How was the slate in North Wales formed?

The Snowdonia Slate Trail visits the sites and landscapes of the Welsh slate industry. But where did the slate come from in the first place? How was it formed? This is a really interesting question, because in order to answer it, we encounter some of the most important ideas in geology. So welcome aboard our imaginary time machine; let's go back in geological history and discover the origins of Welsh slate.

The beginnings of Welsh slate in a very different world

Our story starts about 500 Ma (million years ago), in what geologists call the Cambrian Period. Though plants and animals lived in the sea, they had not moved onto land yet. The continents were not as they are today; thanks to plate tectonic theory, we know that the arrangement of land and ocean on the Earth's surface undergoes slow, but constant change. For example, the British Isles and Ireland did not exist in their present form. The crust that was to become Wales, southern Ireland and England was located on (or near) a small continent called Avalonia. Avalonia lay about 60 degrees south of the Equator at this time. The crust that was eventually to become Scotland and Northern Ireland, in contrast, lay on the far side of an ancient ocean, the Iapetus. This northern half of the future British Isles and Ireland formed part of a large continent called Laurentia, a landmass that eventually became – roughly speaking – North America. Because the Iapetus Ocean lay between land that became Europe and land that became North America, it is regarded as a forerunner of the Atlantic: in Greek mythology, Iapetus is the father of Atlas, after whom the Atlantic is named.

In this far-off time, much of what is now Wales lay under a sea linked by channels to the Iapetus Ocean, but bounded to the north east and south west by land. Rocks on this land that lay above sea level were weathered away (largely by water) and carried into the sea, where they slowly piled up. Geologists call the place where eroded rock (sediment) ends up a 'sedimentary basin' (see *Figure 1*, where the outline of present-day Wales has been added for reference). As sand, silt and mud are washed into the sea and settle on the basin floor, they press down on the material that has arrived before them. This has the effect of compressing the sediments that were deposited earlier. The volume of the rock material is thereby reduced, making space for the next lot of material that will be washed in and deposited. But in addition, as more and more sediment ends up in the basin, the deposited material depresses the crust beneath it, and the basin actually deepens. And the depth of the sediments can get really deep: we're talking about a couple of kilometres or more.

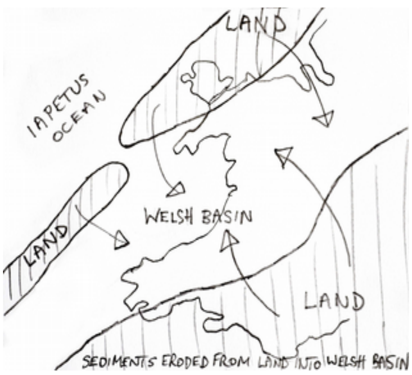

Figure 1: Welsh Sedimentary Basin about 500 Ma

Deep under the surface of the sea in the Welsh Sedimentary Basin, the magic of rock making was occurring. As more and more sediment arrived on top of the layers that were already there, the pressure on the underlying sediments increased and the temperature rose. The sediments became more and more compacted, and more and more water was driven out of them. The tightly packed sediment grains were cemented together by minerals such as silica or calcite that circulated as fluids and then solidified in the remaining tiny pore spaces. The end result – and it took millions of years – were what are known as 'sedimentary rocks': sandstone (made of big grains), siltstone (medium grains) or mudstone (fine grains). The unconsolidated sediments had been transformed into hard rocks. Geologists call this process lithification, from the Greek word 'lithos', meaning rock. The type of rock that was formed in the Welsh basin depended on where the deposition occurred: sandstone tends to form from shallow water deposits, mudstone from deep water deposits. We need to focus on mudstone in particular, because it's from mudstone that slate is created.

The disappearing Iapetus Ocean

Before we move onto the next important chapter in the story of Welsh slate, we need to talk a bit of geological theory. Since the development of plate tectonic theory in the 1960s, we've known that oceans open and close, and continents move around on the surface of the Earth. The surface of the Earth is divided up into chunks of crust called plates – seven major ones and about eight minor ones. These plates drift around the Earth's surface floating on the upper part of the Earth's mantle, which is the layer that lies between the crust and the iron core of the Earth. There are two types of crust: continental crust (about 35 km thick) that forms land above sea level; and oceanic crust (thinner than continental crust at about 8 km thick, and denser too) that forms the seabed of the world's oceans. Underneath lies the mantle, which is hard and brittle at the top, forming a unit with the two types of crust. Together, continental crust and the upper mantle layer are known as continental lithosphere, while oceanic crust together with the upper mantle layer are called oceanic lithosphere. The lithosphere is about 100 km thick in total (see *Figure 2*). It is sometimes thought that the mantle below the lithosphere is liquid, but it's actually solid. Bizarrely, though, it does flow exceedingly slowly, which allows the plates to move around.

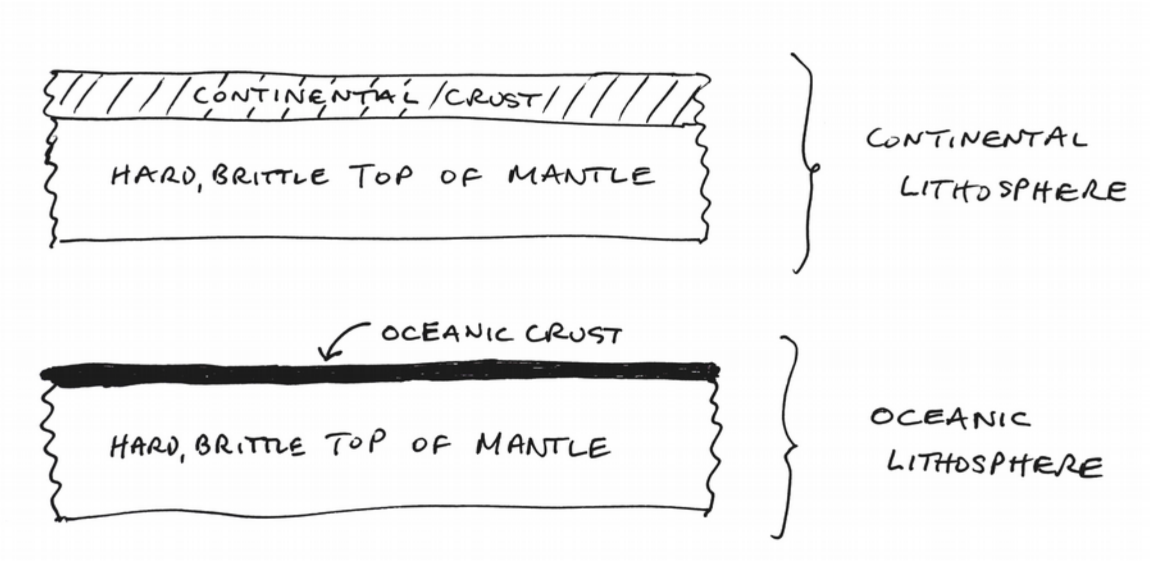

Figure 2: Continental and oceanic lithosphere

What causes the plates the drift about the face of the globe? There are places on the Earth's surface where hot magma wells up from the depths of the planet. This hot magma breaks apart the continental lithosphere. A gap is created and the two sides start to move away from each other. Magma rises to fill the gap and new rock is created by lava flows. Despite the creation of this new rock, however, the land sinks below sea level as it's being pulled apart, and floods with sea water. This is the beginning of a new ocean. The place the new rock is formed is called a 'spreading centre', because it's the central point from which the new ocean starts to expand (typically at the speed of a few centimetres a year, about the speed your fingernails grow).

The new rock created at the spreading centre is the thin and dense oceanic crust we talked about above. As it moves away from the spreading centre, the oceanic crust gradually cools and becomes even more dense. In the end, it starts to sink back into the Earth beneath the continental crust that it split millions of years previously. (This is actually a very useful thing, because otherwise the newly created oceanic crust would have nowhere to expand into.) Geologists call this process 'subduction' (see Figure 3). In fact, the weight of the sinking (or subducting) oceanic crust helps pull the spreading centre open. The famous Pacific Ring of Fire is where a lot of subduction is going on. It's called the Ring of Fire because one of the effects of the sinking slab of oceanic lithosphere is to generate magma – molten rock – in the continental crust above it. This magma rises to the surface and creates volcanoes.

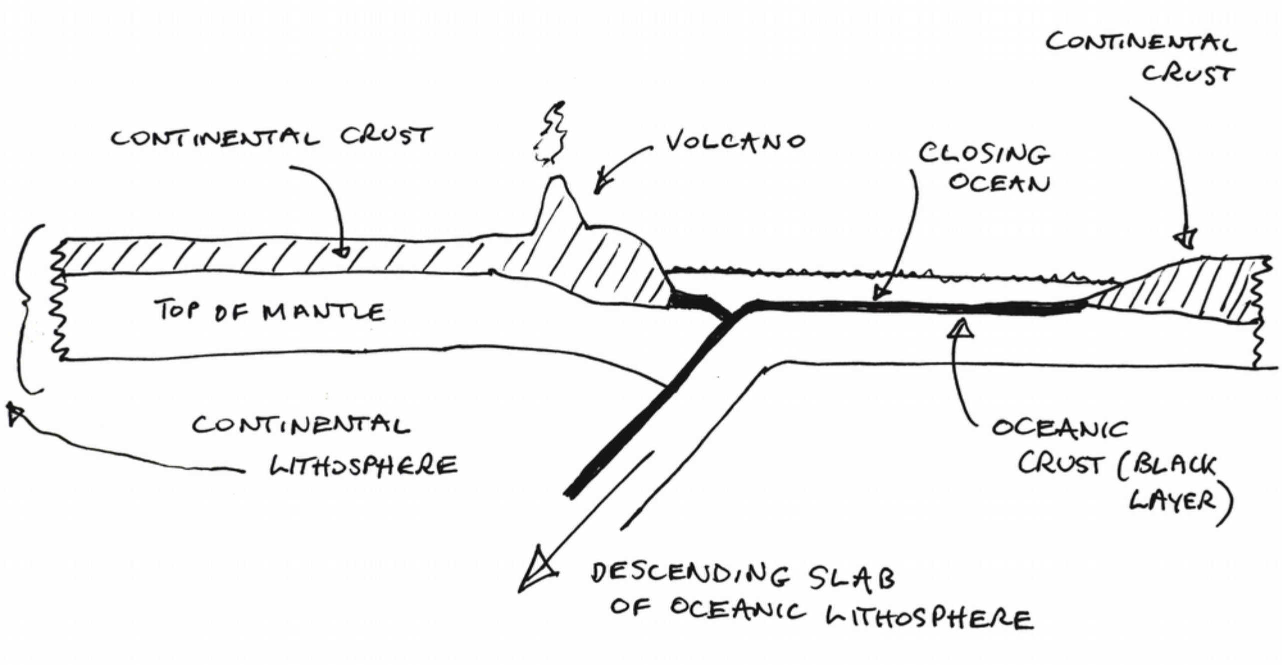

Figure 3: Subduction

Mountain building, or Orogeny

If the subducting slab of oceanic crust dives into the Earth faster than new oceanic crust is created at the spreading centre, the ocean starts to shrink, in a sort of reversal of the initial opening. Eventually, the two continental crust sides of the ocean meet up again (though probably not exactly as they were before). Unlike oceanic crust, continental crust does not dive into the mantle: it's less dense than oceanic crust and the rocks that make up the mantle, so it won't sink. This makes the collision between the two continental crust sides of the closing ocean a very dramatic affair. Neither landmass will submit to the other and sink beneath it. The result is that they plough very slowly, but with incredible force into each other. As they squash together, the lithosphere is drastically thickened to something like 70 or 80 km. The result is high mountains with massive roots beneath them. A modern day example of this mountain building are the Himalayas. India used to be a free-floating continent that over millions of years slowly but surely headed across the ocean towards Asia. About 50-55 million years ago, it finally crashed into Asia: the irresistible force met the immovable object. When India and Asia locked horns, the lithosphere thickened, rearing up into the sky and plunging deep into the Earth. The geologists' term for this phenomenon of mountain building is 'orogeny' (from the Greek word for mountain) – see *Figure 4* for a simplified view of the phenomenon.

Rock changes, or Metamorphism

As you can imagine, things get pretty violent when two bits of continental crust plough into each other. Importantly for our Welsh slate story, rocks in (for example) a sedimentary basin can get caught up in this massive vice and get thrust deep into the Earth. Rocks buried in the Earth by the collision of continents are exposed to very high temperatures and pressures. This rough treatment brings about changes in them: their properties, appearance and even chemical composition can all be modified. The geologists' name for this process is metamorphism, which means 'form shifting'. And the rocks which result from these titanic events are called 'metamorphic rocks'. There are different types of metamorphic rock, depending on the degree of temperature and pressure that a rock has experienced. For our story about Welsh slate, it's the mudstone that has been changed by these extreme conditions that really interests us. Because what happens to mudstone is that it's changed – metamorphosed – into slate. Yes, we've finally arrived at slate (although we haven't reached the end of the story just yet).

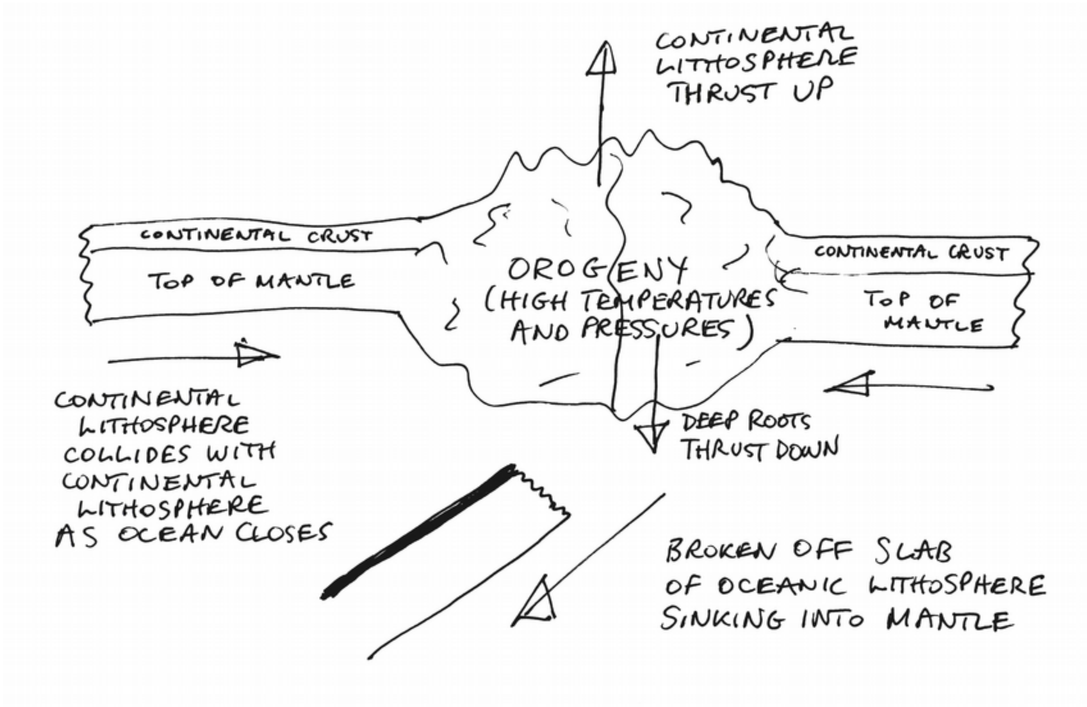

Figure 4: Orogeny

So back to our Welsh slate in the making. We're now in the Devonian Period, about 400 million years ago. The Iapetus Ocean has been closing for millions of years. Finally, early on in the Devonian Period, the two former continental sides of the Iapetus Ocean collide. An orogeny occurs: the continental crust thickens and mountains with deep roots are created. The geological name for this particular mountain building event is the Caledonian Orogeny (although what actually happened was a series of collisions at different places over a period of millions of years, so perhaps it's more accurate to talk about Caledonian Orogenies in the plural). Incidentally, it's the Caledonian Orogeny that brought the northern half of the British Isles and Ireland – Scotland and Northern Ireland – and the southern half of the British Isles and Ireland – Wales, England and southern Ireland – together, and together they have stayed since then (geographically at least). The sedimentary rocks that started out in life as eroded sediments in the Welsh Basin experience high temperatures and pressures as they are thrust down perhaps 10 kilometres deep (or more) into the mantle. The mudstones are transformed into slate. But what exactly happens bring about this change?

From mudstone to slate

It helps to know that mudrocks are made of crystals of various minerals. Especially significant amongst these minerals are clay and mica. The reason they are so important is that they are what geologists call 'platy minerals': they are thinner and flatter than other minerals. In a sedimentary rock such as mudstone, these platy minerals settle out of the water in layers (geologists calls these layers 'beds' or if they're smaller, 'laminae'). During an orogeny, the massive collision of the two blocks of continental lithosphere puts the rocks they contain into a gigantic vice that contorts them this way and that under huge pressure. The minerals react to these forces by lining up at right angles to the direction the pressure is coming from. This realignment of the minerals is the most important process in the formation of slate. The realignment of the platy crystals gives the resulting rock – the rock we call slate – a new property and a very useful one at that: it makes it very strong in one direction but weak in another. To be more precise: when the platy minerals are all lined up in the same orientation, they hold together strongly horizontally, but can be separated very easily vertically. We can now imagine the skilled slate worker taking a piece of slate and splitting its layers apart to make, for instance, a roof tile – it's strong and weatherproof, but easy (for a craftsperson at any rate) to separate along those lines of platy minerals all oriented in the same direction. Geologists call the result of this reorientation of the minerals 'cleavage' (sometimes 'slaty cleavage'), and it's easy to see why: minerals that are all lined up in the same way are easy to break apart, or cleave. Unmetamorphosed mudstones have a tendency to split along their laminae if they have them (e.g. shale), but slaty cleavage is a different proposition altogether, making slate much tougher, more hardwearing and easier to work with. (*Figure 5* shows a simplified example of randomly orientated minerals arranging themselves into layers as a result of pressure to demonstrate the principle of mineral realignment.)

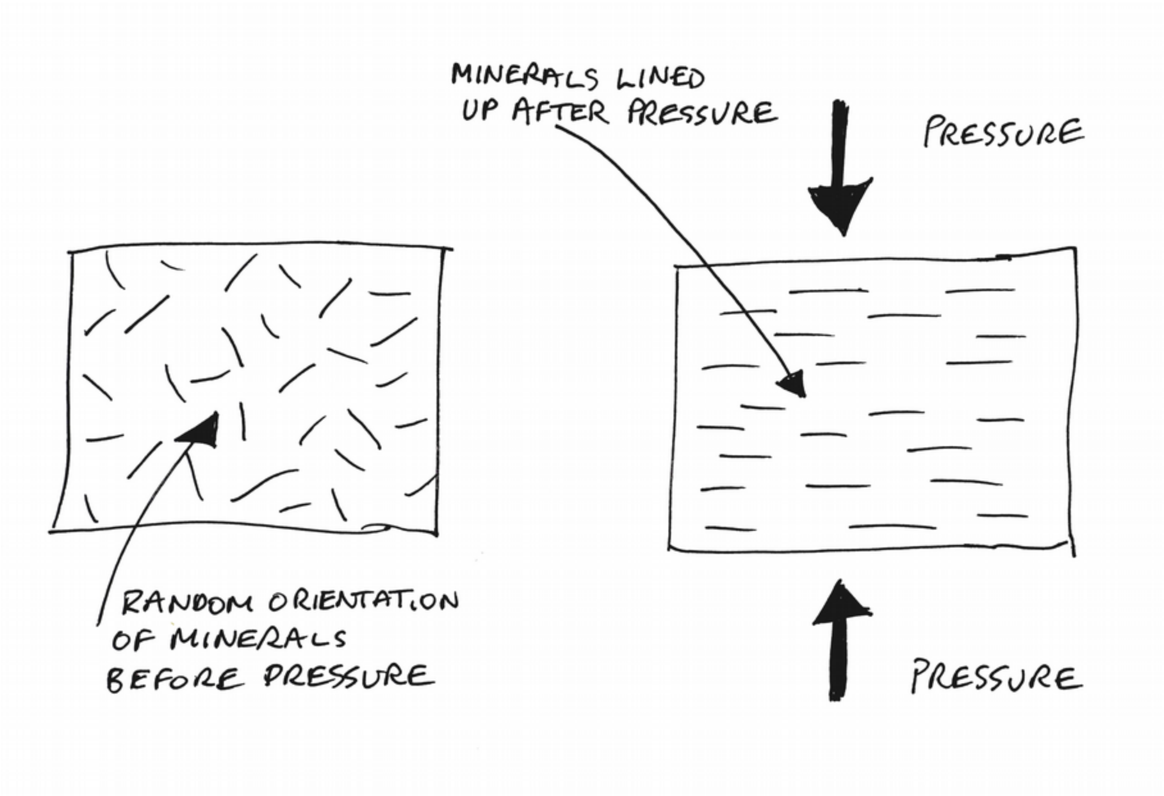

Figure 5: Realignment of platy minerals under pressure

We should also add a short note about the range of colours in North Welsh slates. These various colours are the result of specific chemicals found in the slate in different proportions. An iron compound called hematite (ferric oxide) produces red and purple colours. The clay mineral chlorite imparts green hues. The strength and precise shade of these colours are controlled by the quantity and proportions of these minerals present in the slate.

So just to recap: the sediments that were eroded into the Welsh Basin some 500 million years ago were gradually compressed and cemented to form mudstone as they were buried deeper and deeper beneath the seabed of the basin. About 100 million years later, the Iapetus Ocean closed and a huge mountain range was thrown up in what we call the Caledonian Orogeny. The mudstones that had formed in the Welsh Basin were buried even deeper in the Earth's crust, where they experienced elevated temperatures and pressures. This caused them to be changed – metamorphosed – into slate. The main process in the formation of slate is the reorientation of platy minerals into regular and parallel layers called cleavage. Because the layers are not strongly joined together, they are easy to split. And this is exactly what the master slate worker does.

Uplift and erosion

So we've got our slate. But at the moment, it's deep under the surface of the Earth, possibly ten or more kilometres down. How does it get up to the surface (or near the surface) where it can be mined by Welsh slate miners? To answer this question, we need to go right back to where we started. Do you remember that we talked about the high land on Avalonia being eroded and the resulting sediments being washed down into the Welsh Basin? This illustrates an important geological principle: raised land – hills and mountains – will always be worn down by water, wind and ice. The fact that this erosion is excruciatingly slow by human standards does not make it any less real. As the overburden of material is removed by erosion, the rocks underneath obviously get closer to the surface. At the same time, they are relieved of pressure and start to bob back up like a cork. It's hard to believe and imagine, but this process can bring rocks that were kilometres down in the Earth back up to the light of day. Geologists talk about 'erosion and uplift' - a shorthand way of describing a vast and lengthy process. In essence, this is what has happened to the mudstones that were buried in the Caledonian Orogeny and were metamorphosed into slates. Gradually, over the 400 million years since the Devonian Period, the rocks above them have been worn away and the slates have got ever closer to the surface. But it hasn't all been plain sailing and straightforward: there have been times when the land that is now Wales was under water and new sedimentary rocks were laid down. (This probably happened in the Cretaceous Period – about 145 to 65 million years ago – when it is thought that most of Wales was covered by a shallow sea where chalk was formed. The sea receded and the chalk has since been eroded away, removing all evidence that it had been there.)

Some thoughts about the size of the Earth and Deep Time

If you're anything like me, you'll find all these processes rather hard to grasp. It just doesn't seem possible that oceans can open and close, mountains can be thrown up and then razed to the ground, and that rocks can change from one form into another deep in the Earth and then gradually work their way back up to the surface. And here's another thing that we haven't mentioned yet: since 500 million years ago, the land that eventually became Wales has drifted from roughly 60 degrees south of the Equator to its present position in the northern hemisphere, experiencing all sorts of climates, landscapes and habitats as it did so. How can we make these apparently fantastical things easier to grasp? The trick is partly to realise that the Earth is a very big place, and what appear to us to be huge things like the Himalayas are in actual fact the tiniest of wrinkles when we look at them in comparison to the whole size of the Earth. Look at pictures taken from the Space Station, for instance: the surface of the Earth looks fairly smooth. Another thing to remember is that these events happen so slowly that we don't experience them in our own lifetime (or even in recorded history). We can't emphasise too much the fact that geological processes take time. Lots of time. Unimaginably long periods of time. It's hard to get your head round the lengths of time we're talking about. The changes we've talked about here have occurred over the last 500 million years. At the risk of pointing out the painfully obvious, that's 500 x 1000 x 1000 years. Geological phenomena that seem impossible – for instance, the fossils of sea creatures in the summit rocks of Yr Wyddfa/Snowdon (and even of Everest) – become more comprehensible if you factor in the vast stretches of time they took to occur. We call these mind-bogglingly eons 'deep time'. When we take deep time into account, the fantastic, almost unbelievable story of Welsh slate becomes just that little bit more believable.