The Slates of Cornwall

The south-western peninsula of Great Britain lies at the outer edge of the Rhenohercynian and consist mainly of marine Devonian units. Compared to the other Variscan zones the Caledonian orogeny only weakly influenced Cornwall. The complete Devonian succession of SW-England shows intercalations of Old Red sandstone and its stratigraphy is hardly dividable due to the quick change of the facies and the multiple deformations (Anderton et al., 1979). Cornwall itself is situated within the synclinal structure of SW-England whose Carboniferous rocks are southernly and northernly flanked by Devonian units, containing the Upper-Devonian roofing slate deposits ('Tredorn Slates').

The sedimentation of the Devonian units is characterized by several fault controlled subsidence rates and thus in Cornwall different fault-related sedimentation basins are distinguished (Selwood et al., 1998).

In the Upper-Frasnian the marine transgression started towards Wales in Central England. During this time, the Armorican Massif probably represented the southern rim of the basin and supplied coarse grained material into the area of South Cornwall. To north, in South Devon, cephalopod limestones and ostracode shale deposited and further in N-Devon and Somerset shallow-marine and fluviatile rocks sedimented (Edmonds et al., 1975). The original material for the roofing slates was deposited within an outer shelf facies.

During the Carboniferous the flysch sedimentation of the Armorican Massif moved towards north and so moved the folding and the rejuvenation of the age of metamorphism (Schönenberg & Neugebauer, 1987).

The Armorican orogeny (Upper-Carboniferous - Early Permian) is characterized by North-South directed compression with a general E-W strike of the tectonic elements which were mainly formed by folding. There can be distinguished three stages of deformation or folding, respectively (Edmonds et al., 1975).

The **first stage D1** is observable in the whole of Cornwall and gave rise to west-vergent and NE-SW to ENE-WSE striking folds as well as large scale thrusts which mostly create lithostratigraphical borders. The folding style varies between closed and tight and the axial planes are horizontal or dip moderately to SE. With this folding the formation of an axial planar cleavage S1 was related. **In the vicinity of the thrusts the development of the cleavage is more intense and lead to a god splitability of the 'Tredorn Slates' that means to the origin of roofing slates.** For this main stage of deformation a low-grade and intermediate regional

metamorphism is typical. During this regional metamorphism the 'Tredorn Slate' were modified by a contact metamorphism due to the occurrence of the granites of the Bodmin Moor.

The **second stage D2** is locally developed and again lead to NW-vergent and ENE-WSW striking folds with a moderate to steep dip of the fold axis planes to SSE. The deformation was accompanied by the origin of a regionally occurring crenulation foliation S2. This ductile deformation regime was completed by dextral lateral displacement (Selwood et al., 1998).

The **last stage D3** was related with the origin of E-W striking folds and a second crenulation foliation S3.

The Upper-Devonian 'Tredorn Slates' have a fine-grained sedimentary pattern and a well developed, homogeneous and smooth fracture cleavage. The colour varies from dark grey to green or bluish to grey, respectively.
Slate mining was carried out since the 16th century in a slate quarry between Delabole and Tintagel. Yet the peak of the mining of roofing slates was in the 19th century when slate replaced the straw on the roofs.
The area at Tintagel is a zone of intense deformation with recumbent folds which are overprinted by kink folds as well as extensive thrusts. Other quarries are within the region of Wadebridge where slate was mined for the typical English walls and other architectural purpose. Numerous small slate quarries are distributed throughout Cornwall which have neither mined roofing slate nor have a more then locally restricted economic importance.
Except for the Launceston area in which Carboniferous slates are mined, most of the slate quarries mine their slates within the Upper-Devonian (Selwood et al., 1998). Today, slate is not mined as roofing slate but rather for other architectural demands and as filling material for the chemical industry and for concrete components (Edmond et al., 1975).

Slate deposits of Wales

The Welsh basin with its primary Cambrian to Ordovician rocks is situated within the ‘Southern Britain Terrane’ which is separated from the basin of the Lake District (= ‘Lakesman Terrane’) by the ‘Monian Terrane’. The contact between both terranes is build by the ‘Dinwornic Fault’ at the southern boundary of the island Anglesey or covered by Early-Paleozoic sediments.

At the southern rim of the basins a highland is observable which can be reconstruct from Pembrokshire to Manchester (Schönenberg & Neugebauer, 1987).
The Welsh basin consist primarily of Early-Paleozoic rocks which cover Precambrian continental crust and show a thickness up to 11 mi. Cambrian rocks comprise conglomerates, greywackes (‘grits’) and mudstones which are overlaid by a turbidity sequence.

The influence of tectonic vertical movements which increase from north to northwest are reflected in the distribution as well as the thickness- and bedding conditions of the Cambrian rock units (Coward & Siddans, 1979). The same conditions governed the development of Ordovician rocks, although less succinct.

The Ordovician comprises conglomerates and sandstones, overlaid by shallow-marine mudstones and sometimes volcanic rocks within different stratigraphic levels. The volcanic rocks are supposed to be in relation to the subduction (Wood in Coward & Siddans, 1979).

The roofing slate deposits are situated within Cambrian, Ordovician and Silurian units and are mostly found in Northern Wales. The main deformation occurred during the Silurian, from Llandoverian to post-Ludlowian and the metamorphic facies ranges within the 'low grade zeolite facies' (Dunning 1992, compare Fig..). The multiple deformations led to the formation of anti- and synclines, folds with different styles and thrusts of Early-Paleozoic rock units. This folding was accompanied by the formation of a penetrative and well developed fracture cleavage. This fracture cleavage is the basis for the origin of (roofing-) slates and is partly overprinted by a crenulation foliation or multiple other foliations. The Welsh basin is devised in anticlines and synclines with a strike from NW to SE in the southern part, corresponding to the general strike of the basin. Central and SW-Wales is dominated by the 'Towy'- and 'Teifi Anticline' which are again separated by the 'Central Wales Syncline'. Towards north the structural frame becomes more complex by domes, depressions, faults and an intense flexure of the tectonic elements (Dunning, 1992). One of the most important structures here are the 'Snowdon Syncline' and the 'Harlech Dome' (Table.)

The fracture cleavage varies from a moderate to steep inclination. According to Coward & Siddans (1979), the most intense strain was observed in the center of Snowdonia with a decrease to Northeast and Southwest.
An interesting subject would be a comprehensive investigation about the relation strain-splitability of a slate because many slate quarries are within this area and former the relation mentioned (Baum, 1994; Ehle, 1997).

The Cambrian Slates

At the beginning of the Precambrian and during the Early-Precambrian the Welsh basin was a basin at the marginal basin at the southern flank of the Iapetus-Ocean and the sedimentary material steamed from N and NW from the 'Monian Terrane'. Within the inner parts of the basin the Cambrian comprises about 16,500 ft. thick series of quartzites, greywackes and dark slates. In contrast, the southern part was governed by a shallow-marine shelf comprising the western English Midlands, S-Wales, the Welsh Borderland and probably parts of Bristol (Cowie, 1992). The Cambrian was a period with no tectonic events but rather of sedimentation and consolidation within the Welsh basin (Attewell & Taylor, 1968).
The Cambrian slates are within the 'Caernarvorshire (Gwynedd) Slate Belt' in N-Wales, within the 'Llanberis Slates' of the Lower Cambrian 'Comley Series'. The 'Llanberis Slates' can reach a thickness up to 3,300 ft. and are probably distal turbidites, representing the culmination of the general trend to a deep sea sedimentation (Cowie, 1992).

Within the 'Llanberis Slates Formation' one can distinguish between reddish, reddish-purple and blue slates as well as the upper green slates. The red slates frequently show greenish points of reduction (Cowie, 1992). Slates, for example, were mined in

the ‘Moel Tryfan Quarry’ and show a fine grained sedimentary pattern with a well developed fracture cleavage (Cowie, 1992). According to Cowie (1992), the slates are overlaid by the ‘Dorothea Grit’ which gradually passes into the ‘Striped Blue Slate’.
The Cambrian slates are still mined at Bethesda, Llanberis, Moel Tryfan and Nantlle/Penygroes with the ‘Penrhyn Quarry’ or the ‘Diwornic Quarry’ as the most famous quarries during the 20ies of the 19th century.
At Nantlle and Bethesda/Llanberis the greenish slates show a greater splitting thickness and a more rustic surface than the reddish slates (North, 1927).

The Ordovician Slates

During the Ordovician the tectonic regime changed from a passive continental margin to a active subduction margin which was related with an increasing volcanic activity and led to a complicated interrelation between sediments and volcanic rocks (Rushton, 1999).

During the Tremadocian and Caradocian the sedimentation shows a ‘ensialic back arc basin’-situation or the ‘ensialic destructive plate-margin’ - volcanism, respectively.
This change of the tectonic activity is the reason for the very differentiated local geological setting and division of the Welsh basin in synclines and anticlines with a high varying sedimentary facies.

Enormous masses of ashes, lava and volcanoclastic material was deposited in the single areas of platforms and troughs. This sedimentation was accompanied by simultaneous subsidence, increasing the instability and again which increased the contrast between areas of sedimentation - troughs vs. relative stable shallow - marine platforms (Duff et al., 1992).

Ordovician slates are within the ‘Dolgellau Formation’ of the Tremadocian, which in former times were described as ‘Dollgelly Beds’. This rocks are sediments of a open shallow-marine environment with striking differences in thickness along synsedimentary faults (Howells & Smith, 1997 cited in Rushton et al., 1999).
The ‘Dolgellau Formation’ shows a thickness of about 500 ft. and the profile at Bryn-llin-fawr contains at the bottom hard black mudstones with siltic gray intercalations which are cleaved and show a great angle between bedding and fracture cleavage. This rocks are overlaid by grey to black shales with only a weakly developed cleavage plane which is parallel to bedding. To the hanging layer silty mudstones, tuffaceous sandstones (about 33 ft. thick) and hard black shales follow.
According to North (1927), the most valuable Ordovician slates are mined in the vicinity of Blaenau Ffestiniog. They are more fine grained as those of Bethesda/Nantlle and show a grey to blue colour with a partly shining surface. This slates were mined in at least seven and between 30-148 ft. thick slate beds which are separated by intercalations of sandstone. The fracture cleavage is only partly well developed and thus the mining of thin splitting slate was very selective. Most of the slates were mined by underground mining and carried to the port of Portmadoc

for further shipping or transported by train throughout Great Britain, respectively. A very dark slate was mined in the famous quarries of Penmachno and Dolwyddelan (Prince Llewellyn). Other Upper-Ordovician slates were mined within the about 1,476 ft. thick 'Bala Formation' between Abergynolwyn-Corris and Aberllefenni. As in the other area, the light- to dark bluish slates were selectively mined because of the differently developed fracture cleavage. It was mined at Llangynog for centuries but lost its economic importance already at the beginning of the 20th century. Another important slate district of Ordovician slates lies at the Prescelly Mountains, Pembrokshire and the adjacent regions of Carmartenshire and Cardiganshire. This slates of the 'Llandeilo Series' have an olive-green to grey colour which were caused by volcanic ashes.

North of Pembrokshire one can find Ordovician Slates (Arenigian-Llanvirnian) which are intensely cleaved and show a dark black colour. North (1927) reports of other slates which either easily weather, turn to rusty colour or are too soft in order to be used as roofing slate.

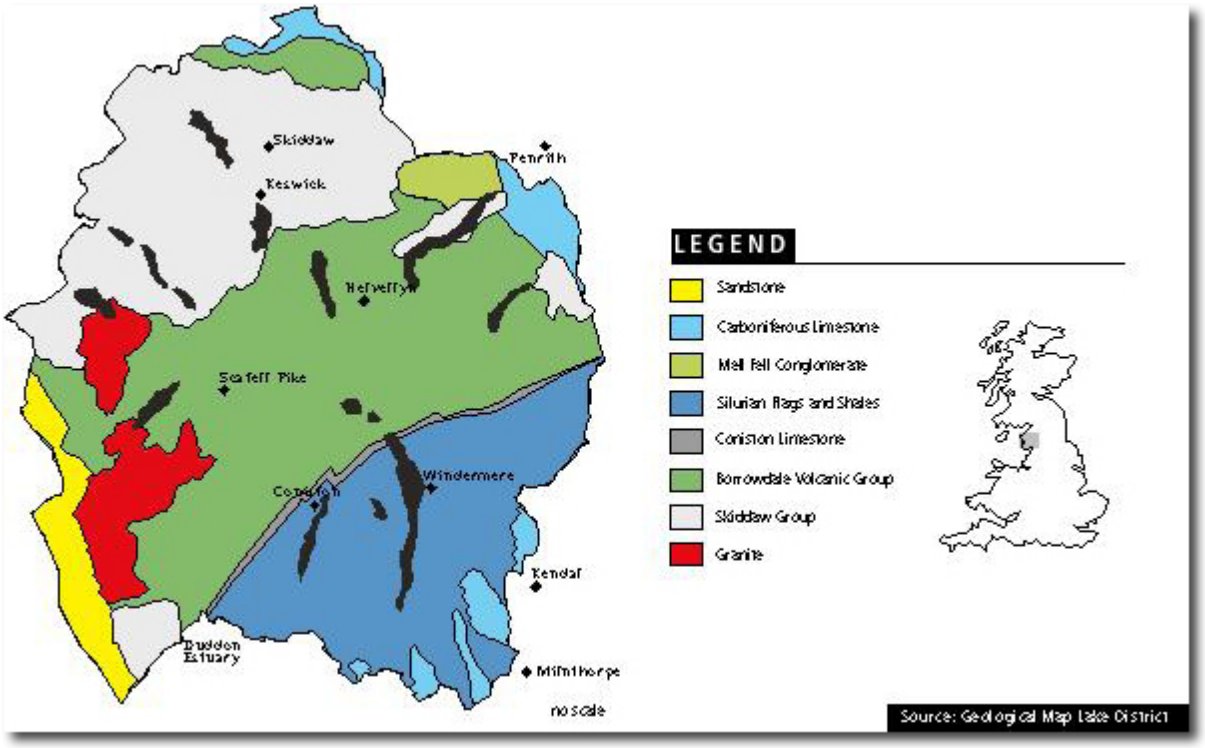
The Silurian Slates

The Silurian slates have never reached the economic importance like the Cambrian and Ordovician slates. One can separate two districts. In the northern district within the Clywdian Range slate of Wenlock-Ludlow was mined. In the area of the Clywdian Range the Silurian comprises greywackes, mudstones and graptolithic slate.

The southern slate district between Corris and Machynlleth are of Llandoverian age. Here one can find dark-grey slates with a steep fracture cleavage which rapidly alternate with non cleaved laminated siltstones. Because the slates are too thick after splitting they were not used for roofing. According to the description the author assumes that the slates show a classical fanning cleavage.

The Slate Deposits of the Lake District/Cumbria

The Lake District be can devised in three different lithological zones: the Ordovician 'Skiddaw Slates' (= 'Skiddaw Group') in the north, the Ordovician 'Borrawdale Group' in the central part and the Silurian slates and limestones in the southern part (see Fig.).



The Lake District belongs to the 'Lakesman Terrane' which borders to north to the 'Southern Uplands Terrane' and to south to the 'Southern Britain Terrane'. From the Welsh basin it is separated by the 'Monian Terrane'. Cumbria lies within the 'Southern Uplands Terrane'.

In the Lake District the Ordovician ('Skiddaw Slate', 'Borrawdale Slate') and Silurian slates of the 'Borrawdale Group' are mined (Taylor et al., 1971).

In the 19th century the term 'Skiddaw Slate' was primarily used for all sedimentary rocks and all volcanic sediments of the same age which lie below the 'Borrawdale Volcanic Group'. Afterwards, Wadge (1978) used this term for the sediments of the Arenigian which lie below the 'Eycott Volcanic Group'. At this point the term 'Skiddaw Group' should be applied for sequences of turbidites and the term 'Eycott Volcanic Group' should be applied to all lava and tuffites which are of the same age as the 'Skiddaw Group'. The author follows hereby the suggestions of Moeseleys (in Duff et al., 1992).

The 'Skiddaw Group' comprises mudstones, siltstones and sandstones (turbidites) which were deposited in a relative stable deep water slope, running parallel to the rim of the Anglo-Gondwana continent (Cocks & Fortey 1982 cited in Duff et al., 1992). Within the Arenigian of the 'Skiddaw Group' one can distinguish the 'Hope Beck Slates' and the younger 'Kirk Stile Slates'. The 'Kirk Stile Slates' have sometimes a fracture cleavage which is parallel to the bedding.

At Coniston, Honister, Kirkstone and Langdale the green slates of the Ordovician 'Borrawdale Volcanic Group' are mined and they show a olive-green, black or black-bluish colour. This group has a total thickness of about 19,685 ft. comprising

calc-alcali rocks and the dominating andesitic lava and tuffs. Within the tuffs there are subaqueously deposited horizons with a well developed bedding as well as subaerially deposited horizons with only a weakly developed cleavage plane (Bassett et al., 1992).

The sedimentary pattern of the fine tuffs varies from very fine grained - similar to hälleflinta (porphyroidic rock) - to more sandy. If the tuffs have a well developed fracture cleavage they are used as roofing slates (Taylor et al., 1971).

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