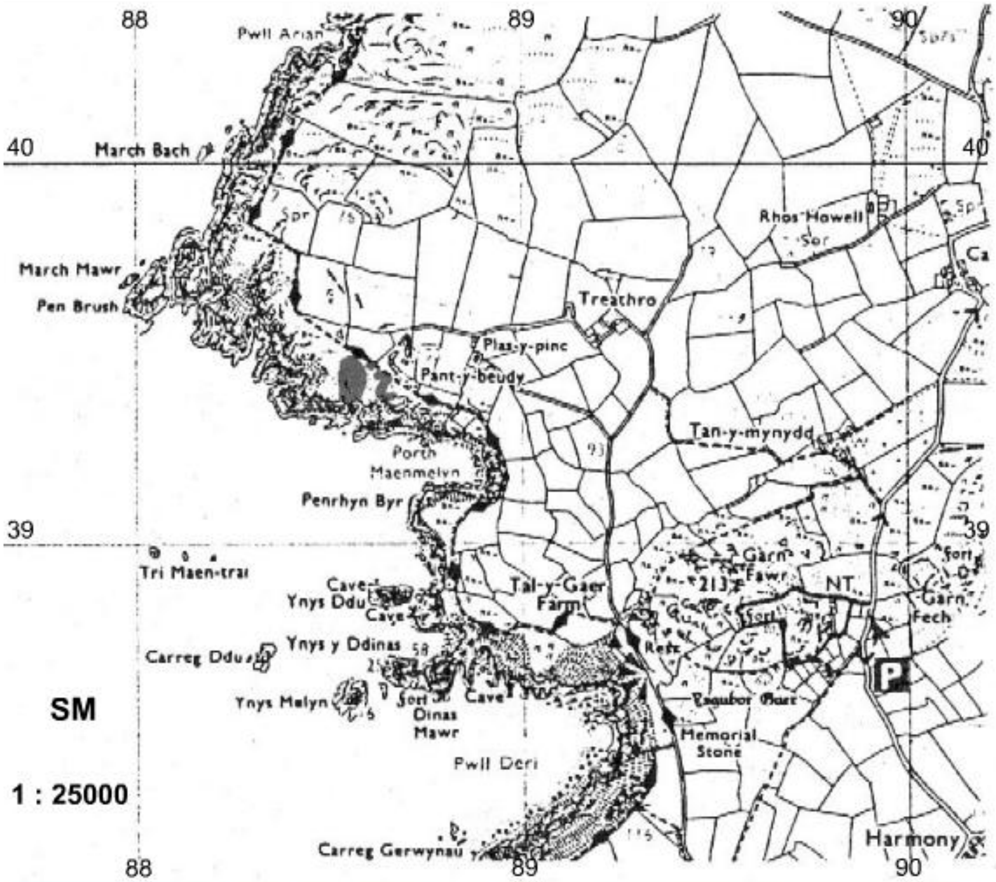
Strumble Head



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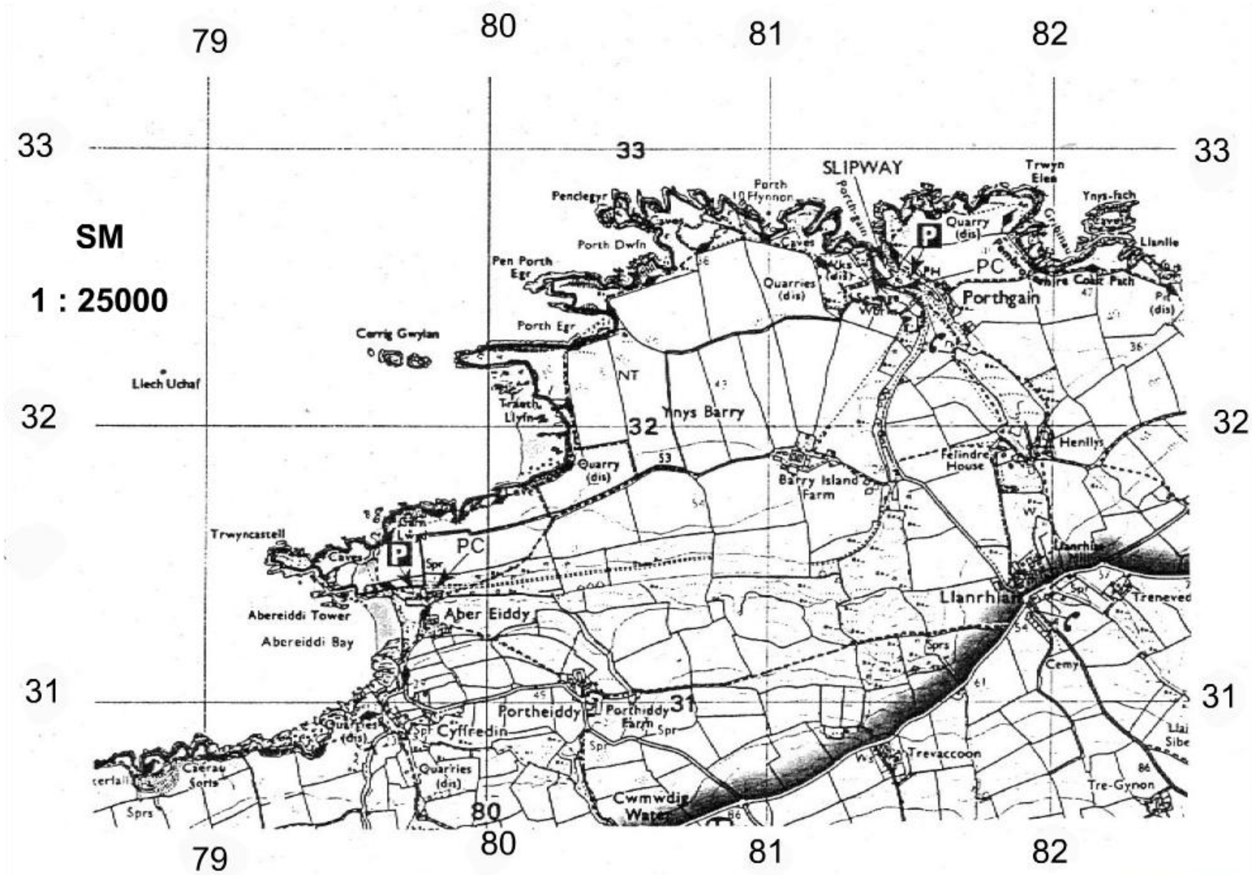
Porthgain and Abereiddy



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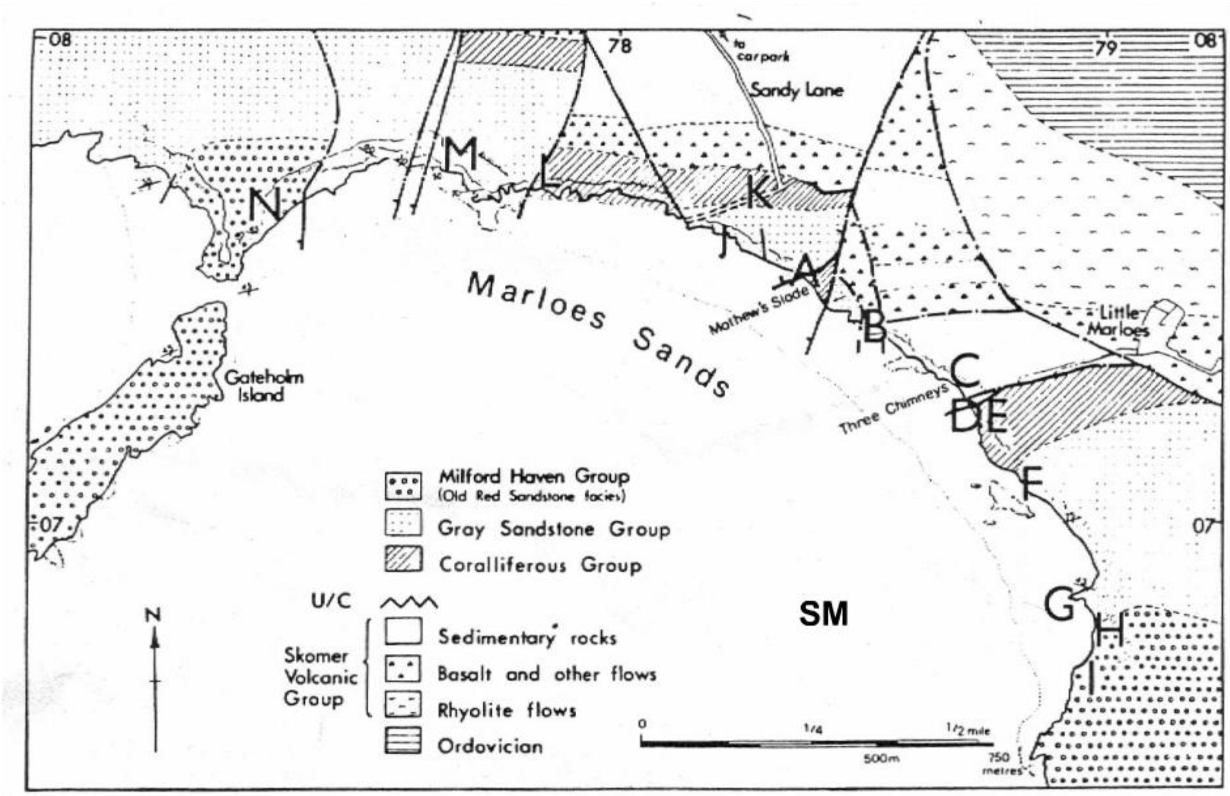
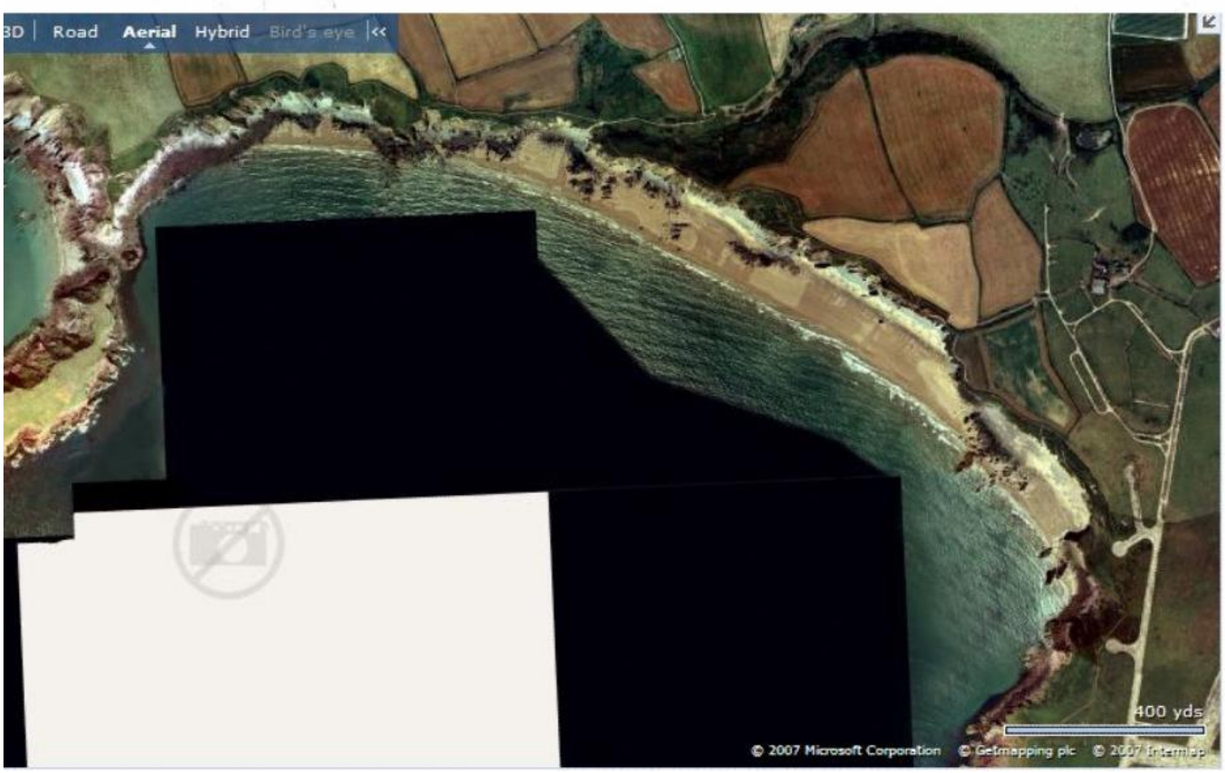
Marloes Sands





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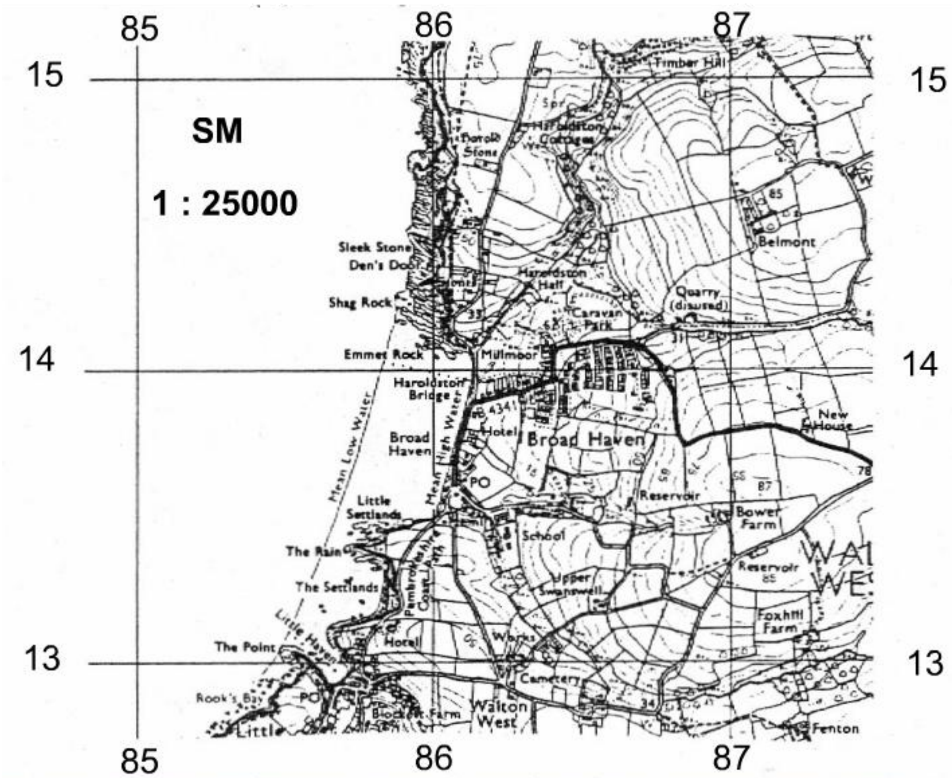
Broad Haven



A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.
Planning Sheet

WJEC A2 GEOLOGY PLANNING (tracking) SHEET GLF2

Centre Name: Brockenhurst College Centre No: 58801

Candidate Name: Martin Yeo Candidate No: 6587

1. INVESTIGATION TITLE

A field investigation into igneous rocks, textures & structures in relation to their mode of origin & cooling histories.

2. ENQUIRY FOCUS

I have already learnt theoretically about igneous textures & structures, & what they can tell us about the mode of origin & cooling history of a rock. I have chosen this investigation in order to prove/disprove these theoretical relationships.

A rock is made from an agglomeration of minerals, in igneous rocks these have crystallised from the cooling of molten rock (magma). The mode of origin (the origin & history of the original magma) & cooling history (what happened during the cooling of the magma) will influence the mineralogy of the rock, as well as its texture & any structures that it forms. On a simple level those rocks formed from molten oceanic crust will be basic & those formed from molten continental crust will be acidic; & quick cooling will produce a fine textured rock, whereas slow cooling will produce a coarse textured rock. Of course in the real world it is far more complex than this. Different cooling histories will also form different structures, for instance lava ejected from the seabed will cool quickly on the outside, forming pillow lavas.

In order to investigate these relationships in full detail, I will need to look at these factors:

- **Rock texture –** this will be the main way of identifying igneous rocks, which have an interlocking crystalline texture, with crystals of random orientation. Certain textures are diagnostic of particular cooling histories, such as a porphyritic texture.
- **Rock mineralogy –** igneous rock mineralogy varies greatly depending on the mode of origin & also the cooling history. In general, a basic magma will form a basic igneous rock, rich in olivines & pyroxenes, but acidic magma will form an acidic igneous rock, rich in quartz, feldspar & micas.
- **Igneous structures –** different structures are diagnostic of certain cooling histories, & can tell us a lot about the environment the rock was formed in.

3. PREDICTED OUTCOMES

I predict that by using igneous textures & structures, I will be able to competently predict the mode of origin & cooling history of the rock. I can cross-reference my predictions with secondary sources such as the Pembrokeshire website, but more importantly I can check my predictions using the theory in text books.

Rock Texture

Going by the theory, igneous rocks will have an interlocking crystalline texture made of crystals with random orientation. Larger crystals will be those formed by higher melting point minerals, as they have had longer to form than the smaller crystals formed from lower melting point minerals, which will have started to crystallise at a lower temperature.

Those that crystallise early on will be more able to take on their true form/habit, as there are no other crystals to obstruct their formation, this is known as **euhedral**, examples include those at the top of Bowen's Reaction Series such as olivine & calcium rich anorthite feldspar. Those that crystallise later on will not be able to take on their true form as there is little space into which they can grow, this is known as **anhedral**, examples include those towards the bottom of the series such as quartz & muscovite mica. Most crystals will be **subhedral**, where they have been crystallising at the same time & so have had some obstructions, but still show some of their true form/habit; biotite mica & potash feldspar are examples of this.

Igneous rock found at contact margins (areas close to other rock) will have fine crystals because this surrounding rock exerts a great cooling force, meaning that the magma cools quickly, producing fine crystals. Igneous rock found in the middle of an igneous body will have coarse crystals because the surrounding magma will have kept this warm for a long period of time, leading to slow cooling, which produces coarse crystals.

Crystal sizes:
- Glassy – no crystals, vitreous. Results from very fast cooling such as that in ice.
- Fine – ground mass <0.5mm diameter, crystals indistinguishable at arm's length. Fast cooling.
- Medium – ground mass 0.5 to 2mm diameter, crystals visible but unidentifiable at arm's length.
- Coarse – ground mass >2mm diameter, crystals identifiable at arm's length. Slow cooling

A porphyritic texture (large phenocrysts surrounded by fine ground mass) will be formed when the magma has first been cooling slowly in a large igneous body, allowing the high melting point minerals to begin crystallising gradually into the phenocrysts. A sudden change then brings to magma to the edge of the igneous body or to be extruded, initiating fast cooling of the remaining minerals into the fine ground mass.

<u>Rock Mineralogy</u>
Igneous mineralogy can be diagnostic of the mode of origin & cooling history of the rock. The key to this is **partial melting** & **partial cooling**, causing minerals in the magma to separate out from each other. In this way ultra-basic peridotite will form basic rocks, when partial melting does not melt the highest melting point ultra-basic minerals (olivine & pyroxene), resulting in a lower olivine & pyroxene content, & a higher calcium rich anorthite content. This process also happens at subduction zones, turning basaltic rock to andesitic (intermediate) rock; & producing rhyolitic (acidic) rock in orogenic belts. **Contamination** is another key process in magma formation; this takes place particularly at subduction zones as the magma rises up through the rock to the surface. The hot magma rising through the rock will melt the low melting point acidic minerals in the surrounding country rock, which are then incorporated into the magma. Sometimes if much contamination occurs it can significantly alter the acidity of the magma, for instance producing rhyolitic magma at subduction zones (where it should be andesitic).

Rocks that I may find:
- Ultra-basic, rich in olivines & pyroxenes.
  - Peridotite – rare to see at the surface, this is formed from complete cooling of ultra-basic magma, the source of all other magma.
- Basic, rich in pyroxenes & anorthite.
  Basic rocks normally indicate a constructive margin.
  - Basalt – a fine grained rock, usually dark in colour. Forms from quick cooling of basic magma. Indicates the edge of an igneous body, or possibly the centre of a small igneous body.
  - Dolerite – a medium grained rock (usually dark green), forming from slower cooling of basic magma than that of basalt. Will form quicker than gabbro, therefore closer to the country rock, but further from the country rock than basalt.
  - Gabbro – a coarse grained rock formed from the slowest cooling, would indicate the centre of a large igneous body.
- Intermediate, rich in albite, with notable concentrations of amphibole & pyroxene as well.

- Andesite – fine grained (due to the nature of its formation, there is rarely any coarse grained intermediate). Normally indicates a subduction zone.

- Acidic, rich in quartz, micas & potash feldspar.
  Will form in small concentrations at subduction zones, & also from the melting of continental crust in orogenic areas.
  - Obsidian – a glassy rock without any crystals, formed from very fast cooling of acidic magma such as eruption into ice.
  - Rhyolite – fine grained, forms from fast cooling of acidic magma, normally indicating close proximity to a contact margin.
  - Granite – course grained from slow cooling of acidic magma, often indicates the centre of a pluton or other large igneous body.

<u>Igneous Structures</u>

- Lava flows – extrusive igneous features formed from the eruption of lava. These appear like part of a sedimentary sequence (so are concordant), as they are extruded on top of one bed, then more sediment deposited on top of them. They display two chilled margins, but only the underlying country rock has a baked margin (where the heat from the magma has altered the country rock). The centre of a lava flow has a coarser texture than the margins due to slow cooling. The top section has a vesicular and/or amygdaloidal texture, vesicles being formed by escaping gas, & amygdales where minerals have crystallised inside these. A basic lava flow (which they normally are, as eruptions of more acidic lavas tend to be violent & explosive) will also display a red colour close to its upper surface from the 'rusting' of ferro-magnesium minerals. Lava flows can display columnar jointing. They can also be seen as way up structures as can be seen from the information above.
- Sills – concordant, intrusive features of magma. These can be identified using the fact that they have two chilled & two baked margins (as opposed to lava flows that have one baked margin). They vary greatly in thickness, from 1cm to large ones such as the Palisade Sill, which is 300m thick & displays differentiation. In larger sills the centre will display a coarser texture than the margins. Sills are symmetrical, so cannot be used as way up structures. They can display columnar jointing, but this is rarer than in lava flows.
- Dykes – a discordant intrusive magma feature of smaller scale, from 10m to 1cm thick. They are formed from basalt or dolerite, & in most aspects their structure is similar to that of a sill. They have two chilled & two baked margins, although will not be able to display such a coarse texture in the centre due to their lower thickness. Dykes can display columnar jointing.
- Volcanic plugs – the in-filled neck of an extinct volcano, can be up to 300m wide. Due to the nature of volcanoes, the texture of the magma is normally fine or medium.
- Plutons – large, roughly spherical, intrusive igneous bodies. Normally formed from acidic magma (although they can be basic), & associated with the melting of continental crust during orogenic events. There are many different types & sizes (1 to 20km across); the most important points are that small ones are known as stocks, while enormous ones (such as the one underneath the Cornwall area) are known as batholiths. Their large size means that the bulk composition (excluding contact margins) is of granites or gabbros. Plutons are normally surrounded by a metamorphic aureole, where the country rock has been metamorphosed by the heat from the magma. These metamorphic rocks increase in coarseness towards the contact margin.
- Columnar jointing – can form in lava flows, sills & dykes if no movement takes place during cooling, & conditions are uniform throughout the feature. As the magma cools, it contracts towards certain points arranged in a uniform pattern. The magma becomes more rigid as it gets cooler, & this cooling puts a strain on the rock. Eventually this strain causes the rock to fracture in a uniform pattern around these cooling points, forming a hexagonal pattern in upright columns. Sometimes this can occur in a less

uniform pattern & create polygonal jointing.

- Pillow lavas – these are formed from lava extrusion in water or ice. They are 'blobs' of lava approximately 50cm across, varying greatly in texture from the outside to the middle. The 'skin' cools very fast, forming a glassy textured rock, which insulates the magma inside, allowing it to cool slower, although probably still under a minute. The rock in the centre can be medium in texture, & sometimes vesicles can also be found close to the centre. While the magma inside can still move, the pillow lava moulds itself around its surroundings, normally other pillow lavas, & creates features known as 'saggy bottoms'. Between pillow lavas, sediment & ash will accumulate, often with high sulphur content, giving a yellow colour.

4. PRIMARY DATA

To get a proper idea of the mode of origin & cooling history of an igneous rock I will need to analyse a small area, looking at rock texture & mineralogy in several defined locations. Having located an igneous body, I will look at an area approximately $1m^2$ (which will be marked using an NGF), checking for any changes in mineralogy/texture across this area, which will then be noted in the field notebook, particularly any diagnostic features. I will also note down what feature my small area is part of (e.g. sill, pluton). I will also assign a relative age to the rock by looking at the surrounding country rock.

To describe the rock & mineral properties I will make use of a ruler to measure crystal size, mineral identification cards to help me identify the mineralogy along with a copper coin & steel blade for hardness. For finer crystals I will also use a hand lens for accurate identification. I will use a compass-clinometer to provide dip measurements complete with azimuths. I will use a geological hammer in order to take rock samples.

I cannot use random sampling because it would be likely for me to have sites that were not on igneous rocks. It is important to sample areas that have significance to the study, therefore the sampling will be stratified, sampling any igneous sections that are significantly different from each other, such as the middle of the lava flow should not be sampled repeatedly, but a sample should be taken at the contact margin, the middle & the top surface. I will not need a control area because by comparing the different areas to each other I can check that I am not drawing similar conclusions from all sorts of different igneous rocks.

After collecting data I will draw a field sketch of the wider area, marking my sampling sites on the sketch along with full annotations (NGF, compass direction, scale, rock types & structures including evidence, anything unusual), this way I can put my sample sites into context. I shall also use photographs of anything significant to provide extra visual evidence.

Safety is a key element when conducting geological fieldwork. There is a great hazard of falling rocks & rock shards from the geological hammer. There is also potential damage from hydrochloric acid, used to test the diagnostic feature of limestone. I will therefore be wearing a hard hat & safety glasses when necessary. Appropriate caution will be taken in hazardous areas, that is, not climbing rocks or standing underneath unstable rocks.

I will undertake a pilot study to check that my procedure works & is functional. I will make amendments to the method in light of the pilot study. Objectives of the pilot study are to become well versed in effective use of complex equipment such as the compass-clino, to develop a quick & efficient sampling procedure, & to flag up any issues with my procedure or coursework plan in general. It will start with a field sketch, checking that my drawing & annotations are correct & of an acceptable standard; this will be followed by rock identification with appropriate logging in the field notebook. The last thing to be done will be a dip/strike reading of a noticeable bed, & recording this in the notebook.

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I found the pilot study helpful in familiarising myself with the correct procedures while in the field. Drawing the field sketch refreshed my memory of how the sketches should be done; the rock identification introduced me to the many subcategories of sedimentary rocks beyond what I already knew. The most important help that the pilot study gave was to flag up the error in my dip/strike measurements – I was forgetting the level the compass-clinometer to zero dip before reading the azimuth. Thankfully I was able to see that I was taking these readings incorrectly & rectify these by observing others. I also realised that it was important to use an even surface when taking the reading, I shall use the field notebook placed on top of the bed, or aligned parallel with it if there is no surface on which to place it. The most important thing about the pilot study is that it gave me practice at most of the skills needed before starting fieldwork in earnest.

5. Methods of ANALYSIS/DATA PRESENTATION to be used.

The field notebook will contain much of the presentable information. Keeping this in mind I will take care to use it properly & make sure all information is well laid out an easy to interpret. I may need to practice my sketching skills before fieldwork so that I can produce good ones while in the field. The notebook shall be kept organised with appropriate use of the contents page, with samples & photographs logged in the log tables. Digital photographs will also be digitally annotated before being inserted into the write-up; they will be referenced to the appropriate page, where they will be marked on the field sketch using a code in blue ink (e.g. P5). I will use OS maps & geological maps wherever possible, also labelled digitally; these will have the sample sites marked on them, as well as labels on the geological maps of any features significant to my study.

The write up itself will consist of an analysis of field notebook data, which will be appropriately referenced to the correct page number. I will take the opportunity to represent any numerical data graphically, using a format relevant to the data I am presenting; I shall use Microsoft Excel in order to draw clear & accurate charts. In general there will not be many opportunities for numerical analysis, but more analysing each sample area & relating them together in order to identify patterns that will ultimately count towards my investigation aim.

6. Anticipated ERRORS/LIMITATIONS and steps to be taken to minimise.

The most obvious limitation is the limited time the group has in the study area. We will be spending three full days in the field, plus a few hours on the pilot study beforehand. While there is nothing we can do to increase the time we have, the limitations of this can be minimised by developing an efficient data collection procedure, using each day to its full potential & doing as much work as possible beforehand. Practice of field sketches in particular, as well as other procedures (which will be practiced on the pilot study), can be used to reduce the time taken when in the field.

Another unavoidable hindrance will be the weather conditions. There is no spare time with which to wait out bad weather, sampling must continue regardless. Therefore in order to minimise the impact of poor weather conditions, particularly rain, I shall ensure that *everything* (including equipment) I am using is waterproofed & there is no chance of wind blowing anything from my person.

The compass-clino is very easily influenced by anything with even small magnetic properties from ferro-magnesium minerals to belt buckles. All lengths must be taken to reduce these unwanted influences when recording azimuths & compass directions.

The rocks themselves can present problems when sampling. Weathered rock will not appear the same as freshly exposed rock, which may result in me missing key features. I can avoid this in most cases by exposing fresh rock using a geological hammer & looking for loose fragments of the same rock. But I must

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be careful with loose fragments also, because I am working in a coastal area, where fragments may be washed in from other areas.	
7. Degree of assistance given.	**Approved by (Supervising teacher)** **Date:**

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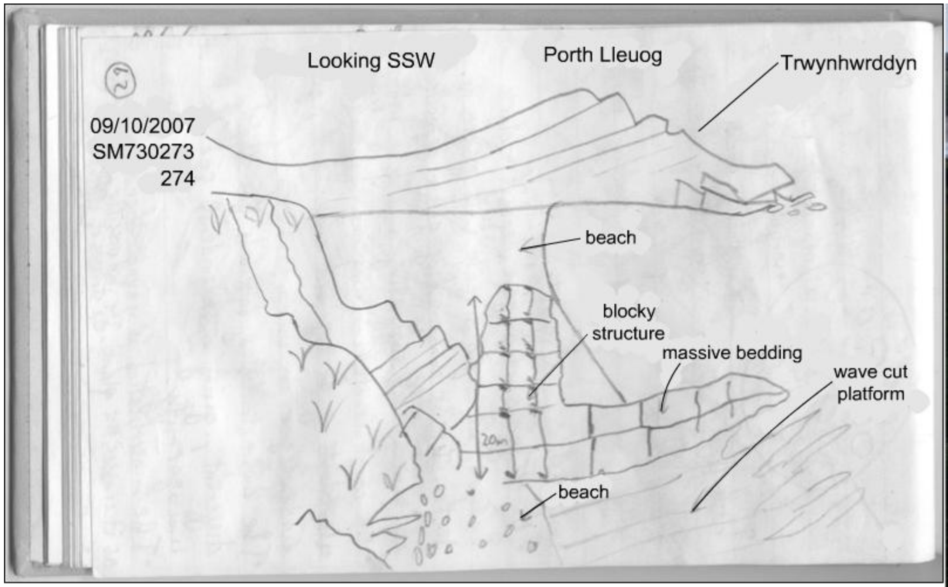
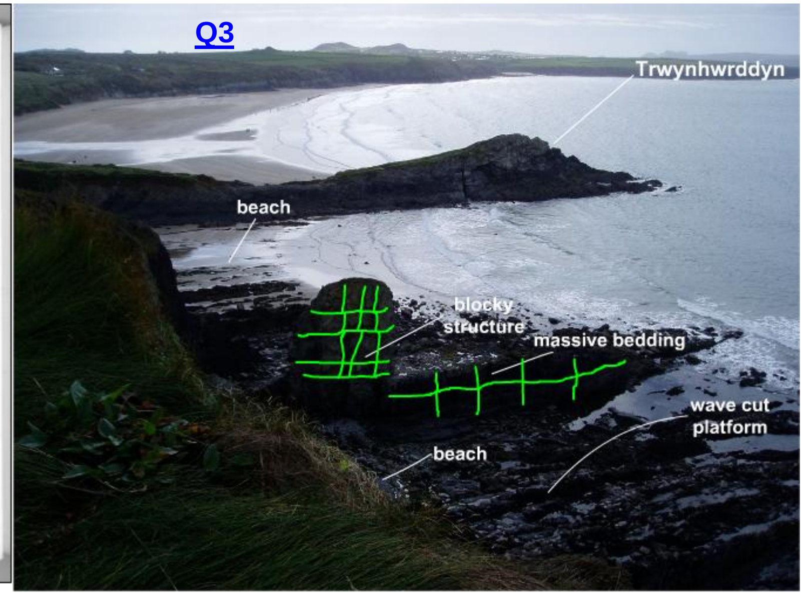
Analysis





- These promontories demonstrate how some rock types are more resistant to weathering than others, as different rates of weathering have shaped this bay (Porth Lleuog).
- The differing resistances to weathering are caused by different mineral composition and arrangement/structure.
- On the surface this doesn't seem to be anything to do with igneous rocks, especially as I have labelled bedding on one of the promontories. But further research on the internet (http://www.jdgeology.co.uk/Ordovician/Ordovician.htm) reveals that the labelled promontory in the foreground is made from rhyolitic tuff. This ash deposit is not an igneous rock, but does indicate volcanic activity in the area, which would have ejected the ash in the first place.
- I have selected this sketch in preference to Ogofgolchfa (p27 & 28 of field notebook) because this one illustrates how igneous mineralogy (as the ash was originally igneous) is normally far more resistant to weathering than other rock, such as the shales found around this feature.
- Also worth mentioning is that Trwynhwrddyn is the northerly boundary of the lingula flag beds, and is next to a fault, which could explain why this also protrudes.

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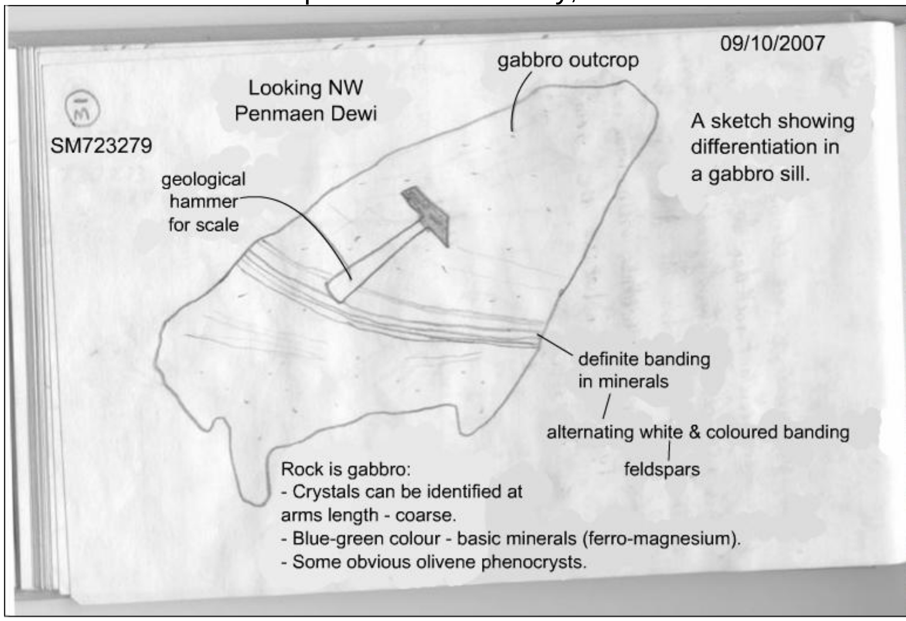
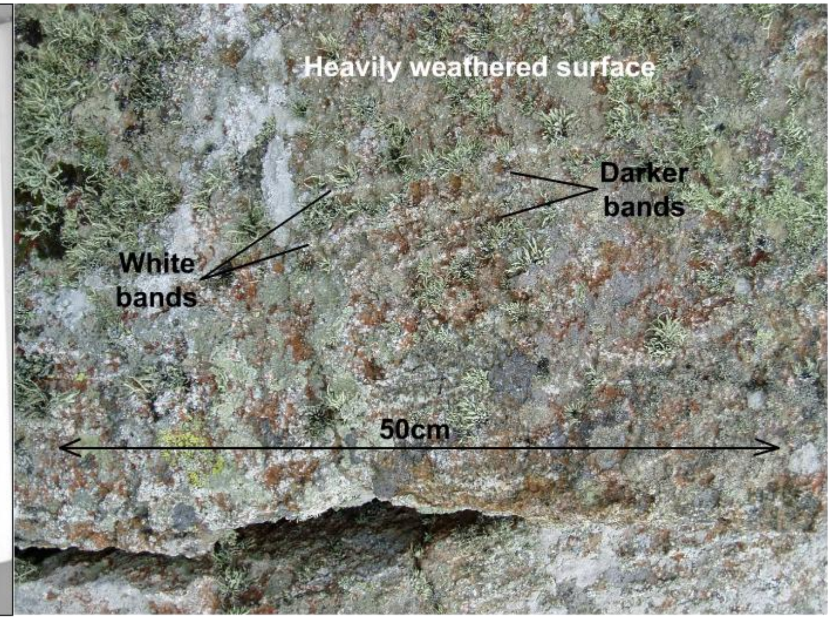
Analysis

NOTE: this is a similar picture taken nearby, but not the same rock.

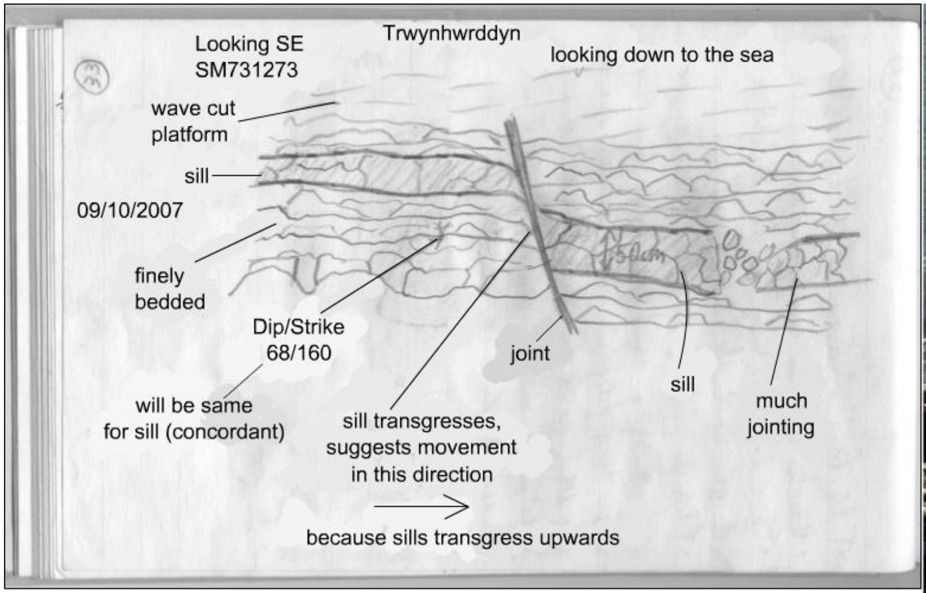


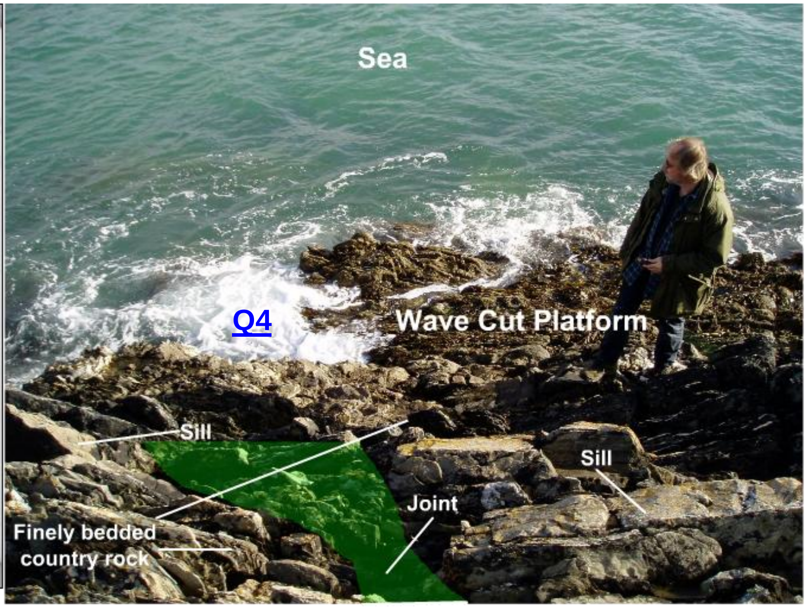


- The banding is caused by differentiation, a process where the molten rock has not moved, and taken a long time to cool. During this time, high melting point minerals such as olivine will crystallise before anything else and so sink to the bottom of the igneous body (fractional crystallisation). Denser minerals, even when molten, will also sink and so a much higher concentration of these will be found at what was the bottom of the body. The lack of movement also allows minerals of different composition (but without significant difference in density) to separate into bands of felsic minerals (quartz and feldspar) and mafic minerals (biotite and ferro-magnesium).
- I measured the bands to have a similar dip/strike trend to the bedding in the country rock, which is evidence that this igneous body is a sill, because like deposition, differentiation takes place on a horizontal plane. As a consequence the gabbro can be said to be concordant to the local trend.
- Further evidence for this being a sill is that differentiation is most common is sills, which can often remain undisturbed for long periods of time.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Analysis





- The evidence for a sill is that it has the same approximate dip and strike as the country rock, and is also symmetrical when looking perpendicular to dip.
- On either side of the joint, the beds are not altered in any way, but the sill appears to be 'displaced' – it has transgressed to a higher bed. Sills do this because they are much hotter than the country rock when intruded; this makes them less dense, so they will rise when possible. This transgression can also tell us the direction that the sill is travelling in (see field sketch annotations).
- The transgression itself provides evidence that this is a sill, because it is diagnostic – no other igneous feature can transgress.

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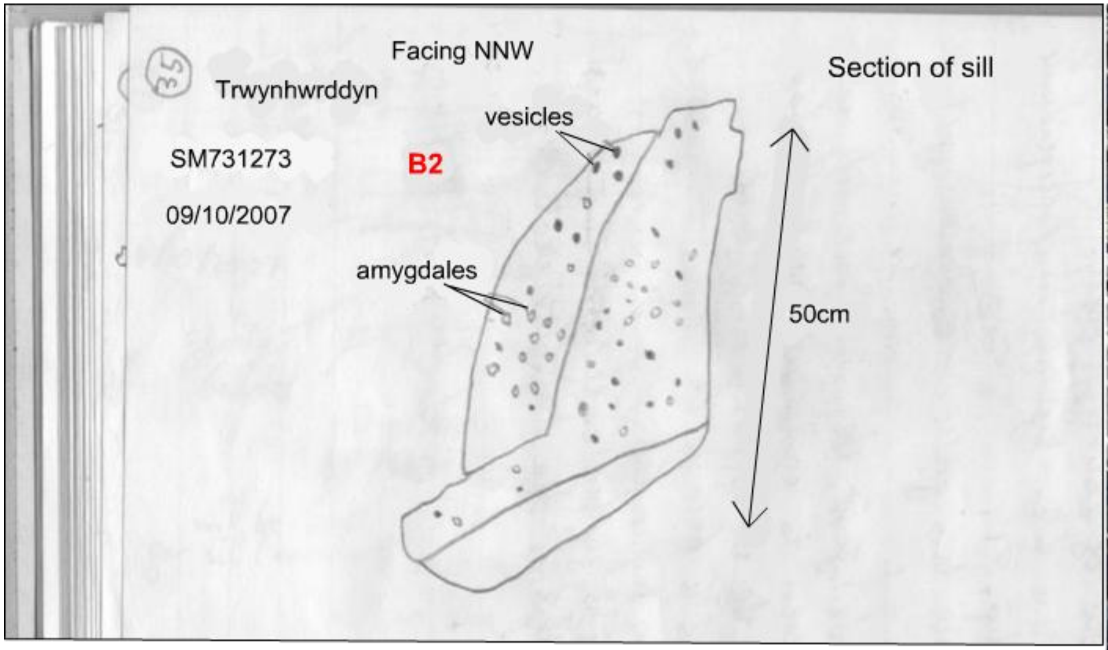
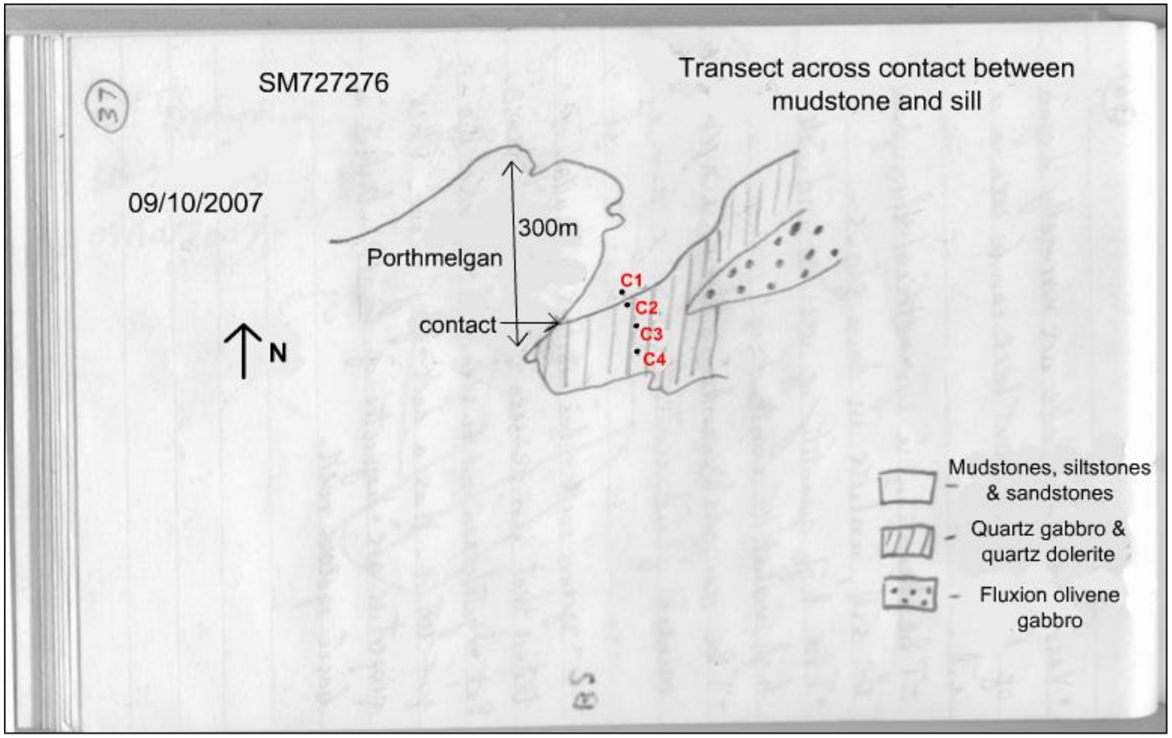
Analysis



- Upon close inspection this rock appears to be basalt, which should be expected of smaller sills:
  - Firstly it is definitely igneous as the interlocking crystals can be seen under a hand lens.
  - These crystals cannot be seen with the naked eye, so is fine.
  - The dark grey colour of this fresh section is diagnostic of basalt.
- There are a high number of vesicles and amygdales in this rock, which is normally diagnostic of lava flows (the high volatile content helps them to be extruded in the first place). There is no doubt however that this is a sill.
- Unlike in lava flows, their distribution is uniform and symmetrical, rather than being more common towards the top.
- As mentioned above, the dense concentration of vesicles indicates a high volatile content.
- The dense concentration of amygdales indicates a high mineral fluid content to fill in the vesicles.
- I expect that had this sill been close enough to the surface there would have been a small eruption.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Analysis



This transect is designed to show the effect of a contact margin on country rock and intrusion, by taking a series of samples from different points along the transect.

C1 – sedimentary, can just feel grains with teeth, so is a **siltstone**. Displays relatively thick bedding. Predominantly made up of clays, with some iron shown by oxidation.

C2 – fine to medium igneous. Can barely see crystals in some places, but can be seen as interlocking where visible. Dark in colour – diagnostic of basic igneous. Some large (2mm) olivine phenocrysts. Conclusion – some **basalt**, some **dolerite**.

C3 – mostly **dolerite**, similar to **C2**. Contains even larger (2cm) olivine phenocrysts.

C4 – a fine-end **gabbro**, can just identify feldspars at arms length. No phenocrysts.

- It would seem that the transect is as expected, starting with the country rock, then igneous rocks getting coarser travelling away from the contact.
- Due to a thin covering of grass, I could not locate the exact location of the contact, which would explain why I didn't find any 'true' basalt from the chilled margin, as this is normally a very small area.
- I should also be cautious about the exact origins of the samples, because I only took loose fragments (which does little harm to the geology), which could have travelled from their original location on the rock. But judging by the results, none had moved far enough to adversely influence the results.

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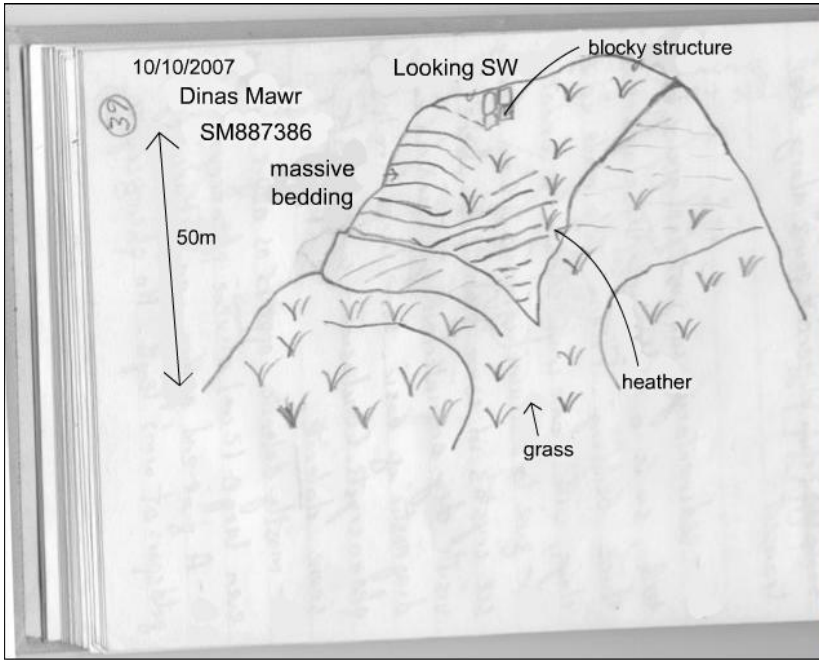
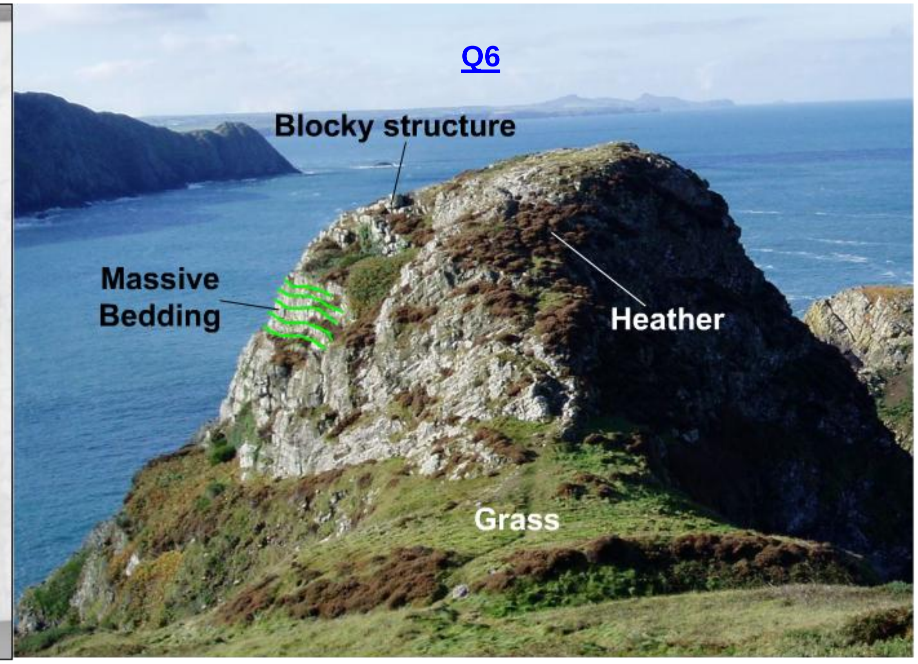
Analysis





- The stack (Dinas Mawr) seems to be more resistant to erosion than the surrounding rock.
- Also, the beds are not concordant to the local trend.
- On closer examination, this stack was revealed to be part of an igneous body, and the 'bedding' is in fact columnar jointing.
- The outcrop to the south of this is known to be a sill, so it is likely that this is, too.
- Dinas Mawr is concordant with the sill to the south, which is of course concordant with the local strata. This makes Dinas Mawr a concordant feature – so it is either a sill or a lava flow.

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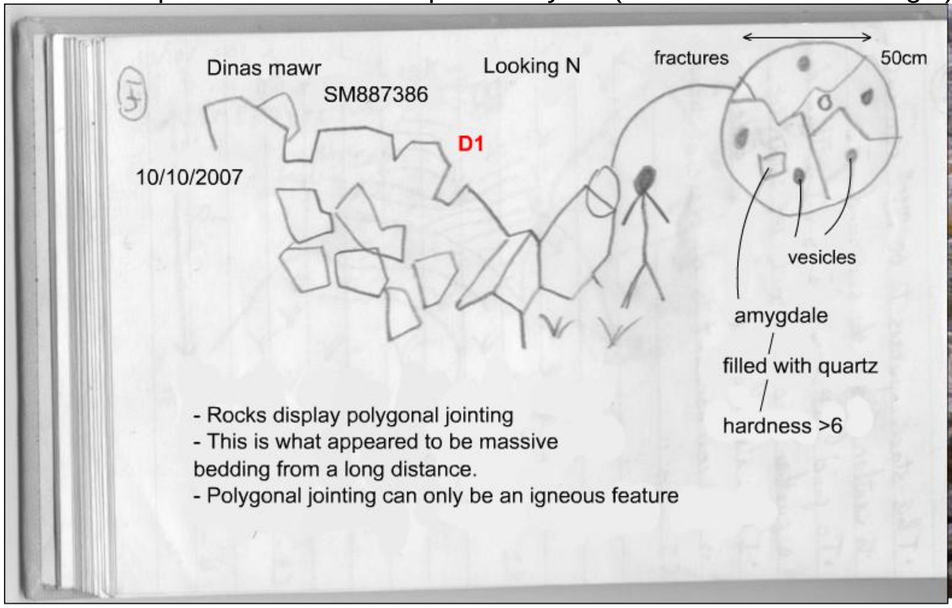
Analysis

NOTE: this photo was taken the previous year (hence the different angle), it is the best photo I have that demonstrates the jointing.

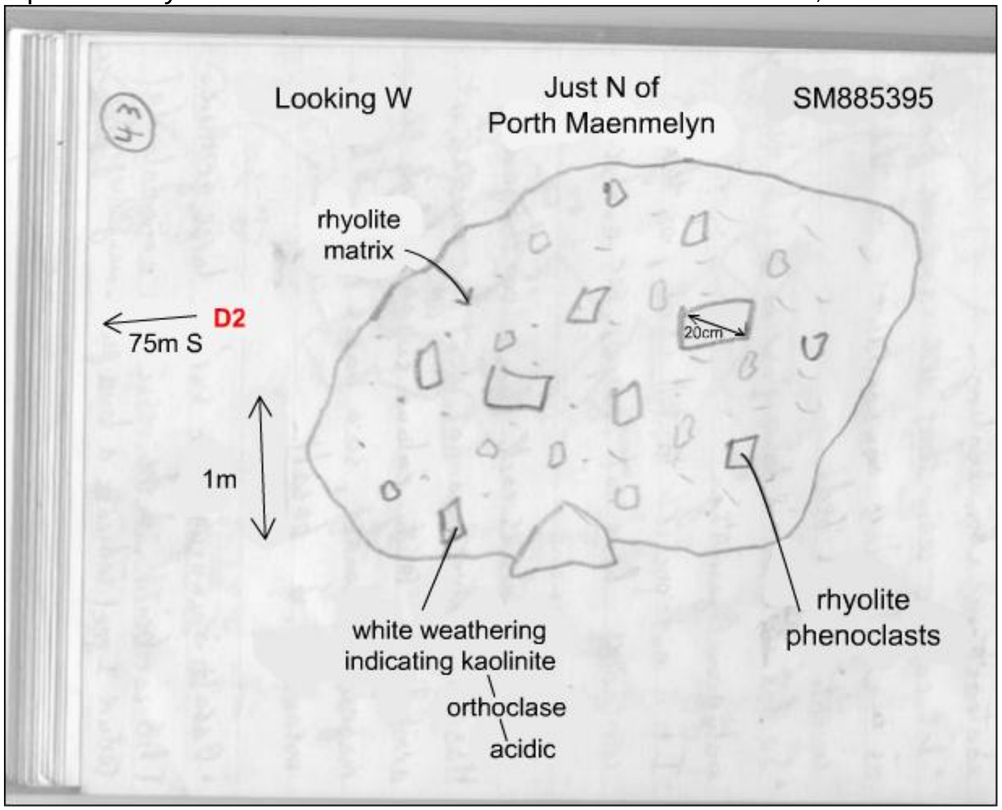


- It can be seen how the columns could be mistaken for bedding at a distance.
- This is more like polygonal jointing is most places – there are few ‘good’ hexagons.
- Polygonal jointing is only found in igneous features; it is produced when the cooling rock (already solid by this stage) shrinks as it cools. Where this shrinking is relatively uniform, fractures appear in a pattern across the rock, producing these columns. Very uniform cooling produces columnar jointing, which is associated with near perfect hexagons. This jointing is normally associated with lava flows, but can be found in other igneous features.
- The fractures when formed are vertical, which explains why the ‘bedding’ appeared discordant to the local trends, and also indicating that this rock has undergone much tilting since formation.
- Because we have already certified that Dinas Mawr as a whole is concordant, we can also conclude that most of the rock in the area has undergone a similar amount of tilting.
- Sample **D1** can be identified as basalt (igneous, fine crystals, basic minerals), which is unusual for such a large/thick feature.
- The magnification also shows a vesicular and amygdaloidal texture.
- The jointing, basalt, vesicles and amygdales would lead me to conclude that this feature is a lava flow, as most of these features are diagnostic. However, it was too dangerous to reach either contact, which would distinguish between a sill and a lava flow, so I cannot make any concrete conclusions.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Analysis

- Surprisingly, secondary research suggests otherwise. A website (http://www.jdgeology.co.uk/Ordovician/Ordovician.htm), which presumably has access to more resources/research than me, claims Dinas Mawr is part of a "sill type intrusion".

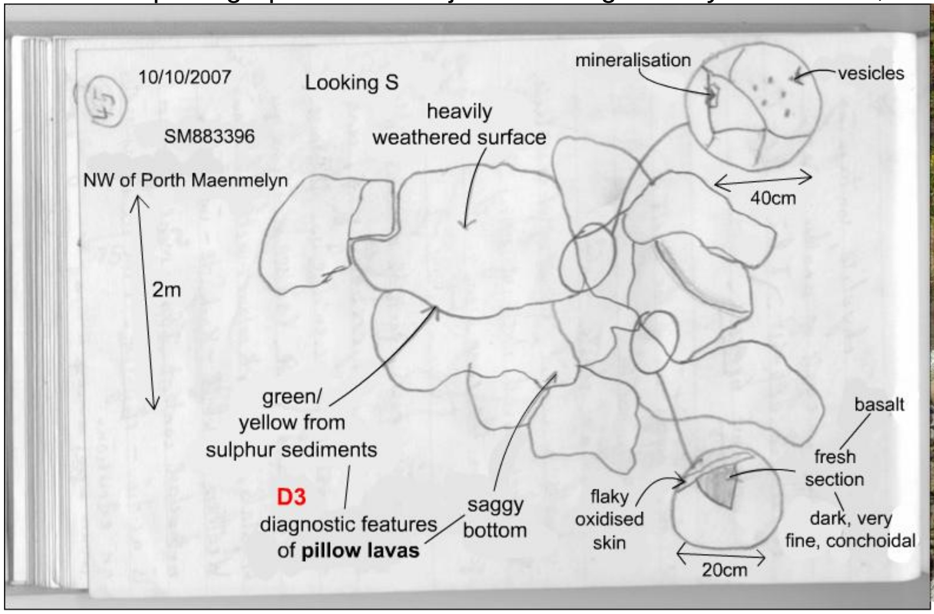


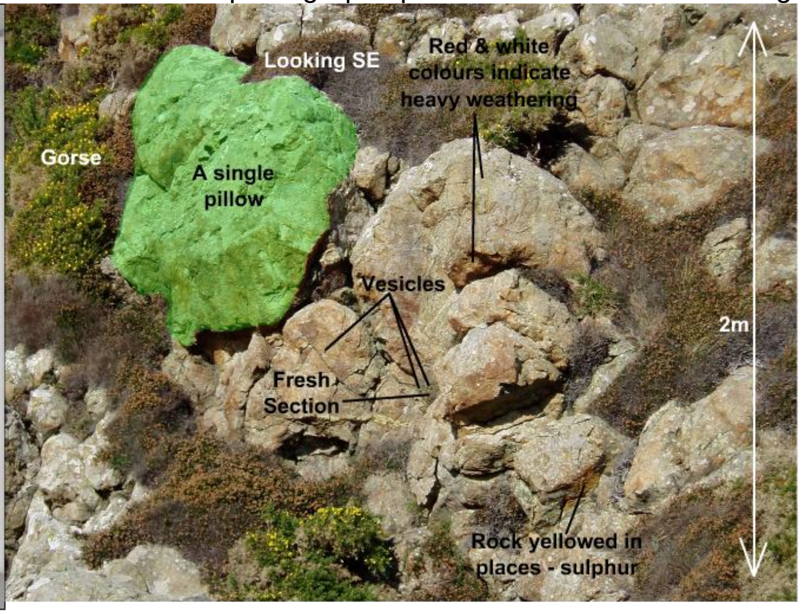
- As indicated by the annotation, we first visited a site 75m to the south. This was a large non-bedded structure with no evidence of layers at all. Therefore I analysed it by means of a loose rock sample.
- **D2** – a very fine igneous rock, cannot see crystals even close up. Displays conchoidal fracture. Can see very fine quartz crystals, but dark colour masks other minerals. Weathers to white – kaolinite – indicating orthoclase content. These minerals mean it is acidic – **rhyolite**. Fine texture indicates an extrusion.
- The rock seen in the sketch is also rhyolitic, and contains large phenoclasts (not formed as part of the same magma, but have been carried along with the deposit) of the nearby rhyolitic deposit to the south (**D2**). It can be defined as a **volcanic breccia**.
- The breccia is poorly sorted and has angular clasts, so was probably formed near the toe of a pyroclastic flow (further back in the flow, large monolithic boulders would be part of the deposit) from a violent, powerful eruption from a nearby volcano.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Analysis

NOTE: the photograph was taken just to the right of my field sketch, as I could not find a photograph specific to where I was drawing.



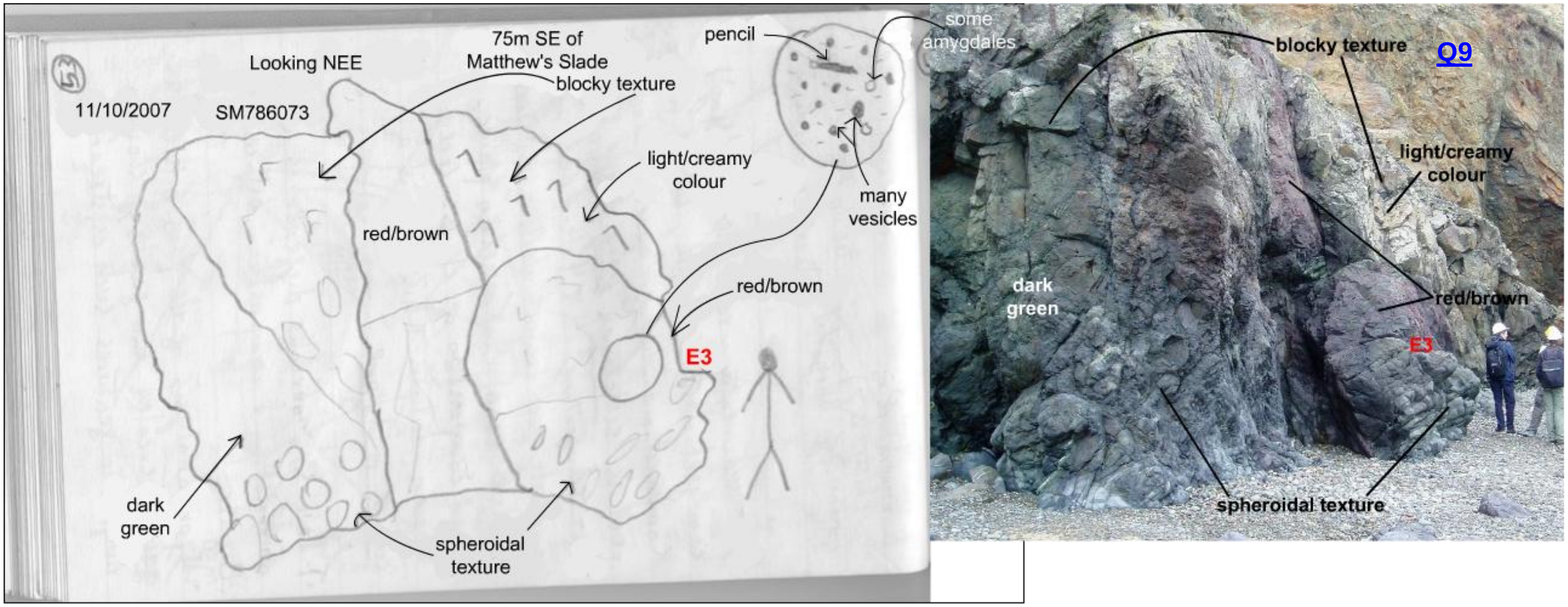


- **D3** – igneous – comes from pillows – heavy weathering penetrates pillows hindering analysis. No crystals visible, and red colour indicates high ferro-magnesium content. So this is most likely **basalt**.
- Pillow lavas are associated with submarine eruptions where the cooling effect of the water prevents large bodies forming. Instead many smaller bodies (pillows) around 50cm across are formed as a skin quickly forms over the molten material as it is extruded.
- The relatively large size of these pillows indicates the water can't have been very deep, because the higher pressure and lower temperature would have formed smaller pillows.
- This is a great contrast to what is seen just 100cm to the south where the volcanic breccia is found. The breccia would have definitely been formed in a terrestrial environment.
- Another contrast is the basaltic mineralogy, which is basic, compared to the acidic rhyolite close by.
- This is a good example of how a small distance can represent a long period in geological time where many changes have occurred. I expect that this small area experienced a prolonged period of volcanic activity for millions of years, over which time a volcano (perhaps more than one) was built up from the sea floor (the pillow lavas). Although the mineralogy started basic, the processes of magma formation would have changed for complex reasons that cannot be worked out from this small amount of evidence. By the time the volcano had broken through the water surface, the magma was acidic, making the volcano explosive, and eruptions would commonly produce pyroclastic flows as seen on page 43.

This is of course just my interpretation of what might have occurred.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Analysis



- **E3**, which is similar to much of the rock, can be identified as **dolerite**.
- The magnification on the field sketch shows that the rock is highly vesicular, and also includes some amygdales.
- The surface of the rock is red with oxidation.
- Basic mineralogy, vesicles, amygdales and surface oxidation are diagnostic features of a lava flow.
- Blocky texture is found at the base of lava flows, so because there is blocky texture found laid on top of the oxidised red layer this indicates that more than one lava flow has occurred.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.
Analysis

Conclusions

In general the features I observed matched the initial predicted outcomes. I could most often use the diagnostic features mentioned on the planning sheet to identify various structures, with the most notable exception for me being Dinas Mawr, which I would have quite confidently said was part of a lava flow, rather than the sill that it was really part of.

Rock Texture

As predicted, the texture was seen to depend on the composition of the magma and the cooling history. The many large sills in the area were composed of gabbro, which is a coarse igneous rock formed from slow cooling. The slow cooling occurred because the sills in which the gabbro was present are large in size, insulating most of the magma while it cooled producing a ground mass with crystals over 2mm in diameter. The only porphyritic texture observed was the occasional presence of olivine phenocrysts in some rocks, present because olivine has the highest melting point so will be the first mineral to crystallise out.

Medium textures were seen in several samples from the contact margin near Penmaen Dewi, where the full range of textures can be seen as a result of the differing rates of cooling depending on the proximity to the contact. Another medium texture was also found in the lava flow on the previous page to this, this is because the atmosphere provides much less insulation than country rock, so cooling is more rapid than in an intrusion, resulting in smaller crystal sizes.

Several fine igneous rocks were also identified: the small sill on Trwynhwrddynn is made of basalt, due to its small size, which resulted in quick cooling so small crystals. One sample from the chilled margin analysed near Porthmelgan was between fine and medium texture, which is again due to the fast cooling caused by the close by sedimentary country rock. There was an unexpected fine texture in the sill of Dinas Mawr (as mentioned above – the only large exception to my predictions), which I would have expected to be coarse due to the large size of the feature, which should have insulated the magma while cooling. I could not put forward a reason for this difference, because I now know that the feature is not a lava flow. A fine texture was observed in the only acidic igneous rock I saw – rhyolitic deposits caused by very fast cooling upon extrusion, probably as part of pyroclastics; this rock was extremely fine and even displayed conchoidal fracture, but there was at least evidence of crystals so could not be described as glassy. As expected, the pillow lavas had a fine texture, because the magma was extruded into cold, deep-sea water.

Most of the crystals in the rocks (when visible) were either subhedral or anhedral, as they all cooled at relatively the same time. The exception to this was with the olivine phenocrysts, which obviously crystallised far before any other minerals and normally presented a euhedral shape.

Rock Mineralogy

Almost all of the igneous rocks in the area are basic, which probably means they were formed from the partial melting of ultra-basic rocks, either as part of a hotspot or a mid-oceanic ridge. The secondary source sited previously (http://www.jdgeology.co.uk/Ordovician/Ordovician.htm) states that most of the gabbro intrusions are quartz gabbro, which is reinforced by some of the geological maps given to me as extra resources (where the information for the sketch map on p37 of the notebook was taken from). With my current level of geological knowledge I could hypothesise that a hotspot is responsible for these intrusions: at hotspots mantle plumes cause partial melting of peridotite, forming basic magma at the base of the lithosphere; this magma then rises through thick crust, which in this case looks like it may have been continental even during formation, resulting in high levels of contamination from partial melting of the surrounding country rock. The contamination of the magma is only of the very low melting point minerals – mainly quartz – resulting in a 'theolitic' basic magma, which means it has unusually high quartz content. Of course I cannot say this for certain, but with my current level of knowledge it would seem to make sense.

It is also possible that even the acidic lavas were a result of high contamination, because this seems to have occurred around sedimentary rock, indicating continental crust country rock. It is possible, due to the extra thickness of continental crust, for contamination to form acidic magmas.

I can also put forward another more likely process for the acidic magma formation. As studied in the other report on orogenic events influencing Pembroke, northern Pembroke was influenced by the Caledonian Orogeny. This was a large scale event that caused the formation of the Appalachians, Scottish Highlands and Scandinavian mountains; this would indicate that it was large enough to have far ranging effects, and for some magma formed from the crustal thickening to reach as far south as Pembroke. Magma formed from crustal thickening is acidic, because only the acidic minerals melt in this process, and then the magma rises through thick crust causing further contamination.

It is an interesting issue, because while the second process is far more common, the argument contradicts other igneous geology in the area. Surely if some acidic magma reached Porth Maenmelyn then there would also be other acidic formations in the area, some plutonic in nature, but in reality there is no evidence of this. So perhaps the first explanation is more likely, but I cannot draw any concrete conclusions without more information.

I must also look at the two basic igneous extrusions – the pillow lavas of Porth Maenmelyn, and the lava flow on Marloes Sands. The pillow lavas are not a particularly surprising formation, because the country rock around most of the nearby intrusions seems to be marine in origin – fine textures (probably not fluvial), low oxidation (not aeolian), so any extrusion of the basic magma was likely to be in a marine environment, which should result in pillow lavas. The nearby acidic magma was definitely terrestrial extrusion, but the stark difference in mineralogy from any of the other local features indicates a large difference in time also. The lava flow is difficult to analyse as it was found in south Pembroke, when all other igneous features were found in north Pembroke; all I can say is that the mineralogy of any magma in the area must have been basic, and the environment terrestrial. There must have been a nearby volcano because the lava flow is multi-layered.

<u>Igneous Structures</u> (in the same order as planning section)
I saw one lava flow feature, with no surrounding country rock – it must have been eroded away before, as igneous rock is more resistant to erosion. It could still be identified as part of a sequence, as a clear boundary between two separate flows can be picked

Analysis

out (see page). The flows displayed many diagnostic features such as vertical variation in texture, vesicles and amygdales close to top surface and ferro-magnesium colours.

I saw many sills, composed mainly of gabbro, with two composed of basalt. They were of varying thickness, and when analysing a contact margin I was able to see how texture becomes coarser away from the contact. I also saw polygonal jointing displayed in the Dinas Mawr sill, which was the large sill with the surprisingly fine texture; I think the texture and the jointing must have been interlinked in some way, because it is uniform cooling that allows jointing to occur. I also saw a transgressive sill on Trwynhwrddynn, which had intruded into a higher bedding plane across a joint in the country rock.

I saw no dykes, perhaps the bedding in Pembroke is too defined to allow for discordant features. I saw no volcanoes, although there were several pieces of evidence for various forms of volcanism, such as the pyroclastic flow of Porth Maenmelyn and the lava flows on Marloes Sands. There were no plutons; I do not think the conditions were appropriate for the formation of large acidic bodies of magma.

I saw pillow lavas near Strumble Head, displaying many of their diagnostic features: 50cm across, fine basaltic texture, vesicles in places, 'saggy bottoms' and a sulphurous sediment in between pillows.

So as you can see, most of the predicted igneous textures, mineralogies and features were observed to be as they predicted. I have been able to prove the theoretical relationships between "igneous rocks, textures & structures in relation to their mode of origin & cooling histories" that were taught to me in the classroom, in the field.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.
Evaluation

<u>Planning</u>

The original factors I chose to investigate were well chosen in my opinion, as they seemed to fit in well when it came to concluding the analysis section. The same applies for the predicted outcomes for these factors, as I had few situations where the predicted outcomes were wrong, the most noticeable 'anomaly' was the sill at Dinas Mawr.

I perhaps went into too much detail for some of these factors, though, as certain variables such as the crystal form/habit are difficult to analyse accurately from field samples. Having said that I think the detail was helpful for certain situations such as explaining other factors, and getting the extra detail in my analysis (e.g. I could back up that the olivine phenocrysts in some of the igneous rocks had crystallised first because they were euhedral/subhedral).

I was rather ambitious with my plan for collecting primary data, demonstrated by the way that I planned a very rigid routine for each site. When in the field this 'objective' routine was quickly replaced by a 'subjective' routine as I learnt that not everything is accessible at each site and it is often not time efficient to look at more than needed when conclusions can be drawn using less evidence. Even putting these factors aside, my plan of strict sampling areas would have quickly been undone by weathering and vegetation. My planned use of equipment was more suitable, and I ended up making use of most of the techniques listed, as well as extra skills acquired in the field (e.g. the tooth test for identifying sedimentary grain size). I was able to use my field notebook and extra photographs just as I had planned to. The pilot study helped to point out my inexperience and allowed me to adjust my expectations for data collection for the rest of the trip.

Because data presentation and analysis was a more familiar technique to me, it was easier to plan this section as I would carry it out. The laying out of my field notebook could have been improved to meet the standards of my plan, but in the field I felt I was pressed for time. In order to achieve the ease of interpretation targeted in the plan, I have typed over all my field annotations (with few amendments) to make them easier to read. Apart from that, everything was logged and recorded as planned, and the analysis section includes everything that I originally wished to include. I predicted there would be little opportunity for numerical analysis, in fact there was none at all for this project, so I simply had to use qualitative analysis to identify patterns and draw conclusions.

As predicted, time was indeed by far the most limiting factor in data collection, and I just had to make sure I took the time saving measures mentioned in the plan. One method in particular that I found helped was to limit to analysis performed in the field and spend extensive time the same evening writing more extensive notes and administrative pieces such as the date, locations and grid references. I feel the limited time was in fact beneficial, as it prevented me from wasting time collected unnecessary data, which is normally a downfall of mine. In the end weather was not a problem, although I still took the precautions of waterproofs and warm gear. Where I could I reduced the influence of metallic objects on the compass, although this is difficult in situations when surrounded by basic igneous rock. Using loose samples proved invaluable in accurately describing rocks, which I often did after the day's fieldwork, and often stopped me making mistakes by analysing a weathered surface.

<u>Implementation</u>

Ignoring some of the naïve things that I planned to do in the field, my work was relatively well conducted. After the pilot study, field sketches gradually became more natural to draw and I started picking out key details and ignoring those that weren't important. My methods became faster and more efficient over the three day period, which helped to streamline data recording.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Evaluation

The main shortfall was my use of the compass-clinometer. Having practised its proper use in the classroom before the field trip, I then forgot a key detail when measuring in the field. Having recorded dip, I forgot to rotate the clinometer to dip 0 before reading azimuth, so rather than recording the azimuth of strike; I was recording the azimuth of dip. I realised this half way through the trip and corrected my method. Those readings taken before this point were amended using information from others who had recorded their values from the same point, and in some cases by using common sense from looking at the field sketches and the direction they were facing.

I also had a problem with the use of the geological hammer. Rather than using a geological hammer as stated in the plan, I was using a fossil hammer, which is designed only for sedimentary rocks. Consequentially this broke early on the second full day while trying to break a fragment of basalt, and I borrowed the college's real geological hammers after that.

I found loose samples very helpful, as they allowed later, more detailed analysis than rushed field descriptions. As a result I collected a sample for about half of my field sketches; the majority of the time these were loose samples, although occasionally when it was necessary and it was from a large body I broke a piece out of the rock.

<u>Results and Analysis</u>

Considering how there was no quantitative data recorded (the dip/strike was normally to tell if a feature was concordant/discordant), there was little opportunity for inaccurate data. I feel that the quality of my field sketches was sufficient enough to give a good representation of what I was drawing, and I was meticulous with my annotations, as well as logging samples of photos, and describing my samples fully. I have drawn as many conclusions as I can from the available information, as well as occasionally commenting on other possible conclusions to be drawn that could not be justified, but could be seen as reasonable.

I have made a good a use of photographs as possible, even selecting some from other years where they better represent what is in the sketch than those taken this year. I have used digital annotations for both sketch and photograph to make them clearer. My conclusion has been designed to amalgamate all the information and conclusions from the main body of the analysis into a review related back to the original plan, covering all sections and analysing any predictions that I made.

One particular analytical technique that I felt was helpful was the sketch map drawn of 4 samples taken from a transect across a contact margin. This technique was specifically suited to looking at a contact margin, when a field sketch would not be suitable. Given this was the only contact margin looked at, the information proved invaluable.

<u>Improvements</u>

The main limitation of the entire investigation was the time in which we had to do it all, and just slightly more time would have made the investigation easier and more detailed. The rushed nature was reflected when we could not reach a particular location simply because of the tides – there was no opportunity to change plans and go back later or another day because we had such a tight schedule to stick to. It is worth noting that the trip had a very good flexible nature to it, which allowed for such eventualities, and there were enough other localities to make up for the loss of access to that particular one. I have already said that too much time would also have been a bad thing, as it would have encouraged inefficiency in data collection.

A field investigation into igneous textures and structures in relation to their mode of origin and cooling histories.

Evaluation

Although by the end of the study data collection was smoother and more efficient, it took longer and may have missed certain pieces of information at the start. With better time management before the study, I would have practiced far more sketching so that it was easy to start to investigation without having to overcome any ‘teething problems’. I would have also further practiced compass-clino use, which would have cemented the method in my memory and prevented the problem mentioned previously.

I had to spend around 2 hours locating and selecting pictures that I could use for the study, having elected not to take my own camera in case it were damaged or lost. Looking back on this I think it would have been worth taking my own pictures relevant to each of my own field sketches, rather than trying to locate the most relevant one from others’ collections. This would have slightly increased the time it would take for each field sketch, but not significantly.

It was short sighted of me to take a fossil hammer for use as an all-purpose geological hammer on the trip, it would have been more sensible to simply have made use of the college’s resources.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Planning Sheet

WJEC A2 GEOLOGY PLANNING (tracking) SHEET GLF2

Centre Name: Brockenhurst College Centre No: 58801

Candidate Name: Martin Yeo Candidate No: 6587

1. INVESTIGATION TITLE

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

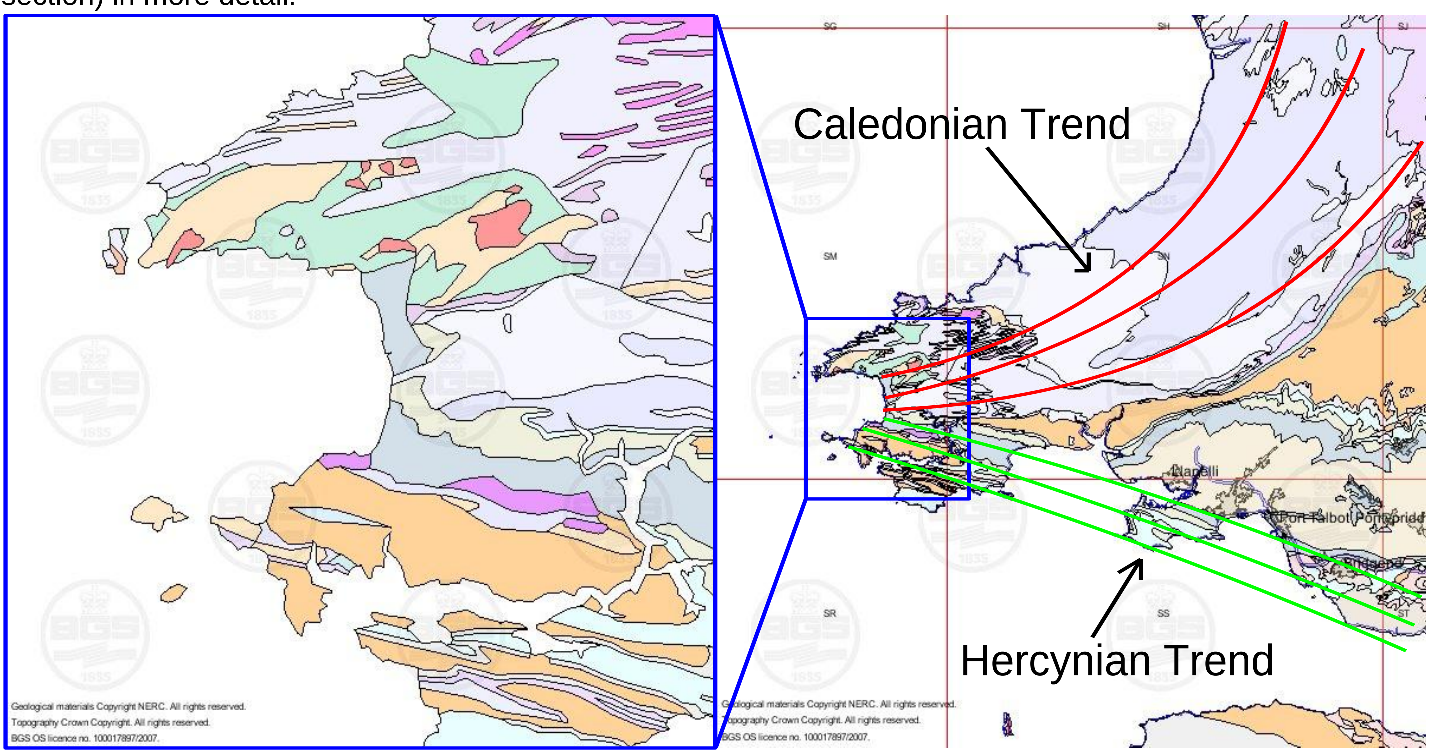
2. ENQUIRY FOCUS

I have studied many features associated with orogenic events in class, but have never seen them in context to the orogenic event itself. I have chosen this investigation in order to enrich my understanding of the relationships between tectonic structures & orogenic events.

Orogeny means “mountain forming”, & in a sense that is what an orogenic event is. It involves the collision of two tectonic plates, most often two sections of continental crust. This collision produces immense stresses & causes folding & faulting in the orogenic zone in the area closest to the suture (collision point/line); moving towards the suture, deformation increases. There are three main orogenic events that have affected Britain:

- **Caledonian –** 670ma to 370ma, centred around the mountain ranges of Scotland & Scandinavia, affecting the northern half of Pembroke.
- **Hercynian –** 362ma to 290ma, centred around Brittany, affecting the southern half of Pembroke.
- **Alpine –** 70ma to present, centred around the Alps, furthest reaching effects reach the extreme south of Britain but not Pembroke.

It can be seen on these maps the differences in the trends, & why it is important to study Pembroke (enlarged section) in more detail:



*Legend attached at end

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Planning Sheet

Pembroke can be seen to be the area in Wales where the two trends 'converge'.

Orogenic events result in many different tectonic (& other) features, which I will need to investigate. I will be looking for **regional trends** in these features, which would indicate a large scale event such as an orogeny.

- **Folds –** when moved gradually, rocks under stress are able to bend, forming folds. They are defined as where there is a change in the dip or direction of the bedding plane. The arrangement & orientation of folds will be indicative of orogenic events that have affected the area.
- **Tilting –** a fold must have two limbs, but sometimes the entire bedrock will tilt in a uniform direction in reaction to stress such as that from an orogenic event.
- **Faults –** if stresses within the rock become too great, the rock will fracture & move so as to release the stress. This will form faults, which are defined as a fracture in the rock that has some displacement caused by compressional, tensional, or shear stress. Again the arrangement & orientation of them will help to understand past orogenic events. Where the rock has fractured but not moved at all, it is known as **jointing**.
- **Unconformities –** periods of erosion but no deposition, identifiable by great differences in age of rock, rock formations & often rock type across a plane (the plane of unconformity). These can often be caused by tectonic activity causing uplift – rock on hilltops can be eroded but no sediment can be deposited.
- **Regional Metamorphism –** this is metamorphism over a large scale, mostly caused by pressure but heat can also be a factor. The degree of metamorphism will be able to tell me how close and/or influential any orogenic events, as the more pressure the rock is under, the higher the grade of metamorphism.

3. PREDICTED OUTCOMES

I predict that by observing regional trends in several different features I will be able to bring these observations together to create an overall picture of how the Caledonian & Hercynian orogenies have affected Pembroke. Study sites in the south of the area will show trends in relation to the Hercynian orogeny to the south, & study sites to the north will show trends in relation to the Caledonian orogeny to the north. I can validate these conclusions by cross-referencing them with geological maps of the area, & secondary sources such as the Pembrokeshire website & local geology guides.

<u>Folds</u>

A regional trend in will show successive folds moving out from the suture, like ripple marks. Each fold will have very similar dip & strike readings, & the axial plane traces (the lines that describe where the axial planes intersect the surface) will all be travelling in the same direction. On a map this could be seen by sequential banding of certain rock types in a repeating pattern. This arrangement can produce fold mountains, a series of parallel anticlines (those with dip pointing away from the axial plane) & synclines (dip pointing towards to axial plane). Closer to the suture, the inter-limb angle (angle between the two limbs) of such folds will be tight (30° to 70°) or even isoclinal (<30°), getting wider travelling outwards away from the suture.

Dip points to the youngest rock, so with synclines the youngest rock will be at the centre of the fold, but with anticlines the oldest rock will be at the centre of the fold. It is common with metamorphic rocks not to know the ages, in which case the folds take on the names antiform & synform. If a structure of known age has been inverted, syncline/anticline is used to describe the age, & antiform/synform is used to describe the shape.

In Pembroke I would expect to see folds that are seen far from an orogeny, because the suture of either orogeny is relatively far away.

<u>Tilting</u>

An orogeny forms mountains, pushing rock upwards; therefore if any tilting is present the rock should be dipping away from the suture. Tilted beds produce features such as cuestas & hog's backs, which will indicate to me that many beds are dipping (rather than just one). I do not expect to see much tilting, as this would more be associated with beds closer to the suture where deformation is greater.

Faults

The main feature to look for when observing regional trends will be the strike of the fault plane (the surface along which the rock is displaced). If the faults have been created by orogenic stresses, these strike readings should all be in the same direction. Close to the suture, extreme deformation will be seen, with all types of faulting. I am likely to be looking at normal & reverse dip-slip faults, as it is unlikely that at this distance from the suture that thrust faults or strike-slip faults will be created.

There are a number of features associated with faults:

- Fault breccias – a small area of rock either side of the fault that has been broken up by the movement, and then cemented in place again producing a breccia.
- Mineralisation – a common feature associated with movement & pressure, where minerals crystallise out in spaces in the rock. May also be seen in other areas of stress such as folds.
- Springs – water will be forced to the surface if permeable rock is pushed against impermeable rock.
- Streams – they will run along fault planes, which are often slightly deeper than the surrounding rocks.

Unconformities

Defined as representing a hiatus in the geological record, (i.e. a break in sedimentation). There are many scenarios when this can happen, such as uplift as mentioned above, but others include wave-cut platforms & cliff-sides. These should not be mistaken for thrust faults, which would also cause a 'plane of unconformity' so to speak at a similar angle to the bedding plane.

There are several different types of unconformity:

- Angular unconformity – the most common type, where the beds below the plane dip at a completely different angle to those above the plane, which in most cases will be near horizontal unless more activity has caused more tilting.
- Disconformity – buried topography, where an uneven surface (possibly an entire landscape) has been overlain by horizontal bedding. This has the potential to be very large scale, & may be difficult to spot in an isolated location; but I am unlikely to see this as it would not be associated with tectonic stresses.
- Non-sequences – this is where there is no difference in bedding angle, but the age of the rock is different. This could be identified by different rock types but in some difficult situations where the rock type is also similar the difference must simply be deduced using zone fossils. There is a possibility I could encounter non-sequences on the fieldwork.

Regional Metamorphism

The immense pressures & heat caused by two plates colliding is enough to cause enormous scale metamorphism. In this case most rocks that were originally igneous or sedimentary will form similar regional metamorphic rocks, which can be sorted into grades – with increasing pressure & temperature comes higher grade rock:

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Planning Sheet

Grade	Rock	Description
Low	Slate	Main composition of quartz & muscovite mica, with 'slaty' cleavage – parallel cleavage planes in the rock due to parallel alignment of microscopic platy minerals.
Medium	Schist	Composed mainly of micas, coarser than in slate at 2 to 6mm diameter. Displays 'schistosity' – wavy foliation. May contain porphyroblasts of garnet in between layers.
High	Gneiss	Arranged in alternating wrinkly bands of mafic (biotite & ferro-magnesium) & felsic (quartz & feldspar) minerals, known as 'gneissosity'. This is caused by partial melting of the low melting point felsic minerals, allowing them to form bands in between the mafic minerals.

Micas also display a series of changes as temperature & pressure increases:

muscovite → biotite → garnet → stavrocite → kyanite → sillimanite

So the presence of certain rocks & minerals can indicate the proximity of an area to the suture. I expect to find low grade metamorphic rocks in Pembroke for reasons explained before. Regional metamorphic rocks can also display regional cleavage, where all cleavage planes are in the same direction – orientated parallel to the direction of the pressure. These show more regional trends that can indicate how the areas have been affected by the orogenies.

4. PRIMARY DATA

In general at each area I will be looking at any larger structures I can see, rather than close analysis of small areas, apart from identifying & describing any metamorphic rocks that are present. Upon arrival at an area, I will first need to work out what structures are present before collecting data.

- **Folds –** take dip & strike measurements of each limb, & the approximate direction of the axial plane using compass points if this can be seen/worked out. From this data I will be able to work out the inter-limb angle & draw up a regional pattern from all folds sampled. Use relative dating to place each bed in an order of age if possible. If there are many folds in the area, not all can be sampled due to strict time constraints, so only one fold of several similar folds will be looked at if necessary, & estimates can then be made for those that haven't been sampled from those that have been. Note down the presence of any mineralisation & other unusual features.
- **Tilting –** all that can be done here is to measure the dip & strike of any tilting, which can then be put together with other data later to contribute to regional trends. Also be on the look out for diagnostic outcrop features such as cuestas.
- **Faults –** measure dip & strike of fault plane, followed by the approximate displacement, which can be used to indicate the severity of stress on the rocks in the area. It will also be useful to relatively date the beds involved. This procedure should be repeated for joints minus the displacement. Note down any other features associated with faults (e.g. fault breccias).
- **Regional Metamorphism –** look for any metamorphic rocks in the area, & analyse each different type present (likely to be just one). Analyse texture, mineralogy & if possible the cleavage direction (dip & strike) with a view to building up an idea of regional cleavage.

All this data should be recorded in the field notebook & referenced to the place it was recorded on the field sketch, which will be drawn after all data in the area has been collected. The field sketch will be fully annotated (NGF, compass direction, scale, rock types & structures including evidence, anything unusual). I shall also use photographs of anything significant to provide extra visual evidence.

From the above bullet points it is obvious that the most important piece of equipment will be the compass-clinometer, because it can measure dip as well as giving compass directions. A stratigraphic column will prove useful for relative dating. For rock identification I will also need a ruler for crystal/clast size, mineral identification cards for mineralogy, and for hardness I will use a copper coin & steel blade (in addition to fingernail). I may need a hand lens to aid identification of finer crystals/clasts, & a geological hammer for exposing fresh surfaces of rock.

Safety is a key element when conducting geological fieldwork. There is a great hazard of falling rocks & rock shards from the geological hammer. There is also potential damage from hydrochloric acid, used to test the diagnostic feature of limestone. I will therefore be wearing a hard hat & safety glasses when necessary. Appropriate caution will be taken in hazardous areas, that is, not climbing rocks or standing underneath unstable rocks.

I will undertake a pilot study to check that my procedure works & is functional. I will make amendments to the method in light of the pilot study. Objectives of the pilot study are to become well versed in effective use of complex equipment such as the compass-clino, to develop a quick & efficient sampling procedure, & to flag up any issues with my procedure or coursework plan in general. It will start with a field sketch, checking that my drawing & annotations are correct & of an acceptable standard; this will be followed by rock identification with appropriate logging in the field notebook. The last thing to be done will be a dip/strike reading of a noticeable bed, & recording this in the notebook.

> *I found the pilot study helpful in familiarising myself with the correct procedures while in the field. Drawing the field sketch refreshed my memory of how the sketches should be done; the rock identification introduced me to the many subcategories of sedimentary rocks beyond what I already knew. The most important help that the pilot study gave was to flag up the error in my dip/strike measurements – I was forgetting the level the compass-clinometer to zero dip before reading the azimuth. Thankfully I was able to see that I was taking these readings incorrectly & rectify these by observing others. I also realised that it was important to use an even surface when taking the reading, I shall use the field notebook placed on top of the bed, or aligned parallel with it if there is no surface on which to place it. The most important thing about the pilot study is that it gave me practice at most of the skills needed before starting fieldwork in earnest.*

5. Methods of ANALYSIS/DATA PRESENTATION to be used.

The field notebook will contain much of the presentable information. Keeping this in mind I will take care to use it properly & make sure all information is well laid out an easy to interpret. I may need to practice my sketching skills before fieldwork so that I can produce good ones while in the field. The notebook shall be kept organised with appropriate use of the contents page, with samples & photographs logged in the log tables. Digital photographs will also be digitally annotated before being inserted into the write-up; they will be referenced to the appropriate page, where they will be marked on the field sketch using a code in blue ink (e.g. P5). I will use OS maps & geological maps wherever possible, also labelled digitally; these will have the sample areas marked on them, as well as labels on the geological maps of any features significant to my study.

The write up itself will consist of an analysis of field notebook data, which will be appropriately referenced to the correct page number. I will take the opportunity to represent any numerical data graphically, using a format relevant to the data I am presenting; I shall use Microsoft Excel in order to draw clear & accurate charts. In general there will not be many opportunities for numerical analysis, but more analysing each sample area & producing regional trends, for which maps are more useful than graphs.

6. Anticipated ERRORS/LIMITATIONS and steps to be taken to minimise.

The most obvious limitation is the limited time the group has in the study area. We will be spending three full days in the field, plus a few hours on the pilot study beforehand. While there is nothing we can do to increase the time we have, the limitations of this can be minimised by developing an efficient data collection procedure, using each day to its full potential & doing as much work as possible beforehand. Practice of field sketches in particular, as well as other procedures (which will be practiced on the pilot study), can be used to reduce the time taken when in the field.

Another unavoidable hindrance will be the weather conditions. There is no spare time with which to wait out bad weather, sampling must continue regardless. Therefore in order to minimise the impact of poor weather conditions, particularly rain, I shall ensure that *everything* (including equipment) I am using is waterproofed & there is no chance of wind blowing anything from my person.

The compass-clino is very easily influenced by anything with even small magnetic properties from ferro-magnesium minerals to belt buckles. All lengths must be taken to reduce these unwanted influences when recording azimuths & compass directions.

There may be some estimation involved in several areas, such as fault displacement, which may be too large to measure, & axial plane directions, where it may not be possible to see exactly what direction the axial plane travels. To minimise this, I must make sure that in every situation possible I do not use estimates, but instead find ways of accurately measuring; the use of a tape measure will be possible for some displacement measurements, & patterns in folds will give clues that can be used to *accurately* estimate the direction of the axial plane.

7. Degree of assistance given.	**Approved by (Supervising teacher)**
	Date:

Map Legend

Bedrock geology			
	Ashgill and Caradoc (includes small inliers of Arenig-Llandeilo in Scotland)		Namurian (Millstone Grit Series)
	Tournaisian and Visean (Carboniferous Limestone Series)		Ashgill
	Upper CAMBRIAN, including Tremadoc		Ludlow
	Gabbro and allied types		Rhyolite, trachyte, felsite, elvans and allied types
	Upper Old Red Sandstone and Upper Devonian		Lower Lias
	Rhyolitic lava		Triassic mudstones including Keuper Marl, Dolomitic Conglomerate and Rhaetic)
	Granite, syenite, granophyre and allied types		Lower Old Red Sandstone, including Downtonian
	Llandeilo		Bovey Formation, St Angus Sands, etc
	Lower Devonian		Lower Westphalian (mainly Productive Coal Measures)
	Open Water		Permian and Triassic sandstones, undifferentiated, including Bunter and Keuper
	Rhyolitic and trachytic lava and tuff undifferentiated		Diorite and allied intermediate types

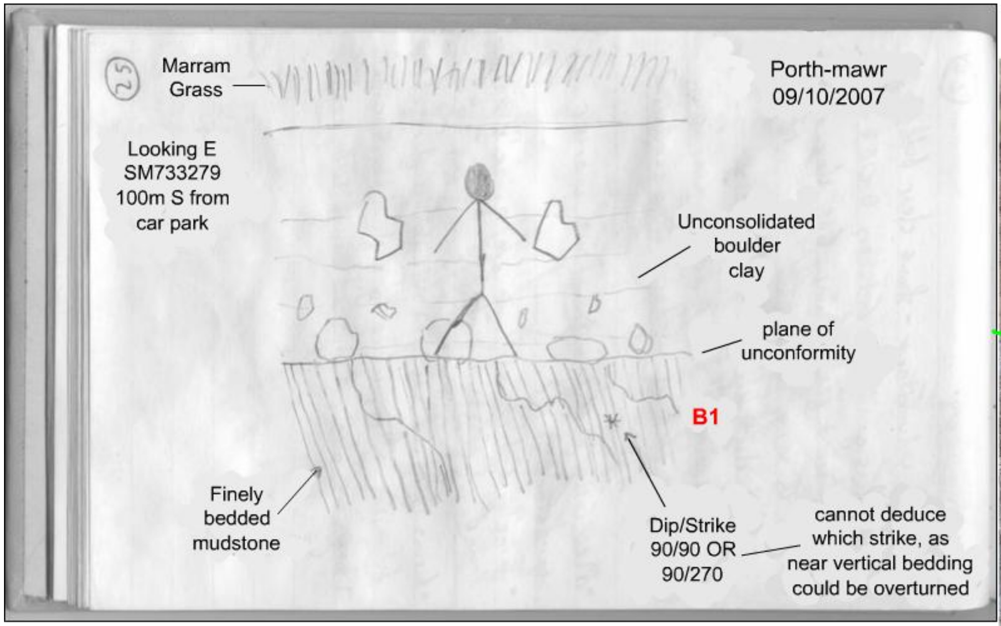
A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Planning Sheet

	Basalt dolerite, camptonite and allied types		Wenlock
	Llandovery		Basalt, spilite, hyaloclastic and related tuffs
	CAMBRIAN		Lower and Middle Devonian
	Andesitic lava and tuff, undifferentiated		Caradoc
	Llanvirn and Arenig		Upper Devonian and Old Red Sandstone and Middle Devonian
	Llandeilo and Llanvirn and Arenig		Upper Westphalian (including Pennant Measures)
	Ludlow and Wenlock		

Mapping courtesy of BGS ‘GeoIndex’ online map service.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

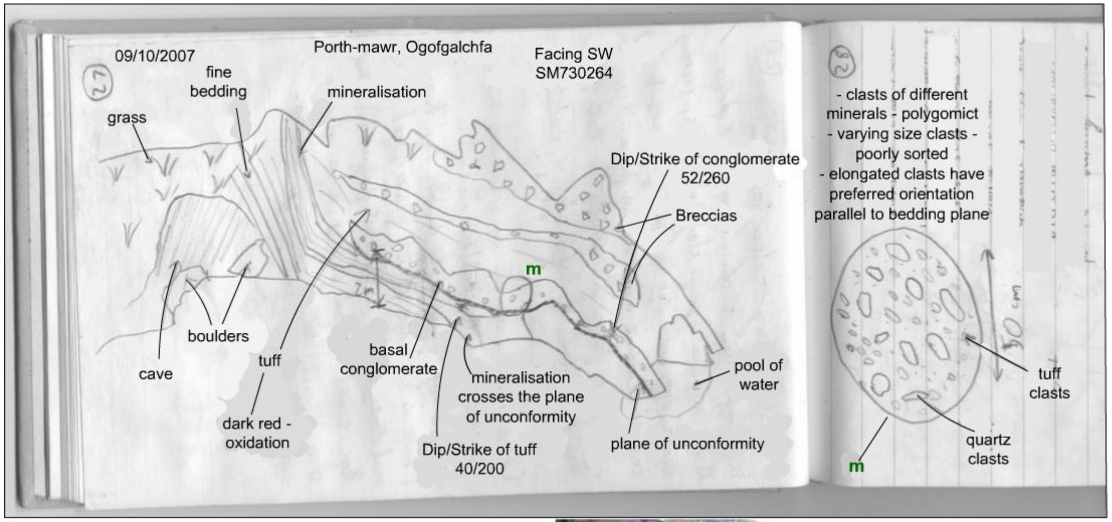
Analysis

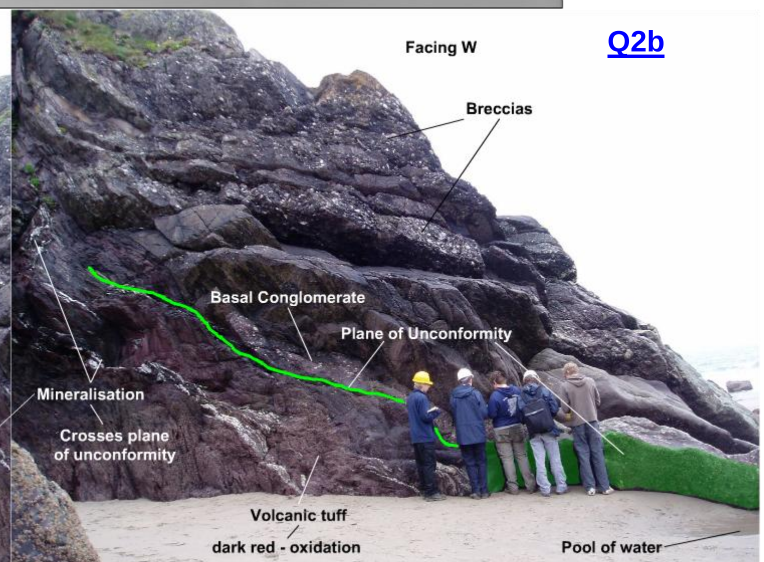


- This unconformity is an obvious angular unconformity, as the mudstone beds are near vertical (indicated by dip reading) and the new boulder clay is horizontal.
- Given the location (a beach), there is evidence that the top surface of the mudstone was once a wave-cut platform, but has since been separated from the sea by a beach and possibly some movement, and the boulder clay has been deposited on top. Now only the very western end of the surface remains as a wave-cut platform on stormy days.
- The boulder clay is glacial in nature (shown from the large boulders), and the fact that it is unconsolidated suggests that this is from one of the more recent ice ages, of which there have been several in recent times.
- Some of the boulders form the basal conglomerate of the unconformity, brought by the glacier from a short distance away, although some of the boulders are of a different rock type and must have come from further away.
- The vertical nature of the mudstone suggests great tectonic forces in the area, and the strike can be analysed later in comparison with other strikes to construct a regional trend.
- Forces in North Pembroke will have been caused by the Caledonian orogeny.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis





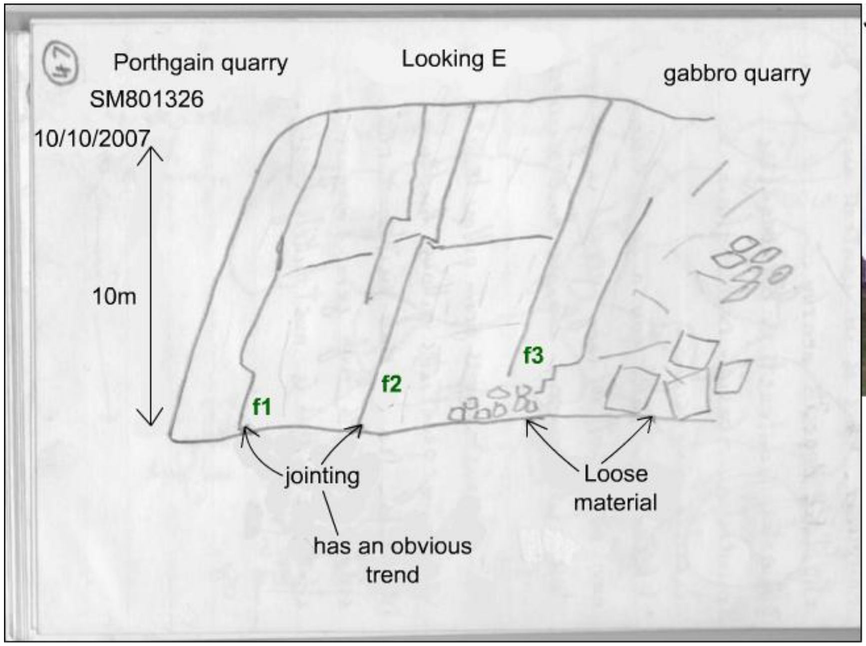
- The main deposit in this location is a volcanic tuff deposited in a series of fine layers, indicating a series of eruptions.
- These are interspersed with breccia deposits in several places, which seem to contain a matrix also made from tuff.
- The complex relationships in this location indicate more tectonic forces.
- There is quartz mineralisation in several places – mineralisation occurs when minerals in solution precipitate out as conditions change, normally associated with weaknesses in the rock caused by pressure.
- These pressures can be seen in many places, for instance I took a dip reading of 40 for the tuff, taken where the students can be seen in the west-facing picture. But looking at the fine bedding in the south-facing picture, it is clear that the dip there is greater. This is most likely part of a large-scale fold, and the rock would have been under a lot of pressure when this formed.
- The unconformity, which can be seen by looking at the basal conglomerate, appears to be a non-sequence, because the dip is similar above and below, although small differences give extra evidence.
- It also does not appear to span a very long period of time, because tuff has been deposited both above and below the plane.

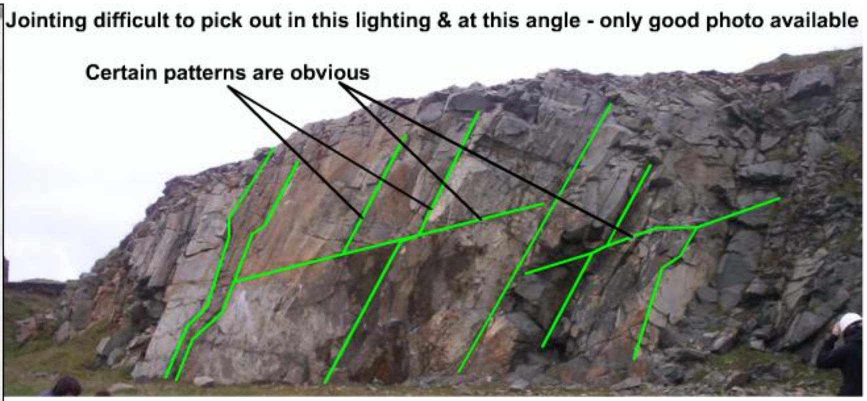
A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

- The basal conglomerate contains clasts of tuff, but also clasts of quartz, the origin of which is unknown. The mineralogy looks similar to that of the breccia, which was inaccessible for analysis.
- Because the mineralisation crosses the plane of unconformity, and because the dip of all the beds is similar within a certain range, it can be said that the forces that caused the folding/tilting (and so the mineralisation), happened after the unconformity and subsequent deposition.
- Because the strike of the conglomerate is 260 and 200 for the tuff, I would say that the strike for the mudstone of the previous sketch was 270 rather than 90 due to regional trends.

NOTE: this photo is from the previous year as it is the best one available.



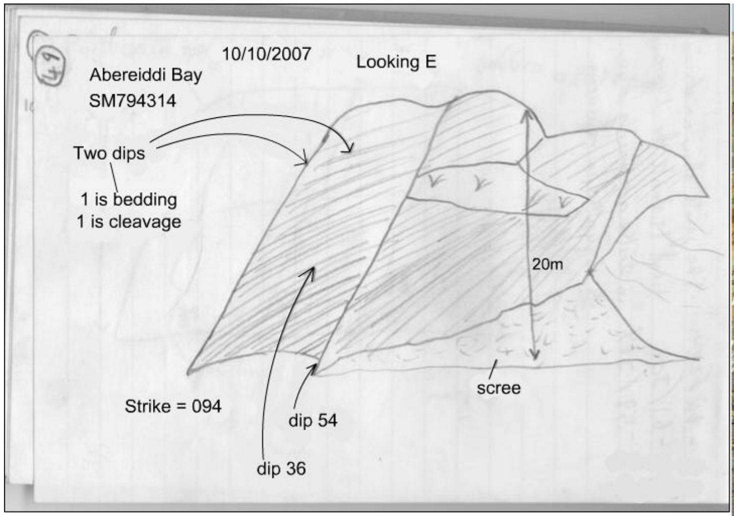


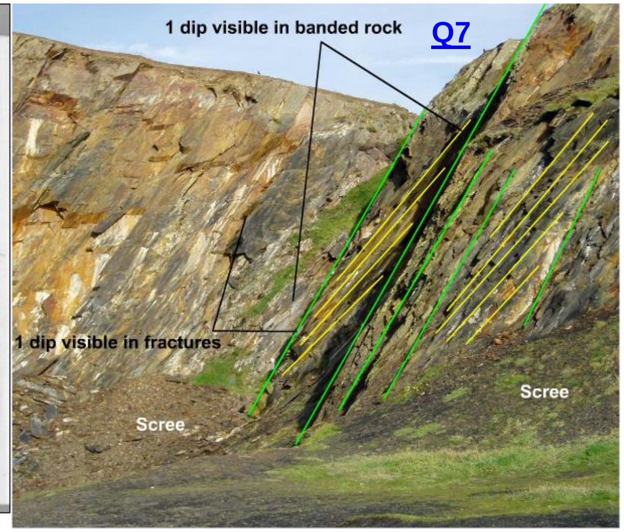
- The jointing in the gabbro at this quarry is perfect for taking dip/strike readings, as there are several joints lined up.
- The jointing all follows a single trend due to orogenic pressure applied after cooling and solidification.
- **f1** – 60/274
- **f2** – 61/306
- **f3** – 59/319

The differences in measurement can probably be explained by the nature of the jointing. First of all, jointing in a single body of rock, especially an igneous body, will not follow the regional trend as strictly as bedding plains. Secondly, the joints measured had narrow planes upon which to take the readings before disappearing into the main body behind, and I do not know whether the measurements I took accurately represent those of the entire joint. The small planes also exaggerate operator error, as it is difficult to take readings in such an awkward position.

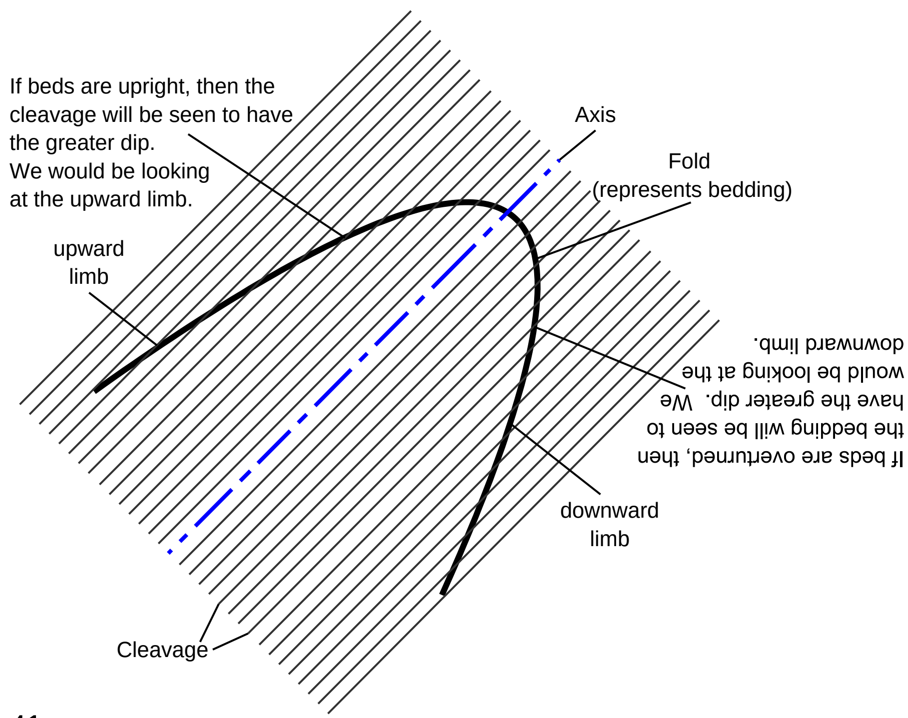
A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis



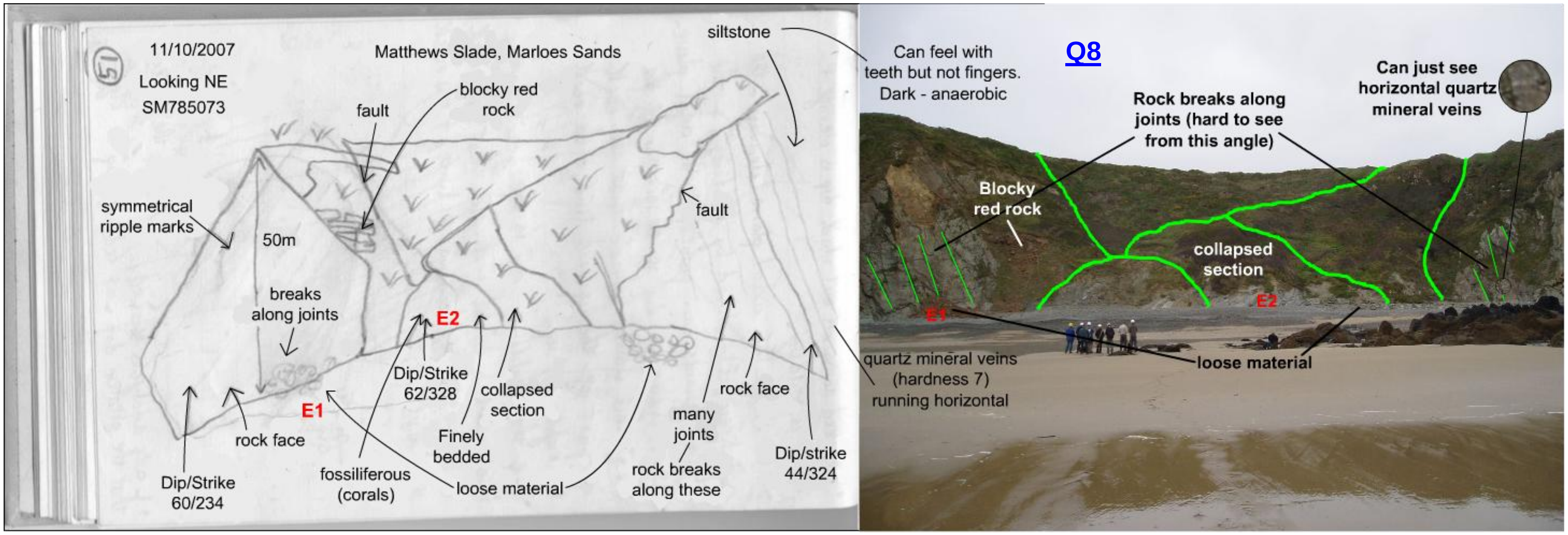


- We need to work out which dip is cleavage and which is bedding.
- The cleavage is called axial plane cleavage, and is a weakness produced by folding. The cleavage planes run parallel to the axial plane.
- The diagram shows how this is significant.
- We moved about 50m to the north of this location and found that the bedding dip was the one marked in green in the picture, so the entire area has been overturned.
- Yet again, this shows the enormous pressure put on the rocks in the area by the Caledonian orogeny, firstly to create large folds, but more importantly to overturn an entire area.



A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

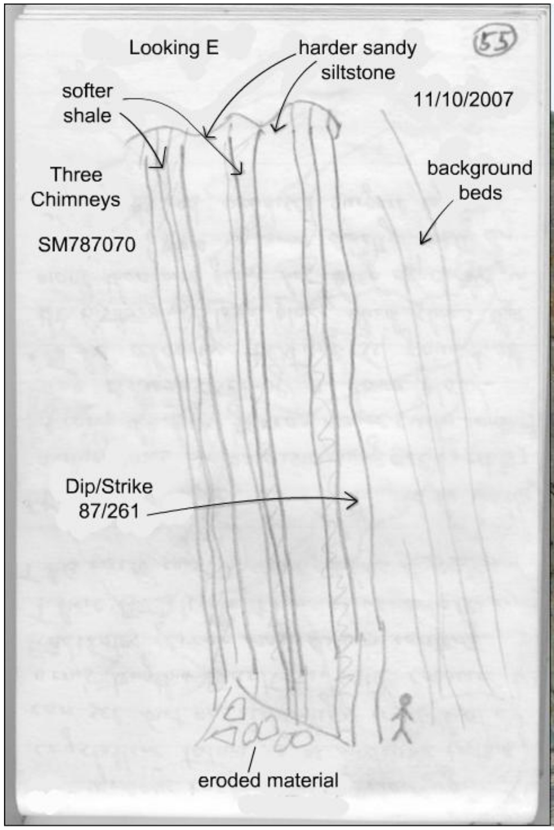
Analysis

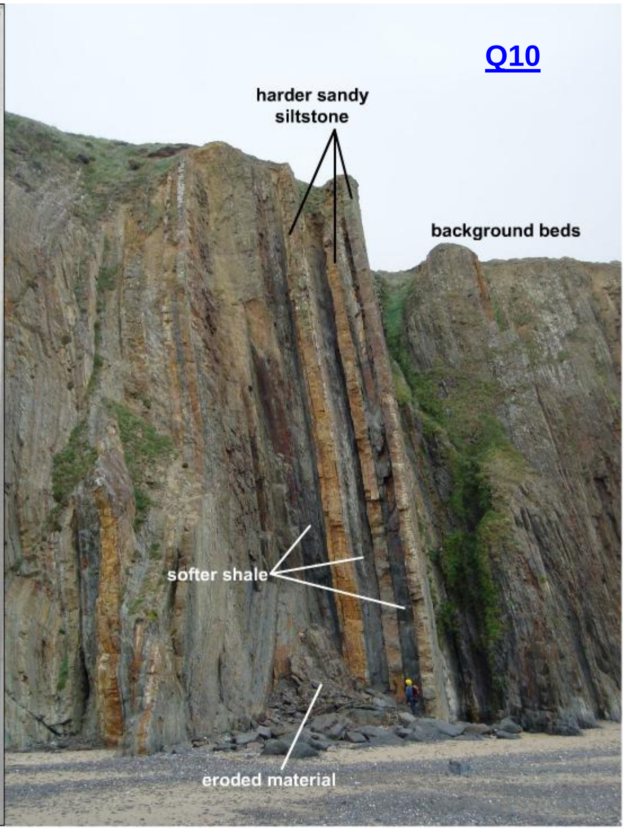


- The first thing to notice about Matthew's Slade is that it appears as if there are two similar outcrops on either side of a collapsed section of rock in the middle.
- Sampling confirms this – **E1** was identified as **siltstone** and the rock on the opposite side is also **siltstone** (although no loose samples were readily available). On the other hand I identified **E2** as a **coarse mudstone**.
- The jointing patterns on the left and right outcrops are also similar, providing further evidence.
- Although the dip/strike readings are different for either side, I would suggest the rock has been slightly folded, as it certainly appeared on location.
- Closer analysis reveals two faults on either side of the weaker central rock, marked out by the furthest left and furthest right green lines. They show diagnostic features such as streams.
- This relatively large scale faulting was probably due to the forces exerted by the Hercynian orogeny, which affected South Pembroke.
- Other evidence for these forces includes the horizontal mineralisation (magnified).

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

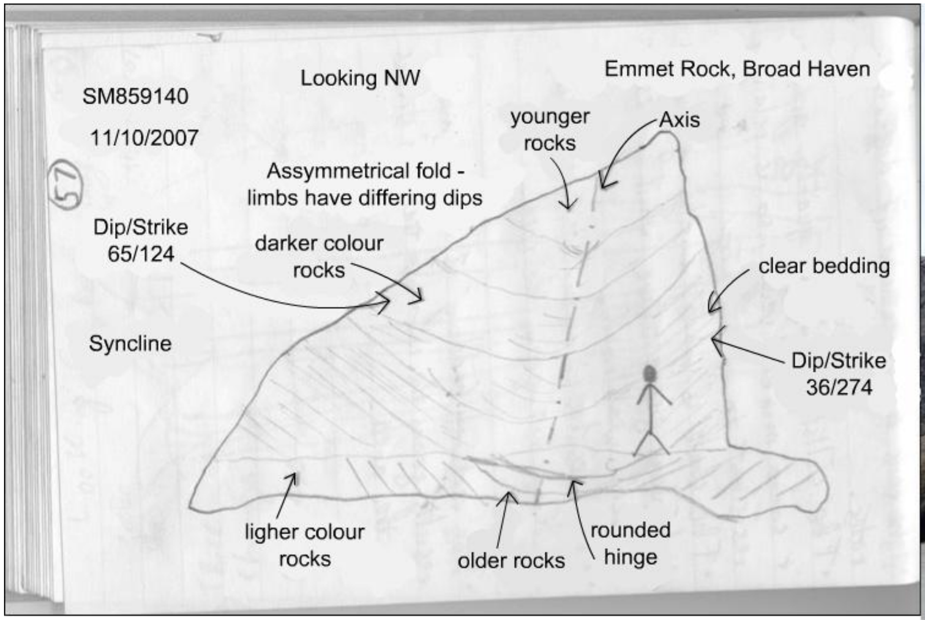
Analysis

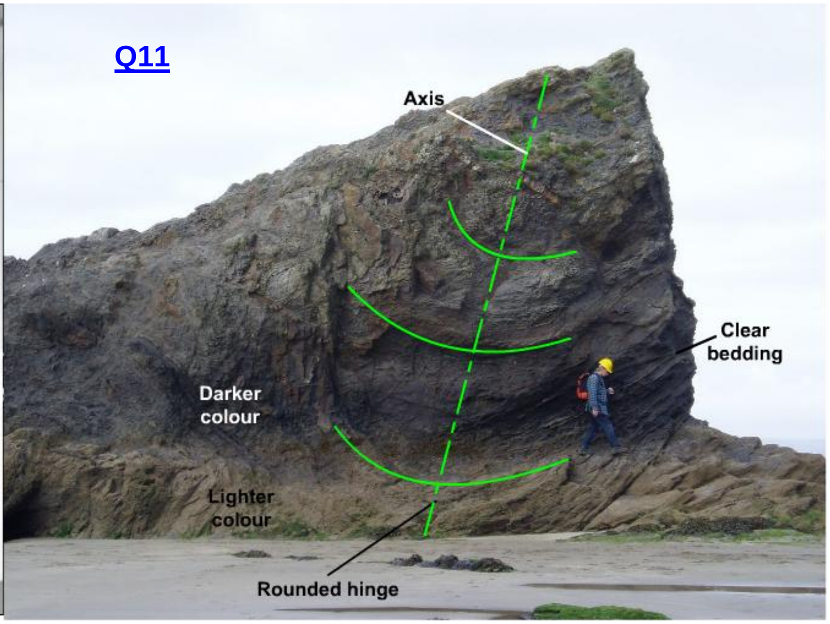




- These beds have experienced immense tilting as a result of the Hercynian orogeny. Most of the beds around this grid reference appear like this.
- It is also noticeable that the alternating beds have weathered at different rates.
- The siltstone contains quartz grains and some mineral veins, making it relatively resistant.
- This is in comparison to the shale, which is predominantly clays and displays fissile texture, making it very weak against weathering.
- This results in the siltstone beds being slightly raised out of the rock, forming the three chimneys.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Analysis



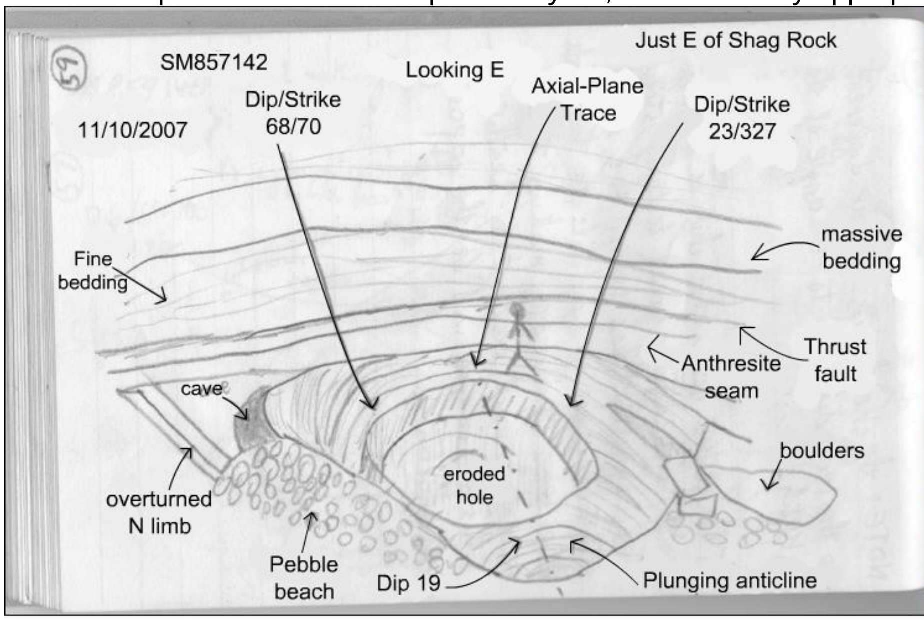


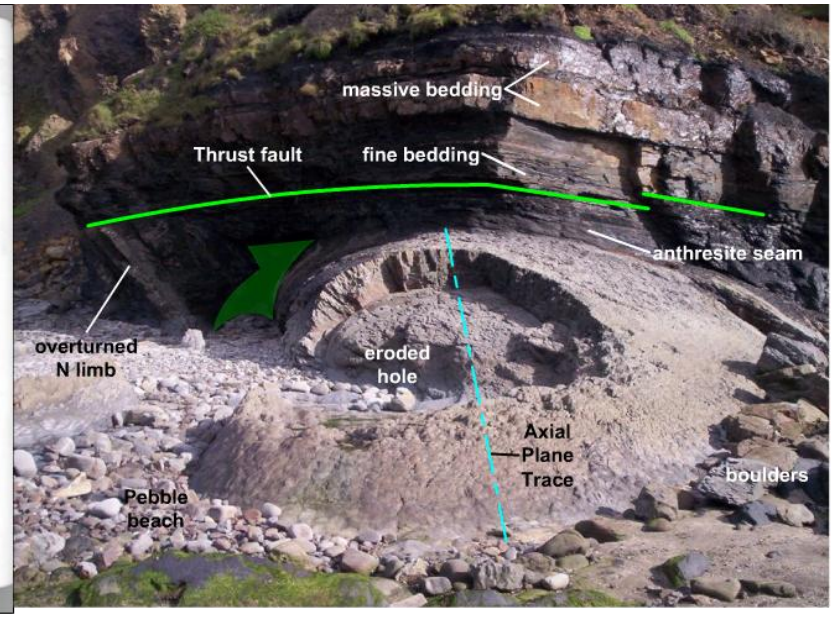
- In a straight fold, the strikes of each limb should be approximately 180° apart, but in this syncline they are 150° apart.
- This makes it a plunging syncline, which involves more complex and disruptive forces than normal folds. It would take a lot of pressure on the rocks to make a fold like this.
- The syncline has formed this small stack because in synclines the top strata have been compressed during folding. This makes them more resistant to weathering than the surrounding rock.
- The opposite would apply in anticlines, where the top strata are often hollowed out instead due to thinning during folding.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

NOTE: this photo was taken the previous year; it was the only appropriate one I could find.



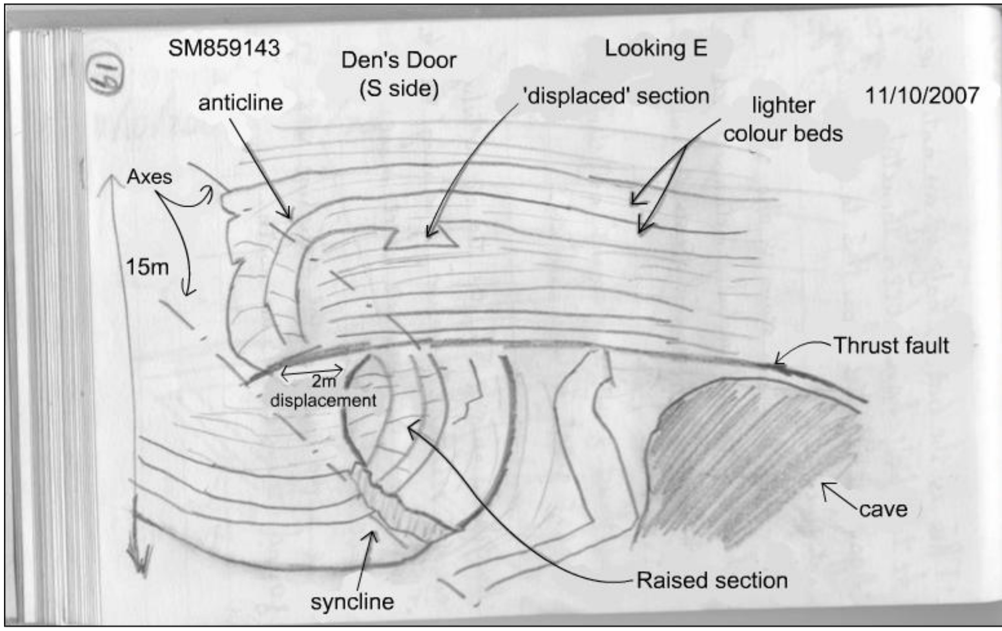


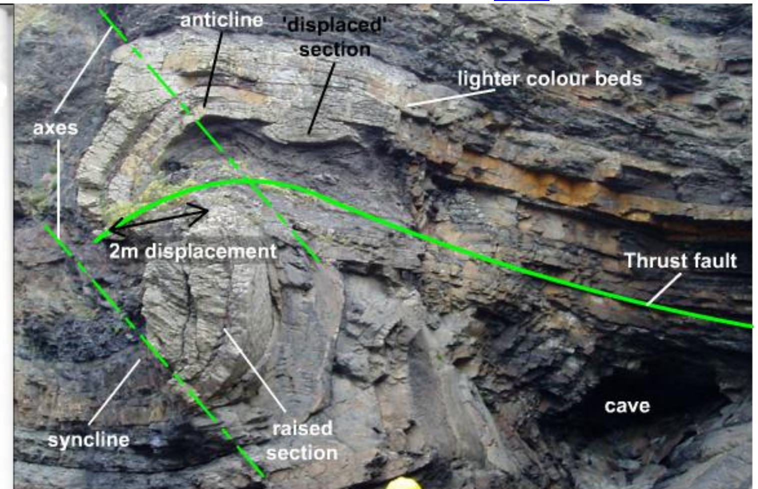
- This location is subject to much deforming.
- To start with, this can be seen to be a plunging anticline (identified by the way it *plunges* beneath the ground, and also the strikes).
- But the anticline leads immediately into another syncline to the north, indicated by the overturned limb.
- The top half of the anticline has been removed by a thrust fault, which are always good indicators of high deformation.
  The upper part of the anticline was found thrusted 25m to the north.
- The final evidence is the anthracite coal seam, which is significant because anthracite is partially metamorphosed coal, showing how much pressure was created by the Hercynian orogeny.
  The cave has been hollowed out from the anthracite seam.
- As explained on the previous page, the top strata of anticlines are less resistant to weathering, explaining the eroded hole.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

Q12



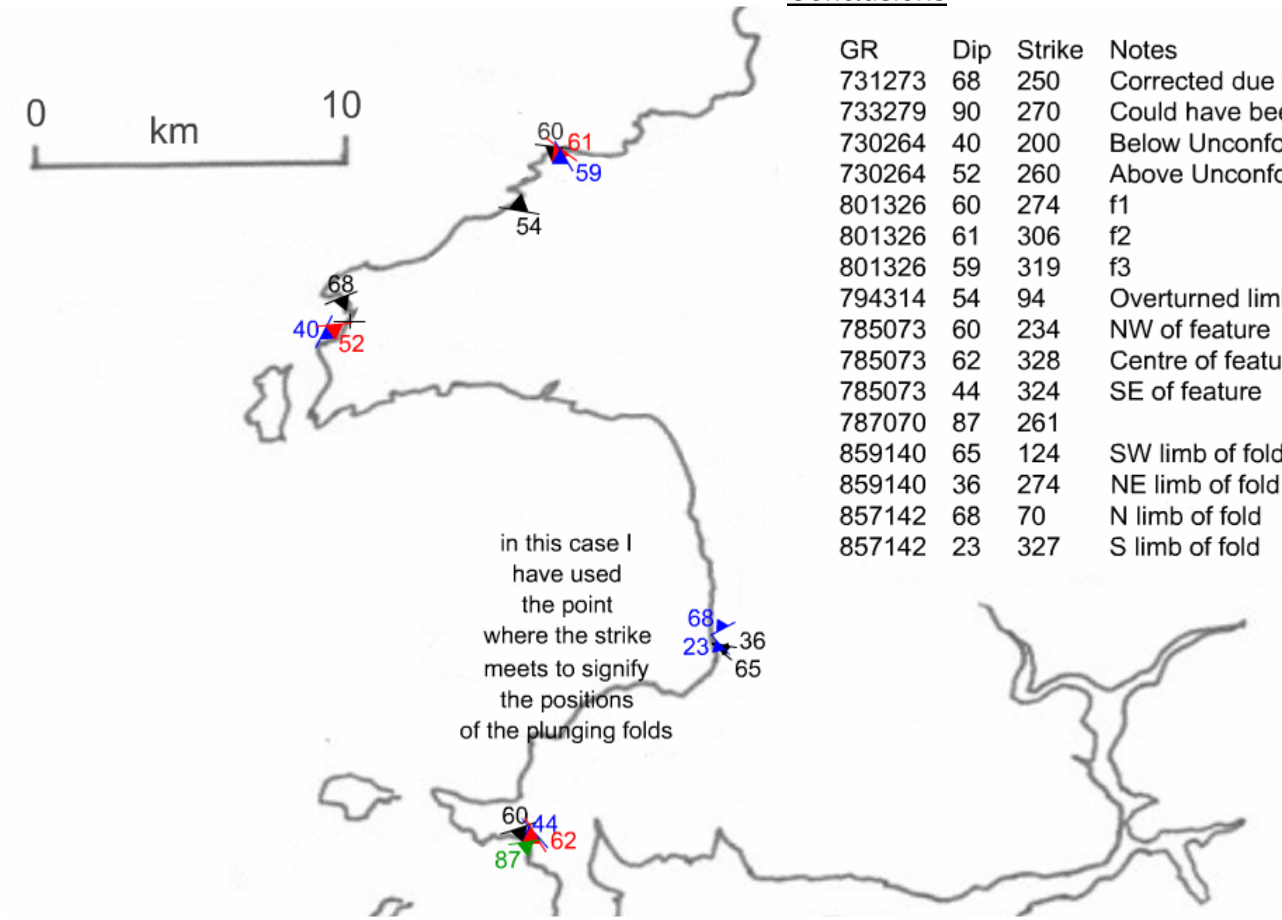


- This thrust fault has a relatively small displacement of 2m, but the folding and faulting are still important reminders of the orogenic forces is the area.
- The lighter colour rocks appear to be more competent and resistant:
  - The 'displaced' section has formed because the bed is too resistant to compress internally when put under pressure, so a section is forced out.
  - The raised section is also composed of these beds; it is raised because the surrounding beds have weathered and fallen, yet this part hasn't.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

<u>Conclusions</u>



GR	Dip	Strike	Notes
731273	68	250	Corrected due to incorrect measuring technique
733279	90	270	Could have been 90 but should follow regional trend
730264	40	200	Below Unconformity
730264	52	260	Above Unconformity
801326	60	274	f1
801326	61	306	f2
801326	59	319	f3
794314	54	94	Overturned limb of fold
785073	60	234	NW of feature
785073	62	328	Centre of feature
785073	44	324	SE of feature
787070	87	261	
859140	65	124	SW limb of fold
859140	36	274	NE limb of fold
857142	68	70	N limb of fold
857142	23	327	S limb of fold

(read notes on the factors causing error at this quarry)

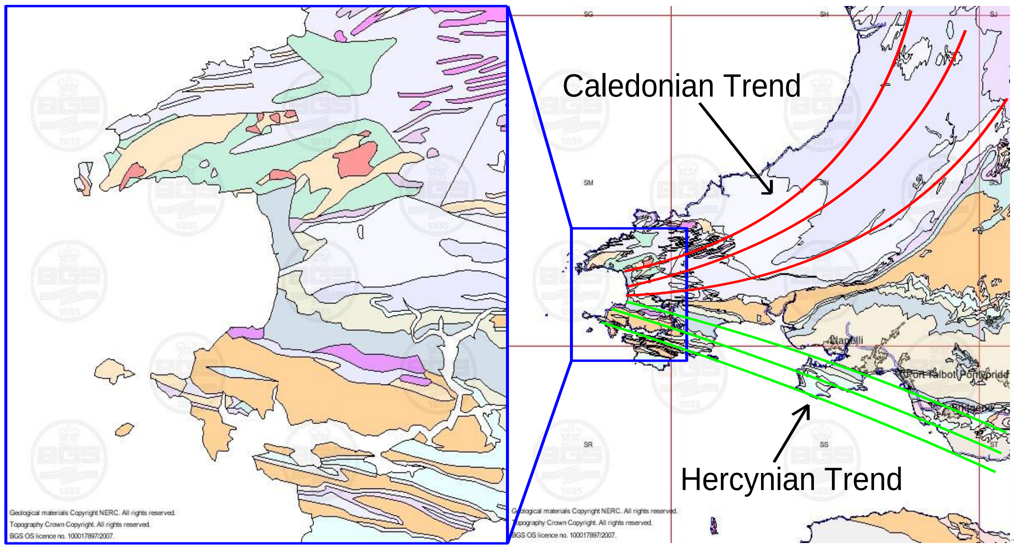
Referring back to the map in the planning section, the readings can be seen to loosely follow the local trends. They do not strictly follow the trends due to local variations and probably a degree of operator error, which would have resulted in measuring an apparent dip close but not equal to true dip; measurements taken on joints are particularly likely to suffer from this. The readings are also complicated by the fact that the same orogenies that caused the regional trends also caused many deformations that cause the dip and strike to vary from what is to be expected. This is demonstrated well at Matthew's Slade on Marloes Sands, where the faulting has resulted in three sections of rock that show different trends of dip and strike, but that should all follow the same regional trend.

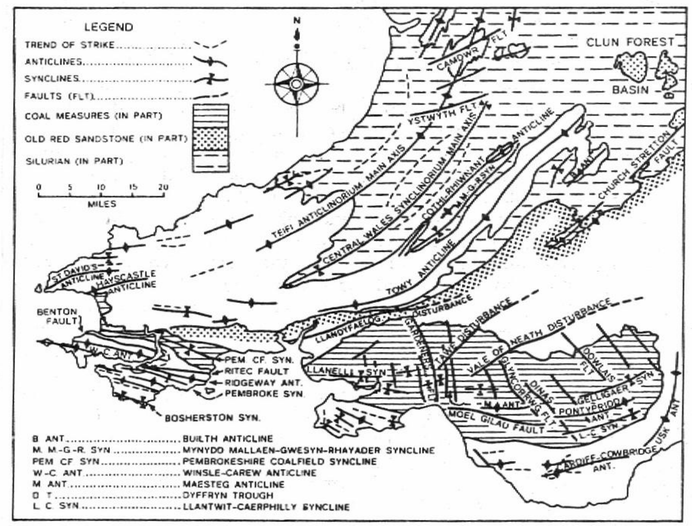
A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

<u>Folds</u>

I did not observe enough folds to verify some of my hypotheses for northern Pembroke, although I saw several in small locality in southern Pembroke. They perfectly demonstrated how the axial plane traces all followed the expected regional trends, something that was not seen so obviously elsewhere for either orogeny. Two of these folds (plunging) can be seen on the dip/strike map above. In northern Pembroke there were fewer folds, and where there were they were much larger, making field analysis difficult. However on the geological maps the repeating pattern of rocks predicted can be seen, here is the map again courtesy of BGS, and another map from my project guide booklet:





Here it can also be seen that there are far more folds in the south than the north, both by the pattern of rock types and the axial plane traces mapped on the right. The folds seen were all open so far as I could tell, although the one on page 61 of the field notebook may be a tight fold. But in general the inter-limb angle is what should be expected for folds such a long distance from the suture of the orogeny, as predicted. I expect that the lack of folds to the north can be explained by proximity to the suture as well, because southern Pembroke is a lot closer to the Hercynian suture than north Pembroke is to the Caledonian suture; perhaps the forces has dissipated to much for the Caledonian orogeny to cause folding in areas as far away as Pembroke.

Any tilting present in the area would be difficult if not impossible to observe and record, due to so many local variations in dip and strike. Anything that may have appeared like tilting has turned out to be part of a larger fold upon further analysis, even the enormous tilting of the three-chimneys.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.

Analysis

Faults

There was plenty of faulting present in southern Pembroke, although none was seen to the north. The faults seen were both dip-slip and strike-slip faults of varying displacement. This goes against what I predicted, because I thought that neither the Caledonian nor Hercynian orogenies were close enough to their respective areas of Pembroke to cause thrust faulting, which requires more force than dip-slip, which is more commonplace. So the Hercynian orogeny must have been close enough to cause both, and again the Caledonian too far away for forces to be strong enough to cause either – there seems to be a pattern emerging here.

The faults in the south displayed many of their diagnostic features. Fault breccias were seen in the dip-slip fault in the SE section of Matthew's Slade, which also displayed a spring that formed a stream (two more diagnostic features). Mineralisation was not only associated with faults, but seen pretty much everywhere across Pembroke, perhaps indicating that only low levels of force are required to prompt mineralisation. All mineralisation seen was quartz, and was seen in both north and south, reinforcing the argument stated above.

The thrust fault seen on page 59 of the field notebook had an anthracite coal seam underneath, and I am not sure whether general pressure in the rocks caused this metamorphism or if the fault had a more direct influence. Either way it shows the high pressures the rocks in the locality were under.

Unconformities

Several unconformities were seen, significantly they were all found in northern Pembroke, which could be seen as a reversal of the pattern seen with faults and folds. I believe this is simply because unconformities are caused by slightly different processes – they result from a period of uplift and erosion with no deposition. In the south it appears that the rocks have stayed in a similar locality the whole time and simply 'buckled and broke' in reaction to the orogenic forces. In the north, perhaps the Caledonian orogeny simply pushed the entire area upwards, reducing deposition but increasing erosion and causing more unconformities.

The first unconformity observed (Whitesands Bay) was in fact between a solid deposit wave-cut platform and a glacial drift deposit. This is a result of more recent processes; in fact a website (http://www.pembrokeshire-online.co.uk/geology2.htm) states that in the last 290ma there has been mostly erosion and little deposition. So this was actually not a result of the Caledonian orogeny, but fits a criterion in the planning section in that the rock underneath is part of a wave-cut platform that has been eroded down over millions of years. The second (Ogofgalchfa) was found in rocks of the right age, although it appears to not span a very long period of time (relatively speaking), as there is only a slight difference in dip and strike, and the rock sequence pattern continues both sides (tuff-breccia-tuff…etc). Nonetheless, all evidence is significant and this cannot be dismissed, it is a definite sign of the forces at work in the area that have caused deposition to stop for tens of millions of years during a pronounced period of uplift, incidentally another criterion stated in the planning section.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Analysis

Regional Metamorphism

There were only two instances of this, found in both the north and the south. One was the anthracite layer near Broad Haven, which was fairly small so probably a result of local stresses. The other was found at Abereiddy to the north, although not marked by a field sketch, which was a small deposit of low-grade slate. This is practically the minimum regional metamorphism that could have taken place, indicating the weakness of the forces from the far away Caledonian orogeny. Having said that, there is seemingly even less caused by the Hercynian orogeny, which seems to have had a more profound effect on the area in other ways. The Caledonian orogeny is known for causing widespread regional metamorphism in Scotland, showing the full range of rock types, and was certainly more powerful than the Hercynian even if in general it had less influence on Pembroke. I can only hypothesise that certain conditions conspired to form this low grade deposit, despite none being formed from the Hercynian.

The presence of only low grade metamorphic rock fits in with my predictions from the planning section, as I did not feel that either suture was close enough to Pembroke to have any stronger effect.

Although it seems that in general the Hercynian orogeny exerted more force on southern Pembroke than the Caledonian did on the north, it is obvious that both had a profound effect on their respective areas, causing many of the main features seen today. Many of predictions about what I would observe were correct, but at the same time many were proved wrong, indicating how unpredictable such large and varied geological forces can be. I have definitely achieved my original aim of enriching my understanding of orogenic events by observing their influences in the field.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Evaluation

Planning

The original factors I chose to investigate proved to almost all be relevant, especially folding and faulting. In hindsight I should have realised that tilting would be a difficult thing to observe and measure in the field, but I did not devote much space in the predicted outcomes to it anyway.

Some of the detail I put in places was difficult to measure in the field, such as the 'tightness' of folds, and some of the mineralogy for regional metamorphic rocks. I did not really know what to expect on the fieldwork, so perhaps it was justified to be overcautious and provide extra detail. My predictions were also disproven in several places, such as my thought that there would not be enough force this far from the orogeny sutures to cause strike-slip faulting. On the other hand all these predictions were justified and made sense, so I was right to put them in, and the idea of the fieldwork was to enrich my understanding of orogenic events and their influences anyway.

I was rather ambitious with my plan for collecting primary data, demonstrated by the way that I planned a very rigid routine for each site. When in the field this 'objective' routine was quickly replaced by a 'subjective' routine as I learnt that not everything is accessible at each site and it is often not time efficient to look at more than needed when conclusions can be drawn using less evidence. It would have been impossible to have been as thorough as in my plan, as many of the pieces of data I wished to measure (e.g. the throw of faults) were not always accessible. My planned use of equipment was more suitable, and I ended up making use of most of the techniques listed, as well as extra skills acquired in the field (e.g. the tooth test for identifying sedimentary grain size). I was able to use my field notebook and extra photographs just as I had planned to. The pilot study helped to point out my inexperience and allowed me to adjust my expectations for data collection for the rest of the trip.

Because data presentation and analysis was a more familiar technique to me, it was easier to plan this section as I would carry it out. The laying out of my field notebook could have been improved to meet the standards of my plan, but in the field I felt I was pressed for time. In order to achieve the ease of interpretation targeted in the plan, I have typed over all my field annotations (with few amendments) to make them easier to read. Apart from that, everything was logged and recorded as planned, and the analysis section includes everything that I originally wished to include. I predicted there would be little opportunity for numerical analysis, in fact there was none at all for this project, so I simply had to use qualitative analysis to identify patterns and draw conclusions.

As predicted, time was indeed by far the most limiting factor in data collection, and I just had to make sure I took the time saving measures mentioned in the plan. One method in particular that I found helped was to limit to analysis performed in the field and spend extensive time the same evening writing more extensive notes and administrative pieces such as the date, locations and grid references. I feel the limited time was in fact beneficial, as it prevented me from wasting time collected unnecessary data, which is normally a downfall of mine. In the end weather was not a problem, although I still took the precautions of waterproofs and warm gear. Where I could I reduced the influence of metallic objects on the compass, although this is difficult in situations when surrounded by basic igneous rock. I was also idealistic about reducing error by reducing estimates – to avoid estimation in some of these situations would involve perhaps spending 10 minutes rather than 10 seconds recording just one item of data.

Implementation

Ignoring some of the naïve things that I planned to do in the field, my work was relatively well conducted. After the pilot study, field sketches gradually became more natural to draw and I started picking out key details and ignoring those that weren't important. My methods became faster and more efficient over the three day period, which helped to streamline data recording.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Evaluation

The main shortfall was my use of the compass-clinometer. Having practised its proper use in the classroom before the field trip, I then forgot a key detail when measuring in the field. Having recorded dip, I forgot to rotate the clinometer to dip 0 before reading azimuth, so rather than recording the azimuth of strike; I was recording the azimuth of dip. I realised this half way through the trip and corrected my method. Those readings taken before this point were amended using information from others who had recorded their values from the same point, and in some cases by using common sense from looking at the field sketches and the direction they were facing.

I also had a problem with the use of the geological hammer. Rather than using a geological hammer as stated in the plan, I was using a fossil hammer, which is designed only for sedimentary rocks. Consequentially this broke early on the second full day while trying to break a fragment of basalt, and I borrowed the college's real geological hammers after that.

I found loose samples very helpful, as they allowed later, more detailed analysis than rushed field descriptions. As a result I collected a sample for about half of my field sketches; the majority of the time these were loose samples, although occasionally when it was necessary and it was from a large body I broke a piece out of the rock.

<u>Results and Analysis</u>
The dip/strike readings, which were the only form of numerical analysis, were also a considerable source of error through a variety of factors. Firstly it is not always possible to measure true dip, but worse than this it is not always possible to tell that one is not measuring true dip, such as the situation discussed about measuring on joints. Secondly, in the field it is difficult to take calm, precise measurements given the limited space of time and often slightly awkward positions of measurement (when measuring on Emmet Rock, there was only ever space for half my boot on the ledge that I had to clamber a short distance up to get to the point of measurement). It is difficult to reduce the error for this, but as discussed later more time and further practice would both help in making readings more precise.

I feel that the quality of my field sketches was sufficient enough to give a good representation of what I was drawing, and I was meticulous with my annotations, as well as logging samples of photos, and describing my samples fully. I have drawn as many conclusions as I can from the available information, as well as occasionally commenting on other possible conclusions to be drawn that could not be justified, but could be seen as reasonable.

I have made a good a use of photographs as possible, even selecting some from other years where they better represent what is in the sketch than those taken this year. I have used digital annotations for both sketch and photograph to make them clearer. My conclusion has been designed to amalgamate all the information and conclusions from the main body of the analysis into a review related back to the original plan, covering all sections and analysing any predictions that I made.

The cartographical summary of all my dip/strike readings in the conclusion is useful. It is possible to see vague regional trends, although in some places such as Broad Haven these are more obvious. It is also a useful demonstration that the readings were not as accurate as they should/could have been.

This project was in general more difficult to analyse than the igneous rocks project conducted in parallel, mainly because the rules on orogenic events are far less concrete that that of igneous rock formation. There are many other factors besides the selected orogenic events that have influenced the local rock formations.

A field investigation of local tectonic structures in relation to the orogenic events in Pembroke.
Evaluation

Improvements

The main limitation of the entire investigation was the time in which we had to do it all, and just slightly more time would have made the investigation easier and more detailed. The rushed nature was reflected when we could not reach a particular location simply because of the tides – there was no opportunity to change plans and go back later or another day because we had such a tight schedule to stick to. It is worth noting that the trip had a very good flexible nature to it, which allowed for such eventualities, and there were enough other localities to make up for the loss of access to that particular one. I have already said that too much time would also have been a bad thing, as it would have encouraged inefficiency in data collection.

Although by the end of the study data collection was smoother and more efficient, it took longer and may have missed certain pieces of information at the start. With better time management before the study, I would have practiced far more sketching so that it was easy to start to investigation without having to overcome any ‘teething problems’. I would have also further practiced compass-clino use, which would have cemented the method in my memory and prevented the problem mentioned previously.

I had to spend around 2 hours locating and selecting pictures that I could use for the study, having elected not to take my own camera in case it were damaged or lost. Looking back on this I think it would have been worth taking my own pictures relevant to each of my own field sketches, rather than trying to locate the most relevant one from others’ collections. This would have slightly increased the time it would take for each field sketch, but not significantly.

It was short sighted of me to take a fossil hammer for use as an all-purpose geological hammer on the trip, it would have been more sensible to simply have made use of the college’s resources.

Geology Fieldwork Pembroke
Bibliography and Acknowledgements

Bibliography

1. Mike Farrington
   Various OS and geological maps of areas.
2. BGS GeoIndex online map service
   Geological maps of Wales and Pembroke used to demonstrate orogenic trends.
3. Google Earth and Google Maps (www.google.co.uk)
   Large scale aerial photographs of Britain and Pembroke as a whole.
4. Windows Live Maps (http://maps.live.com/)
   Smaller maps of each locality.

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3. Pembrokeshire Online (http://www.pembrokeshire-online.co.uk/geology2.htm)
   Information on general geological history of Pembroke