



The Pembrokeshire Coast – processes and landforms of coastal erosion

The Pembrokeshire coastline in the southwest of Wales was designated as a National Park in 1952 as a result of its natural beauty. Its geo-diversity has given rise to an awe-inspiring and dramatic coastal landscape. The National Park covers an area of 612 square kilometres and stretches from St. Dogmaels on the Ceredigion border in the north to Amroth in the south (Figure 1a). The coast is 420 kilometres long and includes 60 Geological Conservation Sites. Forty per cent of the coastline has been protected as SSSI (Sites of Special Scientific Interest) due to its environmental importance. Many factors, including marine, subaerial, geomorphic, climatic and biotic, combine to influence coastal landforms. Geology is the most important factor shaping Pembrokeshire's coastline and its landforms. This Geography Factsheet will focus on the **erosional** features of this coastline and the geology and processes which have shaped them, and continue to shape them, over time.

Figure 1a. The Pembrokeshire coastline



Figure 1b. The geology of the Pembrokeshire coast

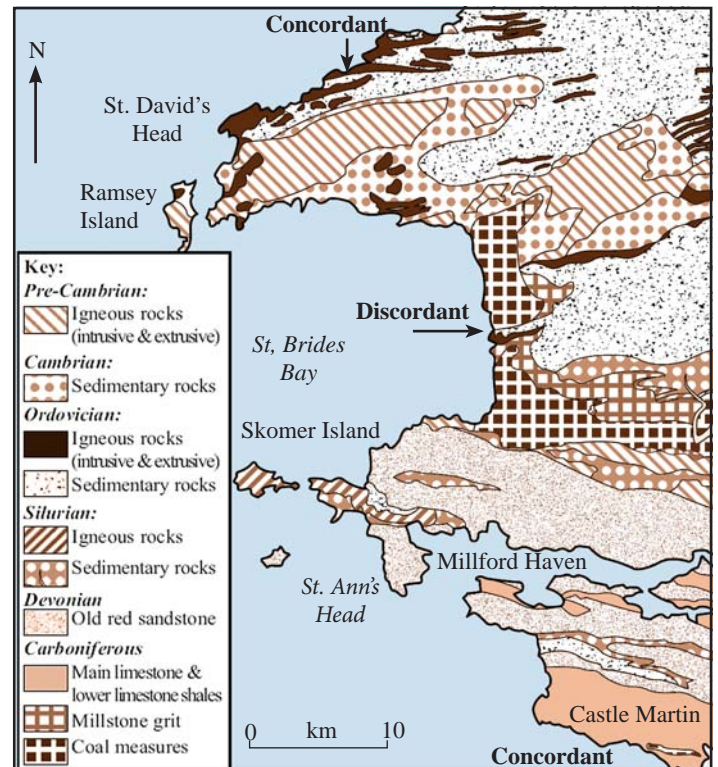


Table 1 Useful geological terms

Concordant coastlines:	<i>concordant coasts lie parallel to the general trend of the geology of a coastal region.</i>
Discordant:	<i>discordant coastlines cut across the structural trend of a coastal region.</i>
Igneous rocks:	<i>rocks that have formed from the crystallisation and solidification of magma.</i> <i>They may be formed within the ground (intrusive) or on the Earth's surface (extrusive).</i> <i>They are usually more resistant to erosion than sedimentary rocks.</i>
Sedimentary rocks:	<i>rocks formed from the accumulation of material derived from pre-existing rocks and organic sources.</i> <i>They are usually less resistant to erosion than igneous rocks.</i>
Lithology:	<i>this concerns rock composition, its pattern of joints and bedding planes, grain size and resultant permeability;</i> <i>this determines how susceptible a rock may be to breakdown by chemical or mechanical processes.</i>
Structure:	<i>this refers to the arrangement of rocks in the landscape and incorporates consideration of faults, dip and strata (layers).</i>
Fault:	<i>a fracture or rupture of rock strata due to strain in which displacement of the rock is observable.</i>
Joint:	<i>a fracture in a rock in which no movement or displacement of the rock is observable.</i>
Dip:	<i>the dip of a bedding plane is the angle which it makes with a horizontal plane.</i>
Bed:	<i>the smallest layer of a sedimentary rock.</i>
Bedding plane:	<i>the planar surface which separates one layer of sedimentary rock from another.</i>
Intrusion:	<i>when molten igneous rock is injected and emplaced into existing rocks (known as the country rock) and, on cooling, becomes an igneous intrusion</i>
Sill:	<i>an igneous intrusion which is in concordance with (in parallel with) the surrounding rock layers and is normally injected as a near-horizontal sheet between the bedding planes of the country rock.</i>
Folds and folding:	<i>a bending or flexure of the Earth's crust due to compressional tectonic forces.</i>

Geology of the Pembrokeshire coast

Why is the geology of Pembrokeshire so complex and diverse?

The rocks in Pembrokeshire are diverse, with a huge variety of rock types compressed into the area (**Figure 1b**). They date from late Precambrian (650 million years ago) to late Carboniferous (around 290 million years ago). Rocks and deposits of Quaternary age (in the past 2.6 million years) are also found in the area, overlying the older rocks. The reason why so many rocks are compressed into this region is because of episodes of **mountain building** (orogeny) and **volcanism** in the past. The Caledonian Orogeny, around 400 million years ago, and the Variscan Orogeny 290 million years ago have shaped the geology of Pembrokeshire and are responsible for the folding, tilting, faulting and shattering of many of the rocks.

Most of the rocks in Pembrokeshire are sedimentary. Sedimentary rocks, including conglomerate, sandstone and mudstone make up the Cambrian rocks which are found on the south and west sides of St David's Peninsula and between Abercastle and Abermawr. Carboniferous limestone forms many coastal landforms on the south coast and Coal Measures (the youngest rocks in Pembrokeshire, made up of shales and sandstones) run from St Bride's to Carmarthen Bay. Igneous rocks are evident in Pembrokeshire as a result of episodes of volcanic activity. For example, during the Ordovician Period (440 – 500 million years ago) volcanic activity created extrusive igneous rocks and also igneous intrusions of sills in the north (see **Figure 1b**).

Processes shaping the Pembrokeshire coast

Marine and subaerial processes operate on the Pembrokeshire coast to create the landforms of coastal erosion. Waves that affect Pembrokeshire are driven by south-westerly winds and have developed strength partly by having a large fetch (the distance over which the winds that generate sea waves blows). Another factor contributing to the strength of the waves is the Atlantic weather systems, which can generate waves around 5-10 metres high, sometimes greater.

Marine erosion involves the wearing down of rocks by the action of the waves and can take the form of hydraulic action, abrasion (corrasion), attrition and solution (corrosion).

- **Hydraulic action**, or wave quarrying, acts when a wave breaks against a cliff, exerting a shock impact as air is compressed and then expands as the wave subsides, which will break away unconsolidated material, or material that has been previously loosened by marine action.
- **Cavitation** may take effect in strong wave conditions, where bubbles form in turbulent water and exert strong pressure impacts as they collapse.
- **Abrasion** occurs as the waves hurl materials such as sand and pebbles (even boulders in the strongest storms) at the cliff face to chip and scour away at the rock. Abrasion may also act to scour wave-cut platforms as the in- and out-going waves and tides move shingle and pebbles up and down the platform.
- **Attrition** does not act on the cliffs or shore-platforms, but on the detached materials, which will collide and eventually be worn down to become smaller, smoother and more rounded over time.
- The process of **solution** varies in its categorisation as either a process of erosion or weathering. Solution involves the dissolving of rocks through chemical reactions with seawater. The action of solution is particularly significant on limestone (as is found on the Pembrokeshire coast).

The **rate** of coastal erosion is influenced by a number of factors, including the point at which the wave breaks; if it breaks at the foot of a cliff it is more likely to erode more efficiently than if the wave is to break further offshore. The erosive power of waves may also be influenced by the presence or absence of a beach, which, if present, may dissipate the wave energy and protect the cliffs from erosion. Geology is hugely important in determining rates of erosion.

The rock type and its structure, resistance and dip determine the vulnerability of a stretch of coastline to erosion.

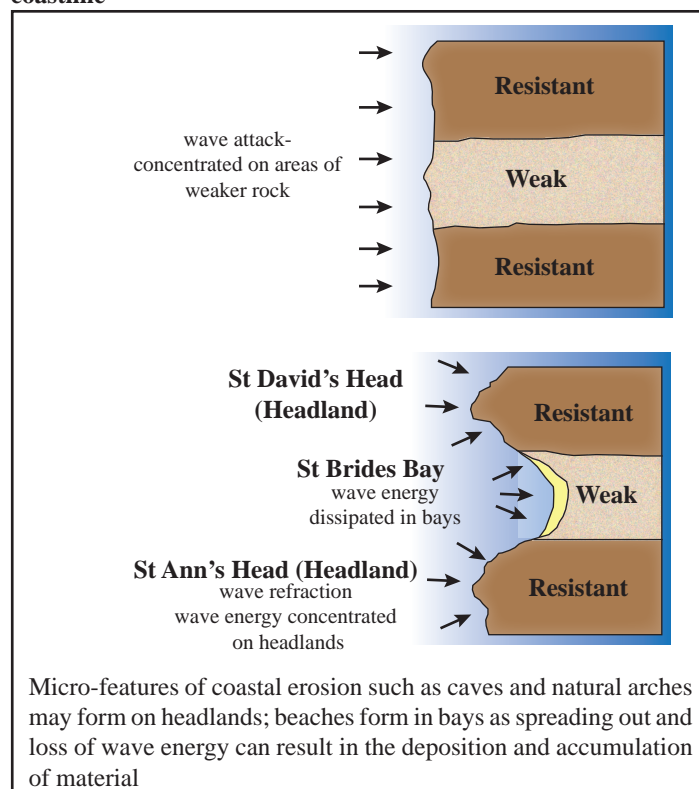
Sub-aerial processes refer to all denudation processes which operate on the land at the coast. This includes processes of **weathering** and **mass movement**, which will often work together and with processes of erosion.

- **Water-layer weathering**, the wetting and drying of the rocks, acts as the tide rises and falls and results in salt crystallisation. This crystallisation will weather porous and coarsely granular rock types.
- **Biological weathering** can also play a part as algae secretions, boring or drilling activity by sea creatures and movement and tugging on rocks by anchored seaweed, can all act to break down rocks in situ.
- **Freeze-thaw weathering** can act in lower temperatures when repeated freezing and expansion, followed by thawing of the water which may enter cracks in the rock face eventually leads to pieces of rock being broken away.
- **Mass movement**, or mass-wasting process, such as rockfalls, slumps and slides involve the downhill movement of surface materials, including solid rock, under the force of gravity. These movements can potentially have the greatest and most sudden impacts on the coast, although soil creep on more gentle, soil covered slopes can act more slowly.

The impact of structure and lithology

Geological structure and lithology determines a coastline's configuration. Concordant coasts lie parallel to the general trend of the geology of a coastal region; discordant coastlines cut across the structural trend. Both concordance and discordance is evident along the Pembrokeshire coastline. Differential erosion involves the relatively greater rate of erosion on less resistant than more resistant rocks. This can result in the creation of headlands and bays on a discordant coast (**Figure 2**) and bays or coves on a concordant coast.

Figure 2 The creation of headlands and bays on a discordant coastline



The discordant coastline of west Pembrokeshire

In west Pembrokeshire, on a macro-scale, the structural trend is at right angles to the coast. This creates a discordant coastline as the main headlands: St David's Head and St Ann's Head are formed by relatively resistant rocks (**Figure 1b**; **Figure 2**).

St David’s Head is formed of a variety of igneous rocks, including pre-Cambrian volcanic tuffs and younger igneous intrusions within sedimentary rocks of Ordovician age. St Ann’s Head is made up of Old Red Sandstone and rocks of volcanic origin. St Bride’s Bay which is flanked on either side by these headlands has been created through the more rapid and pronounced erosion of the weaker Coal Measures sedimentary rocks.

Discordance within St Bride’s Bay

The macro-scale pattern of large headlands and bay is superimposed by a large amount of small-scale coastal forms due to the hugely varied geology in the area which has resulted from the folding and faulting of the mountain building episodes and the emplacement of resistant igneous rocks at times of volcanic activity. As mentioned above, St Bride’s Bay is created by differential erosion of the weaker Carboniferous Coal Measures rocks. Within this large bay there is evidence of differential erosion on a smaller scale. Geological weaknesses such as faults, joints and bedding planes are eroded more rapidly than surrounding rocks. Small headlands, such as Ricketts Head and Settling Nose are formed from the tougher sandstones, while less resistant shales lead to the development of the inlets along the bay, with some steep, narrow inlets (geos) developing along faults.

The concordant coastline of north Pembrokeshire

Hard igneous intrusions form headlands such as St David’s Head and Strumble Head in the north of Pembrokeshire. Between these two large headlands, a number of small igneous intrusions, mostly sills, have formed a series of smaller promontories, for example, Pen Llechwen, Pen Clegyr and Pen Bwch Du, alternating with bays such as Aber Eiddy Bay, Traeth Llynfu and Porth Eger, eroded from the weaker Ordovician shales that surround the intrusions (Small, 1970). These undulations in the coastline plan exist on what can be referred to as a concordant coast, given that the trend of the intrusions lies seemingly parallel to the coastline, creating a resistant igneous barrier (Figure 1b). This shows that small-scale geological variation on a concordant coastline can lead to the formation of headlands and bays (or coves), similar to those found on a discordant coastline.

Landforms of erosion: a case study of the Castlemartin Coast

South Pembrokeshire, most particularly the concordant stretch of coast at Castlemartin, (Figure 1b and Figure 3) is home to many of the typical features of coastal erosion (Figure 4). Many faults and small fractures are present in the limestone here and give rise to the creation of landforms. The complex nature of these micro-features on the Carboniferous limestone coast is further complicated by the relict karst scenery, which the retreating cliffs have intersected. This karst scenery, formed by the dissolution of limestone, is evident in the local area through underground drainage caves and circular depressions or sinkholes on the land surface. Thus, the combination of solution and collapse of the coastline with alteration by marine processes has produced a complex array of landforms.

Figure 3. Some of the many landforms of coastal erosion on the Castlemartin coastline

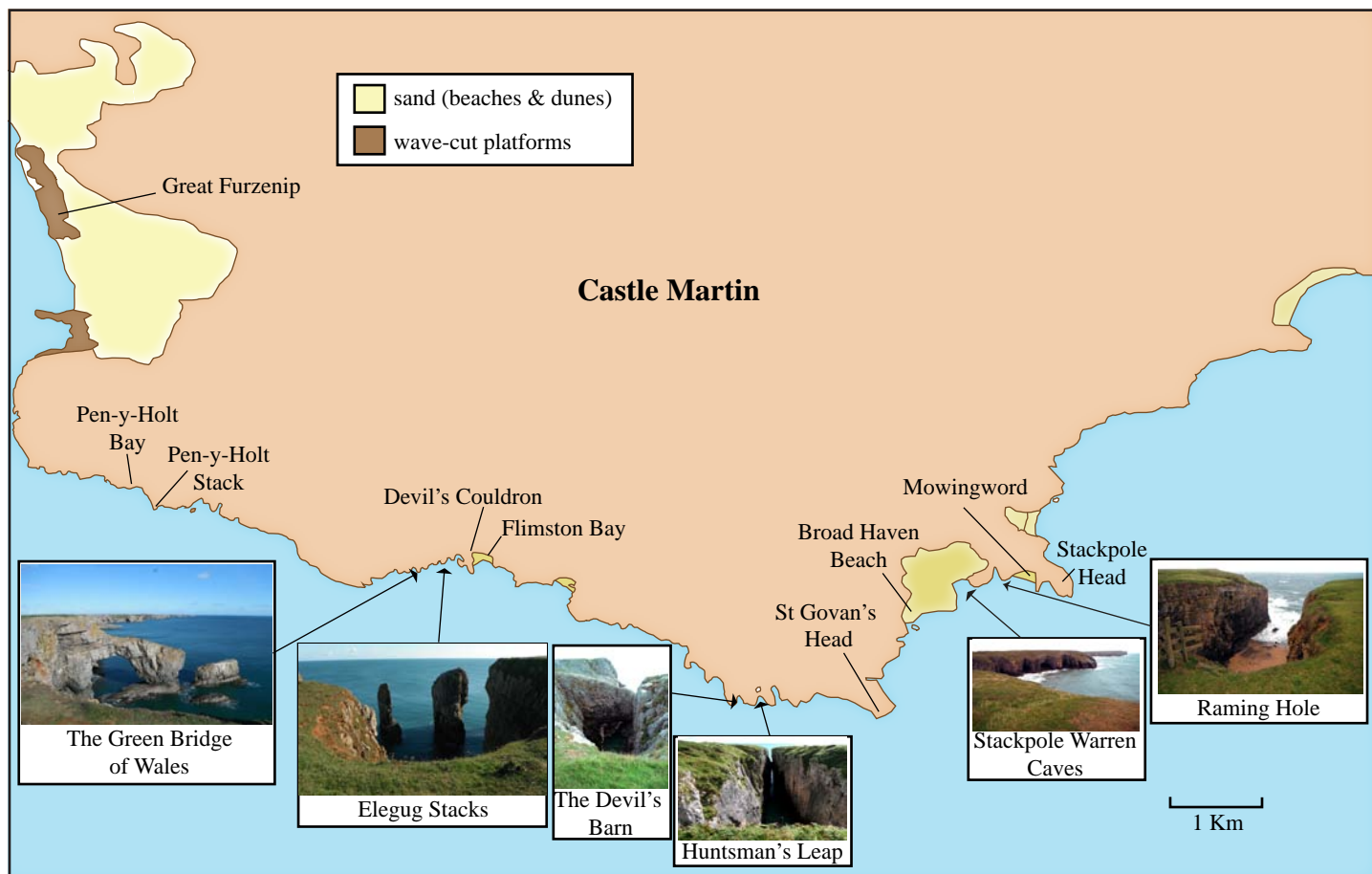
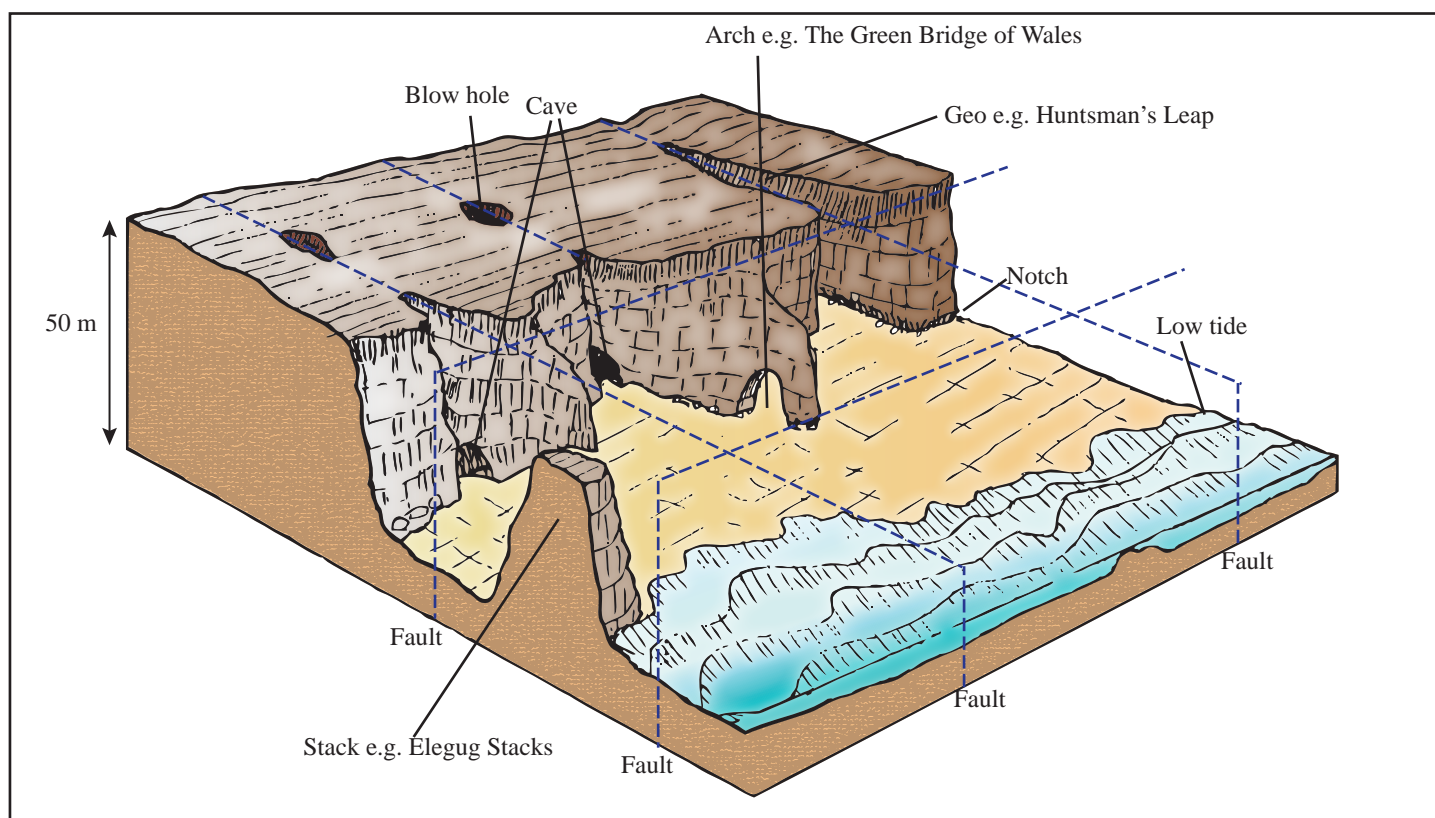


Figure 4. Typical landforms of coastal erosion



1. Cliffs and shore platforms

Cliffs are usually at a steep angle of more than 40° but may even be vertical or overhanging. They are often found at the coast with a **shore platform** (sometimes called a wave-cut-platform) at their base. A **wave-cut notch** may be found at the base of cliffs due to long-term wave-attack and is the point at which cliffs are undercut and the overhanging cliff face will eventually fall under the force of gravity, driven by subaerial weathering and mass movement processes. The shore platform is created as the cliff retreats over time and it is usually covered at high tide. Wave-cut notches may be more rapidly created and pronounced on coastlines with a microtidal range (a difference between high and low tide of less than 2 metres) as the sea's erosive energy is concentrated over a smaller area. Given that the tidal range in south-west Wales can be categorised as macro-tidal (tidal ranges in excess of four metres), *pronounced* wave-cut notches are absent.

Cliff morphology is significantly influenced by the geology of a coastline and most particularly by the **structure** and **lithology** of the rock type (see **Table 1**) as this will affect how cliffs respond to erosion and sub-aerial processes. Cliffs recede mainly during storms when they are subject to attack from wave erosion, and hydraulic pressure and abrasion dominate. Vertical cliffs are well-developed in limestone rock as seen in parts of south Pembrokeshire. The Carboniferous limestone cliffs of south Pembrokeshire rise to between 45 and 50 metres tall and host a variety of coastal features, developed as erosion and weathering processes exploit the weaknesses of faults and joints in the rock, which can, for example, be seen at the steep limestone cliffs at **St Govan's Head**. Evidence of sub-aerial processes can be observed at the foot of some cliff faces as boulders from rock falls of various ages are present. Some cliffs here overhang, owing to the gentle landward dip of the sedimentary limestone strata; near **Flimston**, the limestone dips at 12° landward, helping to form the steep, near vertical cliffs.

Further east from the Castlemartin coastline, in **Manorbier Bay**, the wave-cut platform is created from exposures of Old Red Sandstone, whose strata are standing on edge. The rock strata have been tilted upright by compressional land movements in the past. The wave-cut platform at **Great Furzenip** headland similarly exposes Old Red Sandstone which has been tilted showing its vertical layers, originally laid down horizontally as the rock was formed. In parts of Pembrokeshire, the coastline made up of softer, less resistant clays and sands, cliffs may recede through intermittent **slumping**, encouraged by wet weather conditions.

2. Caves

Caves are natural cavities in rock faces which form when weaknesses in local geology are attacked by marine erosion. They are common in areas in which the rock has many joints, faults or weaknesses. Caves are less likely to develop in weaker rocks as the cave will be likely to collapse soon after it is created and undercuts the rock above. Many caves are found along the Pembrokeshire coast, for example, those found in the limestone cliffs at **Stackpole Head** and **Stackpole Warren**.

3. Natural arches

A natural **sea arch** is an opening through a mass of rock, commonly seen at the coast where waves have eroded through a promontory. The **Green Bridge of Wales**, a sea arch, is the most striking of erosional features found on the Pembrokeshire coastline, and arguably one of the most famous landforms to be found around the coastline of the British Isles. Natural sea arches form when caves extend through headlands due to powerful wave action. This spectacular example of an arch is formed of massive Carboniferous limestone and, at its base, thinly bedded rock strata have been cut out along joint planes. It stands at about 24 metres high and 20 metres across. The limestone strata dip inland (northwards); this is clearly visible in the arch, which has its outer limb resting on a wide base, with the upper portion of the arch gently sloping down from the cliff top. A small stack lies close by to the arch.

4. Stacks

Coastal promontories may be dissected over time; a natural arch roof may collapse as it grows thinner through prolonged attack by weathering and erosion processes to leave a **stack**, an isolated pillar of rock which rises steeply from the sea, which stands separately from the cliffed coast that it was previously connected to. **Stack Rocks**, known locally as **Elegug Stacks**, stand tall, with the tallest being around 36 metres from mean sea level. Another example, **Pen-y-Holt Stack** is found to the west of Elegug Stacks, in **Pen-y-Holt Bay**. (Clear examples of geological folding can also be seen at Pen-y-holt Bay). This stack is surrounded by submerged ledges offshore and a resistant platform lies at its base. This means that the stack is somewhat protected from the full force of marine action and is therefore less inclined to erode down to a **stump** (which would not be visible at high tide) as its near neighbours, Elegug Stacks, may be.

5. Geos

A **geo**, or coastal gorge, is created when a faultline is differentially eroded to form a narrow inlet, or gully. A number of inlets have been created along the Carboniferous limestone portion of the Pembrokeshire coastline. Joints and fault planes have been enlarged by marine erosion to form these narrow, steep sided inlets. The most well-known is **Huntsman's Leap**, creating a 40 metre drop, and a wider inlet, known as **Raming Hole**, is found to the east of **Broad Haven Beach** on the south coast. **Stennis Ford** is another narrow, steep-sided inlet which extends about 180 metres in from the coastline.

6. Blowholes

Blowholes are vertical clefts in coastal cliffs which link sea-caves with the cliff-top. Typically, they are formed along coastlines through hydraulic action. Incoming waves trap and compress air within a cave and repeated force can puncture the roof of a cave and water and spray can be driven through the roof of the cave, being especially powerful in storm conditions. The blowholes found along the Pembrokeshire coast largely differ from the norm in that it is believed that they are formed by solution of the limestone to form a sinkhole, as opposed to marine erosion on the underside of a cave's roof. Rounded **cauldrons** or very small **coves** may be formed as cliffs recede over time and intersect the sinkhole. The **Devil's Cauldron** is a complicated feature created as a cavern has collapsed on the Castlemartin coastline. It is a 45 metre deep shaft, 55 metres at its greatest width, which is exposed to the sea by an arch 18 metres high and 21 metres wide. The **Devil's Barn**, another feature, is composed of two blowholes that have been created by the presence of an arch below.

Conclusion

The Pembrokeshire coast provides a stunning example of a coastline shaped by the interaction of its complex geology with marine and subaerial processes. It clearly demonstrates differential erosion at a variety of scales and is home to many landforms of coastal erosion. Spectacular examples of cliffs, shore platforms, caves, arches, stacks, geos and blowholes, are all evident on this coastline.

Further reading

In addition to general coastal texts, the following offer specific information:

- Downes, J. (2011) *Folds, Faults and Fossils: exploring geology in Pembrokeshire* Llygad, Gwalch
- John, B.S. (1979) *The Geology of Pembrokeshire* Abercastle Publications
- May, V.J. (2003) *South Pembroke Cliffs* Geological Conservation review Volume. 28.
- Sephton, W. (Ed) (2008) *Sanctuary, Number 37* Ministry of Defence
- Geo Factsheet number 129 *The impact of structure and lithology of coastal landforms*
- <http://www.pembrokeshirecoast.org.uk>
- <http://www.field-studies-council.org/centres/dalefort.aspx>

Acknowledgements;

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