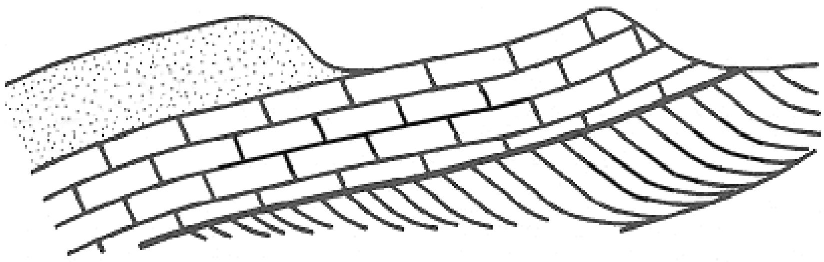
Farnham Geological Society

[**www.farnhamgeosoc.org.uk**]

Farnhamia farnhamensis



A local group within the GA

Vol. 18 No.3 **Newsletter** October 2015

Issue No: 91

List of contents

Editorial

A major highlight of the Society's year was the week long field trip to Dumfries and Galloway, which involved visiting an amazing variety of extremely interesting and often challenging locations. We saw Cambrian to Permian (and Tertiary) rocks - igneous (mantle peridotites; lower crustal gabbroic and upper crustal granodiorite bodies; dykes and terrestrial volcanics); also sediments from varying environments (proximal to deep water turbidites; coastal marine and terrestrial deserts). Consequently I make no excuse for doing justice to this field trip and providing those who were not able to attend a good review of what we saw and how it was interpreted, often after a long discussion. Where no interpretation was agreed or forthcoming, you have to put up with my interpretation.

Finally, a reminder that this year's Society Lunch at The Frensham Pond Hotel is being held on Sunday 22 November and I do hope that all members will make a determined effort to attend what has in recent years been a very successful event. Details from Peter Luckham either at the November meeting or telephoning 01428 – 607229.

Liz Aston, Editor

Building stones of West Sussex Churches
May 2015 lecture given by David Bone, M.Phil., FGS

This lecture was the full version of a talk being given at the Geologists' Association (GA) conference on Building Stones at the BGS in Nottingham on 9th October 2015. It is the climax of a long-term study into the historic building stones of West Sussex and, in particular, stone distribution in the churches of Saxon through to Victorian date. Hopefully, this study will be published in due course in the Proceedings of the GA, but means that publication will not be pre-empted by inclusion of the detailed results here.

Why study building stones in churches? Churches are both monuments to the historic use of building stone and a microcosm of the local area (in terms of building stones), being key elements in local distinctiveness. Although a bit of a buzzword, local distinctiveness is actually very useful in describing the characteristics that make a place unique and a church is often the focus, particularly in more rural areas. Churches are also safe and easy to access, unlike many geological exposures, and provide opportunities for cross-discipline research with spin-off into community engagement. Stone studies also provide information for building repairs and restoration.

The selection and use of a building stone include geological factors such as availability, characteristics and workability, and human factors such as transport, patronage, status and aesthetics, cost and demand. All these have changed through the course of history, resulting in the use of a wide variety of stone types in church building. Sussex is actually relatively poor in good quality stone for building, which leads to the use of many different stone types as well as others from outside the county, usually imported for more structural or decorative elements of the church. In total, there are around 42 significant types of building stone used in W Sussex (the number varies on how much variations on a theme are considered to be separate stone types), ranging in age from Devonian to Quaternary and including reused Roman materials.

There are 258 stone-built churches and chapels in W Sussex, the locations of which have been plotted onto a base map of the area and its outline geology. The variety and use of the different building stones was recorded from simple visual inspection of exterior walls (where the stones are most visible) and then recorded in an excel spreadsheet. Over 2500 records of stone use were obtained in this way, often involving repeat visits as increasing familiarization with stone types resulted in a changing opinion on identification. An abundance and distribution map could then be plotted for each stone type and an assessment made of any significant distribution to the geology or transport routes, such as the major rivers.

A selection of the more common building stones, starting with oldest and working through to the youngest, were illustrated, with examples of their use and the relevant distribution map. The two main building stones of W Sussex are sandstones: the Hastings Beds (Ardingly Stone and similar) from the NE of the county and Hythe Beds (Pulborough Stone and similar) from the more SW areas. The distribution maps show a widespread but marked separation in the use of these stones across the county with a ca. E-W divide.

In contrast, a number of lesser quality and minor building stones, such as Lavant Stone (a form of Chalk), Mixon Rock (from offshore of Selsey) and Bognor Rock, show more limited use around their area of outcrop, even though they may be locally abundant. The historic importance of transport by sea reveals itself in the more coastal distribution of Quarr Stone and Ventnor Stone, both important medieval building stones from the Isle of Wight. Similarly, Caen Stone dominates the S half of the county. This was imported from Normandy throughout the medieval period as a building stone par excellence, and again commonly used by the Victorians for church repair and refurbishment. Another Victorian building stone, but with a more widespread occurrence, is Bath Stone from the Cotswolds (this includes similar oolitic limestones). Because this stone arrived in the latter half of the 19th century after the development of the rail network, its use is even more widely distributed across the county except for the NE where the local Ardingly Stone served just as well.

Some stone types are so tightly tied to the area of geological outcrop that their use elsewhere is very conspicuous. An example of Ardingly Stone, in the area of Hythe Formation sandstone use, really questions the architects' choice of material for maintaining local character; although a mid-20th century restoration with a brown-weathering malmstone (Upper Greensand), that really contrasts with the local grey malmstone, can be forgiven, as the latter is no longer available. Indeed many of the building stones are no longer available due to loss of quarries and prohibitions on foreshore stone removal. Seeking appropriate alternative materials will become ever more challenging.

Whilst many quarry sites are known from historic records, others are completely unknown and require further research. Examples include Sussex Marble used as a building stone in the more easterly part of the county. Another is travertine, which initially forms around the heads of springs as soft tufa. There are two areas of travertine distribution but only one quarry site is known, but there are clues to be followed up and may lead to a discovery of a former medieval quarry. Travertine is one of the stones that also occurs as reused Roman building stone. Another is Ditrupa Limestone, from the Calcaire Grossier of the Paris Basin which, with Roman tile, indicates the proximity of former Roman villas that have been robbed heavily for stone.

Even flint, a more humble but widely used building stone, shows distinct patterns of distribution depending on its separate classifications as fresh, white-weathered (S Downs), brown-weathered (Quaternary deposits), or beach cobbles. The latter is more or less tightly distributed along the coast whilst brown-weathered flints are found on the coastal plain and, to a lesser, extent in river gravels. White-weathered flints are more restricted to the surface outcrop of the S Downs and the lower slopes with solifluction deposits. The question might be why does this matter, but it is important that repairs and refurbishment use the correct type in order to preserve the character of the building. The wrong type of flint can be quite incongruous.

Further analysis of the distribution data confirms patterns that are more or less predictable. Tabulation of the average number of stone types in each of the five landscape areas, designated by the county authority, shows a decrease away from the coastal plain, with its variety of Palaeogene rocks, Quaternary drift and maritime imports, to the sandstones of the High Weald with dense woodland and a historic absence of a good transport network. A graph plot of the average number of stone types against church age also shows a marked reduction with the oldest churches having far more stones than those of recent date, reflecting the multiple phases of building and repair that have occurred in the older buildings.

This lecture only touches the surface of the amount of information that has been collected and its potential use. Nearly every stone type could be further investigated to look at sources, transport routes and changes in use through time – a social dimension to the geology of building stones. Two in-depth studies have already been completed during the course of this investigation – Lavant Stone and Mixon Rock – both with interesting stories to tell. Which one will it be next?

FGS Field Trip to Dumfries and Galloway: August 9-15, 2015

Led by Graham Williams; assistance from Alan Bromley & Liz Aston

We stayed at a lovely hotel on the shores of Balcary Bay, on the N side of the Solway Firth, with gateposts and a gravel drive of probable Dalbeattie Granite origin. The geology spanned from Cambrian to Permian comprising a mixture of plutonic to volcanic igneous rocks and from deep water shales/turbidite sequences to shallow water marine and terrestrial dune sequences. A lot to fit into five days but so well organized by Graham that it was not a problem.

Overview

Tectonics: There are four main periods with different tectonic settings, as shown below:

1. Late Precambrian (ca. 700Ma ago): the supercontinent, **Rodinia** (cratons of Asia, N & S America, Africa, Australia and Antarctica) had existed for ca. 350Ma, but now began to break up; as the rifting progressed the **Iapetus Ocean** formed (Figure 1). By Cambrian times, the present U.K. was part of two continents Laurentia (to NW: Scotland, N America, Siberia), and Baltica (to SE: England & Wales (Avalonia) and Baltic). This separation continued until Early Ordovician (Figure 2); then closing continued until Devonian times, forming the **Caledonian Orogeny:** subduction under the Laurentian continent generated thick volcanic and clastic sequences of island arc/back-arcs (probably similar to the present W Pacific[1a]).

During the Ordovician and Silurian, subduction of oceanic crust changed to being dominantly under Baltica. This SE push continued throughout the Ordovician (Figure 3) and the piles of turbidite fan/deep sea graptolitic shale deposits which had accreted along the N margin of the basin were thrust SE, together with similar sedimentary piles along the SE margin. These thrust sheets now form a series of tectonic tracts with the oldest (early Ordovician) furthest NW, and the youngest (mid-late Silurian) furthest SE (Figure 4). During the Ordovician and Silurian, occasional volcanic activity occurred within the basin, with continued subduction.

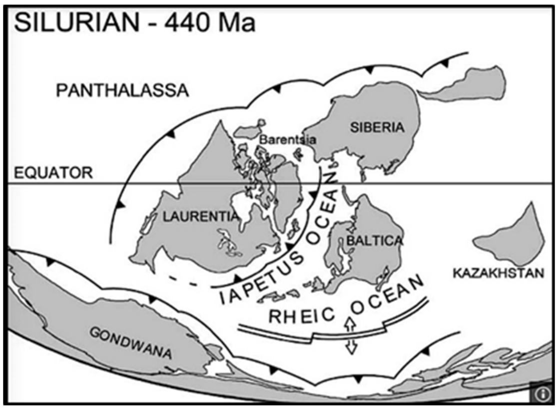


Fig. 1: Paleogeography of the Lower Palaeozoic

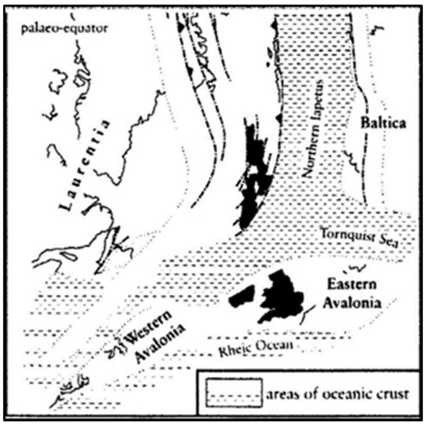


Fig. 2: Detail of Laurentia-Avalonia

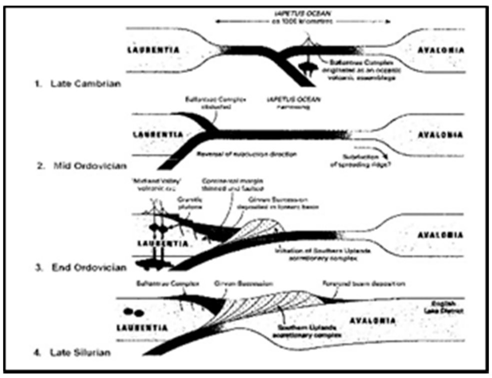


Fig. 3: Evolution of S Uplands Accretionary Prism

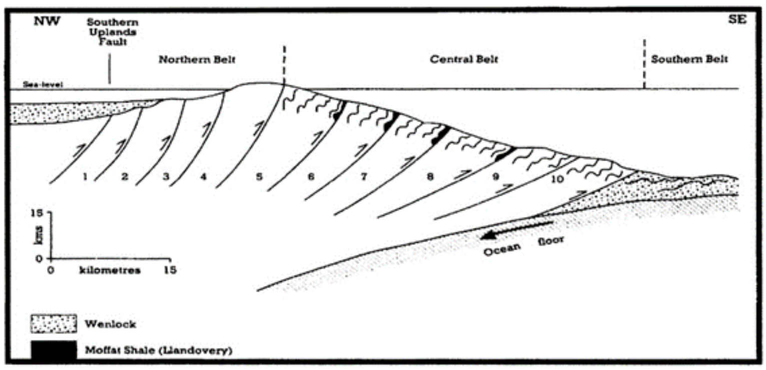


Fig. 4: Profile of S Uplands Accretionary Prism in Middle Silurian; Tracts young to SE; rocks young vertically &/or to NE within tracts

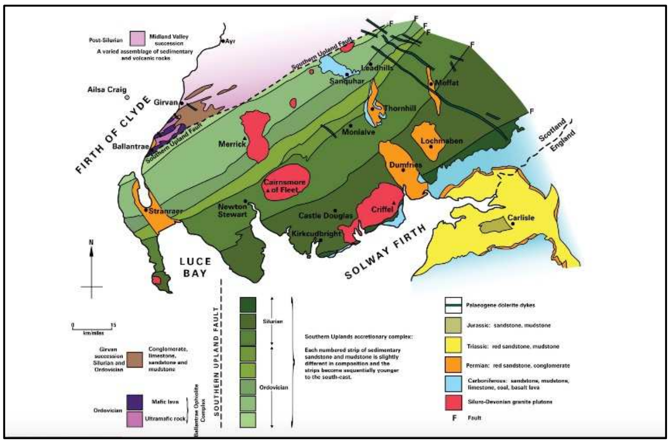
2. From **end Devonian to early Carboniferous** times, extensional strain across this area produced NE-SW trending graben and half-graben basins, including the **Northumberland-Solway Firth Basin**. The N boundary of which is defined by the N Solway Fault, which runs along the S margin of the Criffel pluton.

3. Later crustal extension created a different series of **N-S trending graben/half-graben**, in which, Permian sediments are preserved (see Figure 5 for simple geological map of S Uplands and Figure 6 for a summary of events).

4. The youngest rocks exposed and examined were several **Tertiary dykes, trending NW-SE**, and a distant view of the beautiful Ailsa Craig in the Firth of Clyde completed the enjoyment of the geology. These are part of the Tertiary Igneous Province, associated with the **formation of the Atlantic Ocean**.

Igneous Rocks

(**Interval 1 above**) As the tectonic plates bearing the continents either side of the Iapetus Ocean converged, igneous rocks were generated on both sides of the contracting ocean; abyssal oceanic crust was subducted beneath island arcs along the continental margins whilst shallower oceanic crust and associated volcanic and sedimentary rocks were obducted (thrust) onto the continental margins as major sheets.



Intense crustal shortening during this (Caledonian) orogeny, followed by uplift and deep erosion, gives exposure now of oceanic crustal rocks, subaerial and submarine volcanic rocks, deep-seated plutons and minor intrusions, all juxtaposed with associated sediments (volcaniclastics, turbidites, cherts and graptolitic mudstones).

It is suspected that a great deal of both vertical and lateral transverse faulting has occurred, moving rocks up and down, and sideways along, the large and frequent NE-SW striking faults[1]. The contrasting tectonic environments give rise to a wide range of igneous lithologies and similarly to a wide range of associated sediments.

The end of the Silurian saw intrusion of subvolcanic lamprophyric dykes (trending NE-SW) and volcanic sinter vents and in the early Devonian, the zoned Criffel-Dalbeattie granodiorite pluton.

(**Interval 4 above**) The Tertiary dykes were dominantly basaltic but sometimes had a composite nature with less basic cores.

Sediments

(Interval 1) Sediments accumulated along the margins of the Iapetus basin as it closed, the exposures are dominated by turbidite* sequences: thick beds of large boulder (>256 mm) conglomerates (near-source deposits), well developed turbidite sandstones with Bouma sequences from proximal or channel areas of fans and thin distal turbidite flows within thick shale sequences from basinal environments outwith the channels.

**Turbidite is the name given to a specific sediment, one that has been deposited from a turbidity current, where clasts are supported by muddy water flowing in a turbid fashion, with swirling eddies.*

Deposition is interpreted to be the result of frequent earthquakes which caused the shoreline and coastal deposits to be shaken off the shelf and to flow at speed as large debris flows over the continental edge, down erosional canyons (these start as nicks and become progressively more eroded as the flows continue) and to end up in the depths of the basin amongst the basinal mudstones.

(Interval 2) Lower Carboniferous sediments accumulated along the N Solway Fault and into the basin as a terrestrial alluvial basin, thinning basinward. These are overlain by younger shallow marine sediments including an impressive barrier bar sandstone. Tectonic activities continued throughout deposition in the form of small seismic events downthrowing the basin to SE.

(**Interval 3**) The youngest sediments examined were of Permian age. These comprised classic alluvial fan and wadi deposits, aeolian sands and ephemeral lacustrine mudstones indicating a hot, arid continental environment of deposition.

Day 1 Ordovician Ophiolite Sequence, Ballantrae

The first day was spent examining the Ballantrae Ophiolite Complex at Bennane Lea, just N of Ballantrae. We found a peridotite in fault contact with a gabbro; the peridotite geochemistry suggests it is from mantle at a back-arc spreading zone whilst the gabbro may be from the overlying asthenosphere or a later intrusion, see Figure 7. We came across a major fault bringing mantle rocks and upper crustal volcaniclastic rocks adjacent[1b] (Figure 8). Serpentinization is very common giving most outcrops of peridotite a greenish, often mauve tinge.

One outcrop of peridotite was dissected by veins of enstatite rich rock (green veins shown in Figure 9). The Liz-Alan theory is that these enstatite veins represent the partial melt product from the mantle peridotite (olivine rich harzburgite). These partial melt fluids would percolate from the mantle rock into any incipient lines of weakness and rise from the peridotite source rock up to the surface, forming a classic gabbroic melt to be either intruded or extruded. The peridotite between the veins becomes a restite (i.e. the residual material left at the site of melting) and was probably a dunite.

Ma (not to scale)	PERIOD	Ma (Detailed)	Tectonic Events	Comments
250 275	PERMIAN	299-252 (47MA)	UK part of Pangea supercontinent, drifting N. N-S graben / half-graben formed.	Continental hot, arid, desert regime dominates with alluvial fan, wadi conglomerates, fluvial and aeolian sands and ephemeral playa lake mudstones.
300 325 350	CARBONIFEROUS	359-299 (60MA)	Regional Extension in Southern Uplands (Rheic Ocean subducts beneath Armorica to S). Graben/half-graben form and Solway Firth Basin extends NE-SW with active N Solway Fault bounday along N margin.	Further downthrowing and deposition of shallow marine sediments with sand barrier bar. Alluvial fan, fluvial and terrestrial sediments accumulate. Active downthrowing of basin to SE, sediments thin away from fault.
375 400 425	DEVONIAN	419-359 (60MA)	Subduction ceases, dykes injected, gaseous sub-volcanic vents occur, plutons emplaced (from meta-igneous and meta-sedimentary sources).	Dalbeattie Granodiorite pluton emplaced - first the outer pink granodiorite zones of igneous affinities, then diapiric injection of inner zones of white granodiorite of metasedimentary (Silurian greywacke) sources.
450	SILURIAN	444-419 (25MA)	Turbidite sequences accrete to Baltica (Avalonia) as tectonic tracts. Local volcanics.	Good turbidite sequences in basinal shales with intrusive dykes trending NE-SW and associated vents and gaseous, siliceous volcanic activity
475 500	ORDOVICIAN	485-444 (41MA)	SE push dominates and oceanic crust subducts beneath Avalonia/Baltica. Collision & emplacemnt of Ballantrae complex (ca. 470Ma)	Turbidite sequences range from thick, near-source boulder beds ... to well developed medial turbidites with Bouma sequences... to thin distal turbidites in basinal shales. Arc and back-arc sequences are obducted onto the Laurentian continental margin
525 550	CAMBRIAN	541-485 (56MA)	The continents of Laurentia (NW - Scotland) & Baltica (SE - England & Wales) converge.	As ocean subducts beneath Laurentia, volcanic island & back arc volcanics form. Also basinal lavas & sediments accumulate on oceanic crust.
575 600 625	NEOPROTEROZOIC	541	Rodinia continues to split Iapetus Ocean spreads	Oceanic crust and spreading centre forms
650 675 700		ca. 700	Rodinia Supercontinent starts to split & Iapetus Ocean forms	Mid-oceanic basalts pour forth as Rodinia rifts

Fig. 6: Synopsis of timing of events and associated comments of the rocks seen at Dumfries and Galloway

Fig. 7: Peridotite faulted against gabbro

Fig. 8: Major fault at Bennane Lea

Fig. 9: Enstatite veins: partial melt of peridotite leaving restite between veins

As we progressed NE along the beach, the exposures were dominated by volcanic material: basalts (believed to be back-arc basin basalts, Figure 10) and spilitic pillow lavas (submarine ocean floor basalts, Figure 11), more acidic volcanics and lava breccias or lahars (island arc origins), also occasional featureless siliceous rocks (?sinter). Much of the sequence was folded and faults were common.

We came across a large area comprising a jumbled up mixture of massive blocks of lava (up to ca. 10m), lumps of spilite, volcanic breccia, other volcanic rocks and sediments, e.g. cherts. The complete lack of sorting of either rock type or boulder size, lack of bedding or any boulder orientation, together with the presence of localized ‘glide planes’ of smooth, finely slickensided, rock where parts within the ‘blocks’ had slid over each other, indicated that this was a very large submarine ‘slump’, from the flanks of a volcano, probably triggered by an earthquake, which had slid to its final resting place, collecting local cherts en route. Such a massive slide is called an olistostrome.

These rocks formed in an early Arenig marginal basin (Figure 10) and were then obducted, as thrust sheets, onto the margin of Laurentia. Radiometric dates and graptolite biostratigraphy give an early Ordovician age with collision at ca. 470Ma but some enclaves have given Neoproterozoic ages also (>600Ma).

There are several isolated ophiolite complexes of Cambro-Ordovician age, which outline the vestiges of the Iapetus Ocean from Norway/Shetland in the NE and to Newfoundland & beyond in the SW.

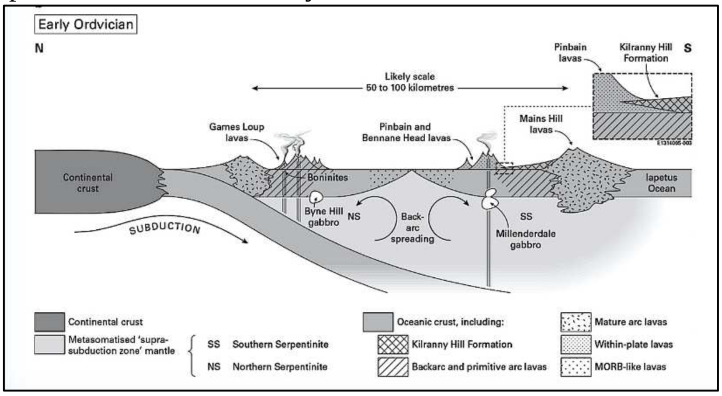


Fig. 10: Supra-subduction zone setting for Ballantrae Complex from Stone (2014[1a])

Fig. 11: Crudely bedded lavas including some spilitic pillows, Bennane Lea.

Day 2 Ordovician Fan Complex (by Paul, Jean & Jonathon)

We viewed the turbidite fan complex traversing from proximal through medial to distal sequences and from N to S along the W coast, Rhins of Galloway, the hammerhead peninsula that lies W of Stranraer. These deposits are of Llandeilan to Llandoverian age, Late Ordovician to Silurian.

The first stop was at Corsewall Point, on the N tip of the peninsula, where we saw conglomerate beds (polymictic) comprising very large rounded boulders. Amongst the boulders were gneisses that had formed 1.2Ga ago and granites that had formed 0.6Ga ago; also boulders of spilite and gabbro and of greywacke and chert (Figure 12). The boulders were of various sizes, ranging from ca. 10-15cm up to 150cm, sometimes supported by a sandy matrix but at other times supporting themselves (boulder:boulder) with the gaps (pore spaces) infilled by sand.

Each boulder bed was interpreted as a debris flow from an earthquake in the early Ordovician, when this part of Scotland was on the edge of the Laurentia continent, along with Newfoundland and Greenland. There was a narrow continental shelf before the deep Iapetus ocean and the debris flows formed a fan, with the coarser material near the source (proximal turbidites) and the finer material travelling into the basin (distal turbidites).

The adjacent sandstone bed only contained a few large boulders and represented a separate event, either a more remote quake where the coarser material had already fallen out or alternatively an event that occurred so shortly after the previous event that the coarser material had not yet been renewed.

The whole sequence had subsequently been upended during the closure of the Iapetus Ocean in Silurian times.

At Killantringan Bay, which is about half way down the W coast of the peninsula, we were delayed from accessing the beach as the tide had not retreated far enough for us to safely access part of the cove, so we took a higher route across the rocks, and found an exposure of turbidites which exhibited parts of a typical Bouma sequence - thinly bedded deposits of sand and mud showing ideally 5 stages of a vertical succession deposited from a dense turbidity current: (a) coarse grained sandstone at an erosional base, (b) planar laminated medium grained sandstone, (c) ripple laminated fine grained sandstone, (d) parallel laminated siltstone, ending with (e) massive ungraded mudstone. In reality, bed 'e' is rarely present, as it is disturbed by erosion at the start of the next cycle. Each sequence of sand and mud represented one event, with the coarser sand deposited first (very quickly) and the finer shale and mud being deposited later (possibly over thousands of years).

Once we were able to get across the beach, we found a spectacular exposure with a large number of turbidites, with the strata at 90°. The very dark colour of the exposed layers was probably due to surface algae.

Turbidites often show sole markings where the turbulent flow has eroded into the underlying sediment, they result from submarine avalanches where accumulated sediment suddenly flows downslope, often as a result of earthquakes. The sediments accumulated on the N edge of the Iapetus Ocean, in a mid to outer fan environment and the earthquakes were associated with the subduction tectonics arising from the closure of the Iapetus Ocean in the Early Silurian.

The sequences of alternating siltstone and sandstone were seen to be of varying thickness, the siltstone beds reflecting the time periods between the avalanche events. The size of the sandstone beds reflected the volume of sediment moved by the earthquake.

It was pointed out that a similar process can be seen in Sumatra in modern times, with the interval between earthquakes having an average of 40 -50 years, but having a significant variance.

At Port Logan, near the SW corner of the peninsula, more mid- to distal fan turbidites with often thin, ca. 5cm, Bouma sequences were seen. Here, folding swung from ca. 50° E to overturned and then to 85° W.

Fig. 12: Boulder beds, Corsewell Point, show variation in boulder size & lack of bedding, having been 'dumped'.

Fig. 13: Subvertical medial fan turbidite beds Killanatrangen Bay, showing stacked Bouma sequences.

Fig. 13: Distal fan/basinal turbidites, Port Logan, the red lines show successive Bouma cycles

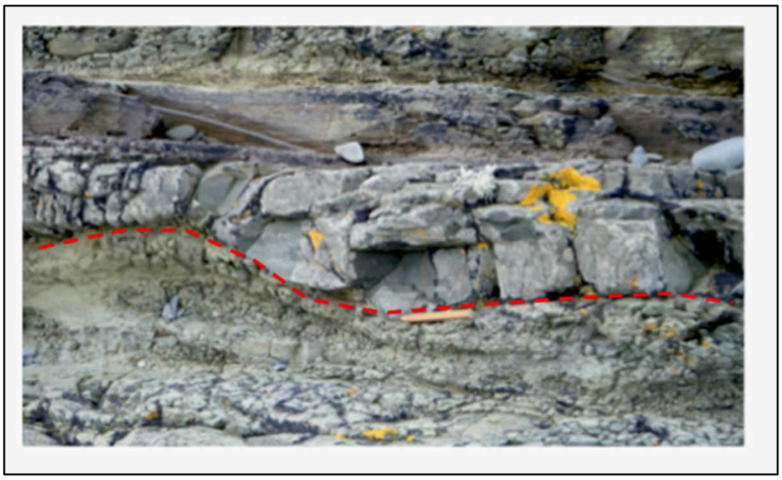


Fig. 14: The red line shows the basal surface at the start of a new cycle, where the overlying turbidite has eroded into the underlying sediments.

Fig. 15 (far L): Whale back fold in thick turbidite sandstone
Fig 16a (above L): Microfold showing asymmetrical folding of whale back.
Fig. 16b (above R): Brittle folding in thin bedded sandstone:shale sequence

Day 3 Caledonian Structures in Silurian Turbidites, Associated Dykes and Volcanics

At Ross Bay another sequence of Silurian turbidites was present, varying from thick to thin sandstones and to shale dominated beds. Here the effects of the Caledonian tectonics were visible in the beach outcrops. A gentle 10m whaleback fold affecting a thick turbidite sandstone was exposed, striking NE-SW and plunging at both ends (Figure 15). The S limb was overturned and much was 'missing' believed thought to have been faulted out and this was confirmed by a micro-structure just a short way away (Figure 16a). Within thinner bedded alternating sandstone:shale sequences, the fold structures were brittle and the fold apex was angular (Figure 16b). Later kink folding had a very different orientation, cross-cutting the Caledonian trend. Two dolerite dykes were examined here, also trending NNE-SSW, following the Caledonian trend.

Further NE along the coast at Shoulder o Craig, more Silurian turbidites were exposed. As we clambered slowly and precariously NE along the beach, this turbidite sequence was pierced by another doleritic dyke (described as a lamprophyre by BGS), which expanded into an irregular somewhat circular doleritic body, ca. 5-10m at outcrop, it was difficult to establish its exact geometry.

Graham hastened us on to view an interesting outcrop, this turned out to be a fine grained intermediate igneous rock with angular fragments of 5-10cm, often with reaction rims and, near the margins, inclusions of country rock (sandstone and mudstone fragments), Figure 17. This was interpreted to be a subterranean volcanic intrusive breccia or subterranean vent agglomerate or diatreme (*a breccia-filled volcanic pipe formed by a phreatic explosion, from pressure release and the interaction of hot magma with relatively shallow groundwater*). The vent is described as Siluro-devonian in age.

The surrounding country rocks appeared to be fine grained sandstones and interbedded siltstones/shales, often showing flame structures, but the sediments appeared to be completely recrystallized and silicified. These sediments were folded steeply to subvertical.

Day 4 Devonian and Carboniferous Sequences

We first went to Rockcliffe where a good sequence of Silurian Ross Formation turbidites were cut by doleritic dykes trending ca. NE-SW, they showed pinker margins with greyer inner dolerite. One was particular wide, over 4m. We walked along to Castlehill Point where we could look along the NE-SW trending N Solway Firth Fault scarp (Figure 18). Although the dominant movement on this fault is vertical, it may well have had a sinistral strike slip component as well[2]. We didn't attempt to climb down although Graham had previously climbed down the near vertical cliff and was able to inform us that the sediments at the bottom were a) a fault breccia of andesite, greywacke and mudstone; and b) Carboniferous sediments which we could clearly see thinned rapidly away from the base of the cliff (50° dip) to much thinner beds (15° dip) within 50m towards SE.

Fig. 17: Agglomerate from a subterranean vent, or diatreme

Fig. 18: North Solway Firth Scarp Face

Fig. 19: Thin Sandstone Bed With Bioturbated Top Within Mudstone-Limestone, Southerness.

Fig. 20: Rippled Sandstone Of Carboniferous Age

In the afternoon, we went to Southerness where Carboniferous sediments were examined. They comprised cycles of sandstone-mudstone-limestone, reflecting the repeated movements of the N Solway Fault. The sandstones were planar laminated, frequently bioturbated along their top surfaces (?grazing patterns), Figure 19, with black bituminous shales, also shelly, crossbedded sandstones with bioturbated tops. Further up the sequence there was a large sandstone bed, probably a beach deposit that appeared to coarsen upward. Plant material, brachiopod shells and algal limestones are present, although we didn't see these.

Near the lighthouse, sandstones, pebble conglomerates, siltstones and sandy limestones are present. They are red, white and purple in colour, deposited in a coastal, shallow water, environment, occasionally exposed and oxidized. Also present (although not seen by us) were thin sandstone-mudstone-limestone beds with thin coals of an intertidal / lagoonal environment, and mudstones with frequent coarser grained sandstones, probable flash flood deposits.

This sequence was seen as a protected sedimentary environment within a general shallow marine coastal region, occasionally being exposed giving red (iron oxidized) shales, elsewhere the red staining had percolated down cracks into the underlying grey shales.

At Powillimount, there was an exposed fold of thin beds of Carboniferous sandstones, some with rippled surfaces (Figures 20, 21) with interbedded micaceous shales.

Further NE along the beach was a 250m long, elongate, outcrop of cross-bedded sandstones, the Thirl Stane Sandstone Member, nestled within a (?down) faulted outcrop shown in Figure 21. It comprises a thick sequence (>9m) of cross-cutting, cross-bedded, medium to coarse grained sandstones. The individual units seemed to have been deposited fairly rapidly, Graham measured 24 separate units in the vertical sequence (Figure 22). This was interpreted as a deposit within a high-energy marine environment. All cross beds appeared to dip in a similar direction (towards ca. NE), suggesting deposition under a dominant tidal influence, such as longshore drift (Figure 23) and accumulating in a growing basin, allowing the thick sequence of beds to develop.

In places, units of overturned beds, interpreted as slump features, or 'nappes' were present, but the overturning dipped in the opposite direction (probably to SE) to the cross-bedded units (Figures 24, 25). At other places, there were large dewatering features such as 'sand volcanoes', which appeared to be associated with the 'slumps' (Figure 26). On the E side of the bar (Figures 27, 28), individual beds ca.10-20cm thick had flowed/slumped down the edge of the bar (toward SE). It was uncertain how many intervals of slumping were present, certainly a thick (>2m) interval of disturbed bedding occurred with either slumping, sand volcano, contorted bedding and/or other slumping/dewatering features.

Fig. 21: Folds on Powillimount Beach and crosscutting faults running E-W (in yellow). The long outcrop of the barrier bar extends in downfaulted area between these faults. *From: Google Earth*

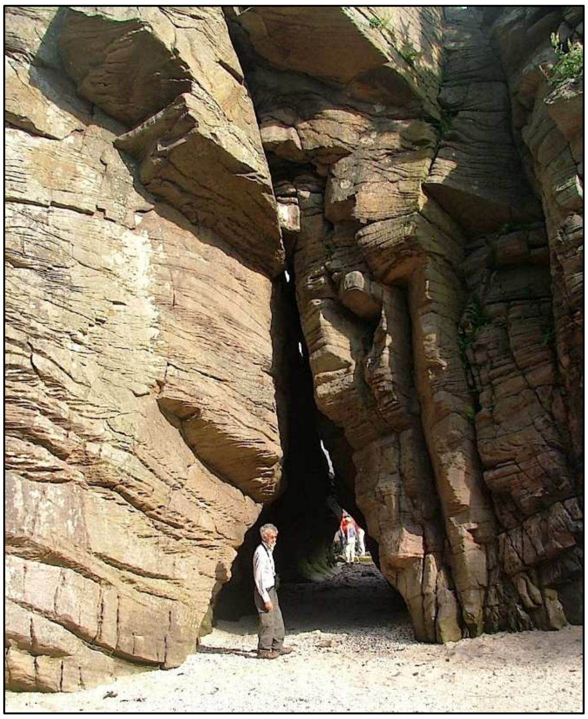


Fig. 22: The 24 individual beds of the Thirl Stane Member at Thirl Stane Arch. Note the cross bedding on the left is consistently in the same direction, but now tilted.

The overturned slumps appeared to occur at more than one horizon (although time did not allow this to be verified) and are interpreted as responses to movements of the N Solway Firth fault, probably downfaulting to SE in little jumps during the deposition of the bar, each little jump causing instability and slumping and/or or dewatering of the sandstones at or near the top of the bar, where the recently deposited beds would retain much water in their pore space. Certainly one major fault displacement must have occurred to cause the thick unit of disturbed bedding. The following figures hopefully give a representative selection of these features.

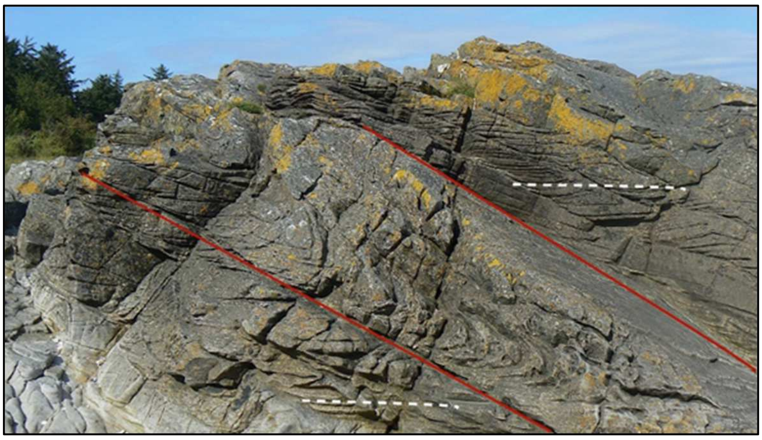


Fig. 23: The cross beds (ca. 30cm) dip one way, to ca. NE (white lines) and slumped bed (within red lines) (ca. 50cm) deforms in the 'opposite' direction.

Fig. 24: Several slump folds (white lines) within a disturbed unit overlying compacted, undisturbed, cross bedded sand units.

Fig. 25: Close-up of one slump, apparently the bed had rolled completely over. Figs. 23, 24, 25, 25 have ca. NE on L and ca. SW on R.

Fig. 26: 'Sand volcano' due to sudden dewatering, apparently connected to, associated with, underlying slumping.

Fig. 27: View of slumping from the other side of the outcrop; slumping toward the camera (to ca. SE

Fig. 28: Another sand volcano, dewatering structure probably, from other side of the bar

Day 5: Permian Deposits

The Permian beds lie within a half-graben (the Dumfries Basin) trending NNW-SSE, which formed in Late Carboniferous - Early Permian times. The Permian beds were first examined in a cutting along a disused railway track where polymictic, pebble-boulder conglomerates, with a coarse sand matrix showing large scale bedding. Within the outcrop was a small, isolated, channel fill structure with tabular siltstone clasts. Conjugate and Y-shaped joints, striking ca. N-S, showed smearing along planes. Such joints allow percolation of water vertically up along them but restrict flow of pore water horizontally across them, any horizontal flow would be forced vertically at the joint plane.

Later, we stopped at Castledykes Park in Dumfries - a good location with two vertical outcrops at 90° to each other, on the sides of a former quarry.

The Permian sandstones showed classic desert dune features, being fine-grained, very well sorted, rounded, red sandstones, with steep foreset beds (>30°) passing down into gently sloping basal cross sets. The dune bedded sequence (>2m thick) passed up into basal beds (somewhat coarser grained) of another dune, which had eroded into it as that dune migrated across. This dune exposure was cut by conglomerates interpreted to be a wadi channel-fill, however this channel fill was notably asymmetrical; the ca. S side being subvertical and highly erosional through the dune, the ca. N side being subhorizontal and (surprisingly) almost non-erosive with the underlying sandstone which continued beneath the dune beds. As we were leaving, it was realized that the asymmetry of this wadi outcrop had been seen in the other wall, outcropping at 90°, where the ca. W side was subvertical and the ca. E side essentially non-erosive with the underlying sandstone. This matching asymmetry suggested that the outcrops (ca. 50m apart) were probably part of a meander core with a steep outer erosional edge where the flow had cut down into the desert dune, and a gentle slope, barely erosional with the underlying sandstone (probably already hardened by early diagenetic cementation), on the internal part of the meander.

Igneous intrusive rocks – Criffel Dalbeattie Pluton, Caledonian and Tertiary Dykes and Ailsa Craig

The contact between the outermost zone of the Criffel-Dalbeattie pluton was examined on the beach at the end of the W coast of Balcary Bay, very close to our hotel. It had a thin thermal aureole of baked Silurian turbidites, mainly mudstones (now hornfels). The margin rocks were pink granodiorites, described as the most basic of the granodiorites of the pluton, with accessory clinopyroxene, biotite and hornblende from meta-igneous influences rather than meta-sedimentary. Detail of the contact is shown in Figure 26. Graham had explored other potential exposures of the pluton but these were either overgrown or impractical.

The Paleozoic turbidite sequences of Ross Bay, Rockcliffe and Shoulder o' Craig, were all cross cut by doleritic dykes trending ca. NE-SW, described as Siluro-Devonian. That at Shoulder o' Craig developed into an irregular body. This dyke was trending directly toward the nearby diatreme.

The sequences at Bennane Lea, Corsewell Bay and Port Logan were cut by Tertiary dykes all trending ca. NNW-SSE, as in Figure 27. That at Bennane Lea was trending directly towards Ailsa Craig (although the map showed other nearby dykes trending NE-SW).

Several of the dykes showed two phases of intrusion, either having harder or softer external edges or different mineralogies between the edges and the centres.

Fig. 26: Junction of Dalbeattie Granodiorite with country rock of Silurian turbidites, now hornfels. Balcary Bay.

Fig. 27: Tertiary dyke at Corsewell Point, ca. 4m thick, which appeared to have experienced several pulses of injection. It had a rather irregular winding strike.

We also made a trip to Creetown Gem Rock Museum - well worth a visit. Whilst Mike Rubra introduced us to some excellent archeological sites but these are described in a separate article, to be published in February 2016.

References

[1a] *Stone, P., 2014, A review of geological origins and relationships in the Ballantrae Complex, SW Scotland Scottish Journal of Geology, Vol. 50, 1-25, 2014.*

[1b] *Stone, P., Vol. 17: Caledonian Igneous Rocks of Great Britain Chap 2: Early Ordovician volcanic rocks & associated ophiolitic assemblages of Scotland Site: BENNANE LEA (GCR ID: 2407). Extracted from http://www.jncc.gov.uk/page-2731 © JNCC 1980–2007.*

200 Years of William Smith's Map

'A Delineation of the Strata of England and Wales and part of Scotland' is rightly regarded as an icon of geology. Its attractive colouring demonstrates Smith's clear understanding of the subsurface geology of much of S Britain and bears comparison with the modern 10-mile map of the British Geological Survey (BGS).

Smith was the son of an Oxfordshire blacksmith. Due to the death of his father when he was eight, he was sent to work picking up stones on his uncle's fields. These stones included many fossils, especially echinoids and brachiopods. Interest in fossils and his skills in drawing and colouring were recognized by Edward Webb, a local surveyor. This was the start of his career as a land surveyor, then a canal surveyor and engineer. His irrigation and land drainage work were much in demand as there was a desperate need to increase food production in wartime.

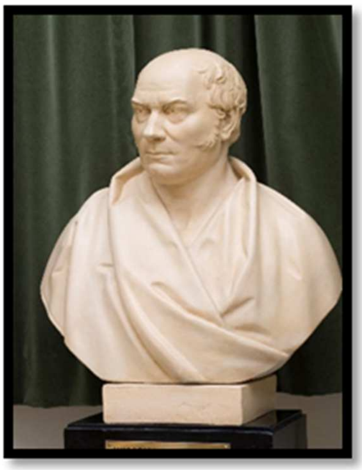


Fig. 1: William Smith
Burlington House

Fig. 2: Bath - A Chart of the Rock Strata.
(from BGS ©2008 NERC All rights reserved. IPR/100-28DR)

It was while working on his many projects around the country that he was able to map the strata and to build up an extensive collection of fossils and drawings. His first map covered the area around Bath 'A Chart of the Rock Strata' (Figure 2). He and two friends identified 23 layers e.g. Fuller's Earth, Blue Lias, Millstone and Pennant Sand. It was in these last two layers that they noticed something odd - a dramatic change in the fossils. In the Millstone layers plant fossils dominated; in the Pennant layers marine mollusc shells dominated. Today geologists recognize this as the boundary between the Carboniferous and Permian periods.

His map was published in 1815, largely at his own expense, on a scale of 5 miles to 1 inch and consisted of 15 sheets. Each was hand coloured in 20 tints, each colour representing a different strata. Each hue was graded, darker to indicate the base of the formation. As well as the map there was a legend, profile views and cross sections. It was the complexities of geological coloring that meant production was slow and at times poor quality. These problems together with alleged plagiarism by the Geological Society of London (GSL) resulted in him accruing debts and a spell in the King's Bench Prison. He had to sell his collection of 1600 fossils and 107 rock samples to get out of the debtor's prison. The collection now belongs to the Natural History Museum and is still intact, stored according to his 'Order of Strata'.

After his release from prison, he took a series of jobs in N England, teaching courses for local philosophical societies. In Scarborough he helped establish the city museum including designing the Rotunda. His design allowed fossils to be displayed along the outer walls in the same order in which they are formed in the strata, giving visitors ascending the spiral staircase, a visual guide to life on Earth.

At last recognition came for his work. The GSL awarded him the first Wollaston Medal in 1831 (its most prestigious award). He received an Honorary Doctorate of Letters from Dublin University. Perhaps, most practical of all, a pension of £100 p.a. from King William IV. A copy of the map hangs in the east staircase of Burlington House, the current home of the GSL.

Susan Williams, FGS Member