Charles Darwin's 1831 geological fieldwork in Shropshire

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Abstract: During the first half of 1831 Charles Darwin's new enthusiasm for geology was triggered by his mentor J.S. Henslow and plans for an expedition to Tenerife. During mid-summer 1831, when living again at his Shrewsbury home, he undertook his first independent geological field work and practised using his new compass-clinometer. At Llanymynech he observed infilled 'great cracks' within the 'Mountain Limestone' outcrop. Over 150 years later it was suggested that these cracks were Carboniferous-aged horizontal intraformational clay beds. An alternative possibility is that the cracks were indeed vertical as Darwin implied and were of Quaternary age representing either karstic pipes or periglacial gulls, with later infills of clay. If true, Darwin's field description had greater precision than previously implied.

From the perspective of the history of geology in Britain, the now abandoned limestone quarry, which bestrides the Shropshire–Powys border at Llanymynech Hill [SJ263221] (Fig. 1), is a locality of some consequence, since Charles Darwin went there in July 1831 to practice the use of his newly acquired compass-clinometer. At that time Darwin had written to Charles Thomas Whitley, his old school friend and undergraduate contemporary, saying '*I am present mad about geology*'.

The initial rationale of this paper was simply to revaluate the dilemma which had confronted Michael Roberts after he had examined the outcrops at the former Llanymynech quarries in the 1990s. Roberts (1996) was unable to reconcile Darwin's description of 'infilled great cracks' with the character of the current exposures, leading him to admit that he was baffled by these structures. His proposed solution to the problem was to postulate that Darwin's cracks were likely to have been horizontal intraformational beds. However, this hypothesis appears implausible, and three alternative scenarios are suggested, any of which could account for what Darwin recorded. If any of these is correct, then Darwin's innate ability as a careful observer is confirmed, even though he might have been 'struggling in the field to gain competence in a discipline in which he was a neophyte' (Herbert, 2005, p390). Although Darwin did occasionally confuse compass directions, these instances alone hardly support Roberts's wider suggestion that he might have been dyslexic.

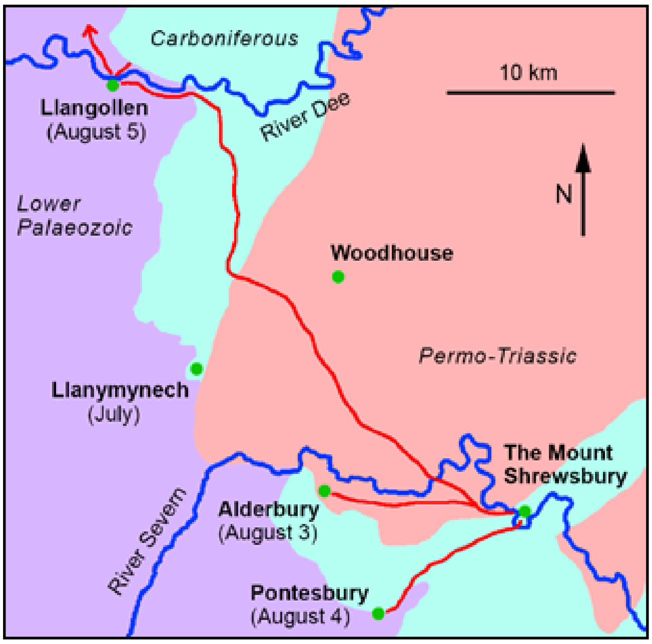

***Figure 1**. Routes to the main localities in northwest Shropshire visited by Adam Sedgwick in early August, 1831. It is highly likely that Charles Darwin accompanied him on August 3rd and 4th. It is well established that they travelled from The Mount to Llangollen along the Holyhead toll road on August 5th. Whether they jointly inspected Llanymynech is in doubt, but certainly Darwin went there on an unknown date in mid to late July. The Llanymynech site refers to the quarry, which is north of the village.*

Darwin's early field training with Adam Sedgwick in North Wales (from August 5, 1831) has been examined exhaustively (Barrett, 1974; Secord, 1991; Roberts, 1996, 2001, 2012; Herbert & Roberts, 2002; Herbert, 2005). This contribution will examine first, the events that led to Darwin becoming a geologist, second, the Llanymynech Hill geology and quarrying history, and third, the genesis of Darwin's 'great cracks'.

Darwin in Cambridge, 1831

On January 22, 1831, the University of Cambridge Batchelor of Arts results were published, and these showed Darwin placed a creditable tenth out of 178 candidates. He had first arrived at Christ's College in Cambridge in January 1828, thereby missing the Christmas Term and as the college rooms were fully occupied, he was obliged to live in lodgings for the remainder of the academic year. His delayed arrival was due to him having remained in Shrewsbury for a crash revision in classics with a private tutor, as he had forgotten most of what he had learned at school. In the previous two years he was notionally a medical student at Edinburgh University. The Cambridge requirement of ten terms residency prior to formal graduation meant that although Darwin had earned his degree, he needed to remain in college for a further two terms (from January 13 to July 7). Accordingly, the university regarded him as an 1832 graduate (van Wyhe, 2009).

This additional period of residence in Cambridge, without any course or examination constraints, was the catalyst for his adoption of geology as a major interest, primarily through the influence of the Reverend

Professor John Stevens Henslow (1796-1861), who later become well known as his mentor (Waters & Stow, 2001). In old age when writing his autobiography for his family, Darwin recorded that he '*influenc[ed] my career more than any other*' (Barlow, 1958). Originally, Henslow had held the Cambridge Chair of Mineralogy from 1822 until 1827, although subsequently he switched disciplines to become Professor of Botany, a position he held from 1827 to 1861, when he died in post. Earlier Henslow had shown himself to be a very capable geologist; he had accurately mapped the complex geology of the Welsh island of Anglesey and had written a detailed memoir. Henslow held regular Friday evening soirées at his home and Darwin was introduced to these through his fellow undergraduate and second cousin William Darwin Fox. Darwin and Henslow progressively became firm friends and mutual admirers. At one of the soirées, he encountered Henslow's colleague the Reverend Professor Adam Sedgwick (1785-1873) who occupied the Woodwardian Chair of Geology from 1818 to 1873 (Fig. 2). Thus, the mineralogist Henslow and the geologist Sedgwick concurrently held Cambridge 'earth science' chairs between 1822 and 1827.

Darwin first came across Sedgwick in his capacity of Senior Proctor at his matriculation in the Senate House on February 20, 1828 when he took an oath of allegiance to the University. Another student taking the oath on that day was Alfred Tennyson. Although in Darwin's autobiography (Barlow, 1958), he claimed not to have attended Sedgwick's famed extra-circularly lectures, circumstantial evidence strongly suggests that he voluntarily attended at least some of them.

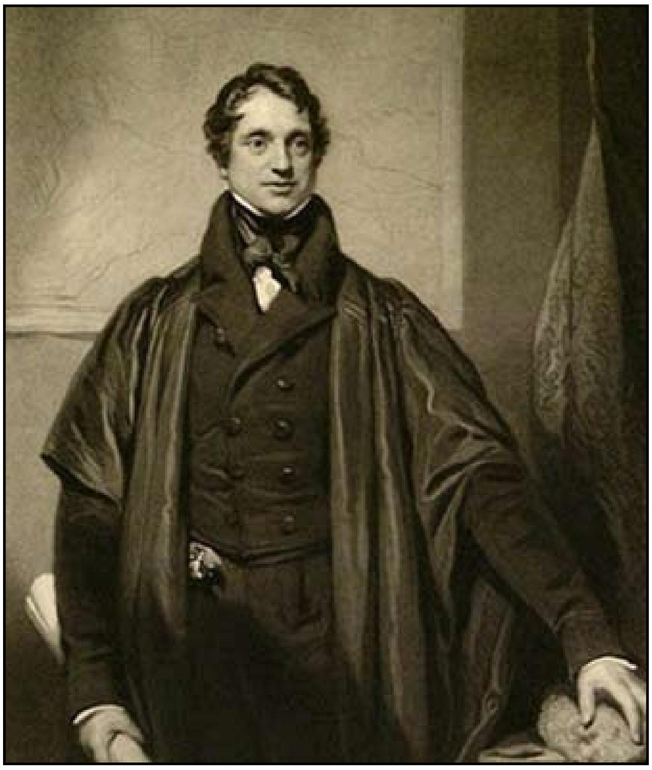

Figure 2*. Rev. Adam Sedgwick in 1832, aged 46 (painted by Thomas Phillips).*

Figure 3*. Bronze statue of Charles Robert Darwin as a 22-year-old undergraduate student in 1831, sited in the grounds of Christ's College, Cambridge, to mark the bicentenary of his birth in 2009 and the 150th anniversary of the publication of* 'The Origin of Species'*. Darwin is seen holding Volume One of Humboldt's 'Personal narrative' and the other volumes lie on the seat. No portrait of Darwin between the ages of 6 and 31 is known to exist.*

Following Henslow's recommendation, Darwin read the recently translated editions of Alexander von Humboldt's 'Personal Narratives', which vividly described his travels from Spain to south and middle America (Fig. 3). This was no small task as the six-volume narrative amounted to 3754 pages. Prior to embarkation on H.M.S. *Beagle,* Henslow presented Darwin with a full set to add to his on-board bookshelf. In Volume 1, Humboldt (1818) describes his voyage on the Spanish frigate *Pizarro* from La Coruña in Spain as far as the Canary Islands where, after a brief stop at Garciosa Island close to Lanzarote, the ship anchored off Santa Cruz in Tenerife for five days in 1799. During this period, Humboldt and his companion, the botanist Aimé Bonpland, travelled overland to the town of Orotava on the north coast of the island and from there they climbed almost 4000 metres up to the summit crater of the volcano Pico de Teide (Fig. 4). Earlier, Humboldt had been trained as a mines inspector at the famed mining school in Freiberg, Saxony, where the neptunist (universal ocean) ideas of Abraham Werner held sway. However, Humboldt's experience of the volcano convinced him that the plutonist (Huttonian) school of thought was the key to understanding volcanoes. Humboldt wrote an enthused account of the geology and physical geographical environment of the

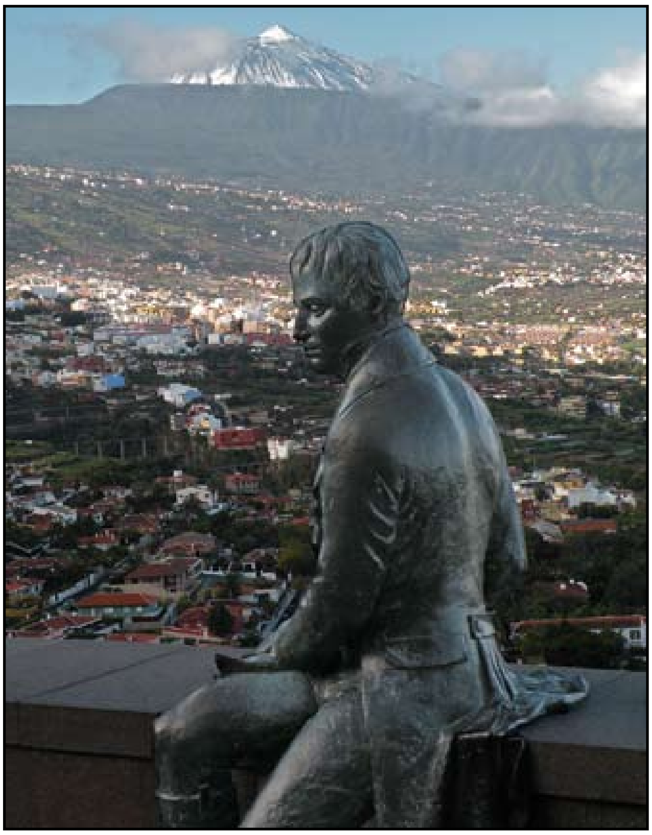

***Figure 4**. Statue of Alexander von Humboldt at the 'Mirador Humboldt' looking west towards the snow-covered volcano of Pico de Teide, on Tenerife, in the Canary Islands. The town of Orotava is in the middle distance.*

island, and this motivated Darwin to plan that he and a small group of Cambridge friends would visit Tenerife that summer. To facilitate this, he started to learn Spanish even though he considered the language to be stupid. Alas several problems arose which led to deferment of the proposed mini expedition to a future date.

Darwin's compass-clinometer

An essential piece of geological field equipment is the compass-clinometer. A clinometer per se, may be defined as 'apparatus for measuring vertical angles, particularly dips, by means of a pendulum or spirit level and circular scale' (Howell, 1962; Barnes, 1981). Probably Darwin was first introduced to this instrument in 1827 (at the age of 18) while enrolled on the Natural History course given by Professor Robert Jameson at the University of Edinburgh. This was a major undertaking involving five days each week extended over five months; the course was regarded as one of the finest available at that time. Jameson placed emphasis on the principles of geology (from a Wernerian/ Neptunist perspective), the concepts of stratigraphy and mineral identification both in the museum and in the field. Unsurprisingly, the recommended course book was Jameson's own 'Manual of Mineralogy' of 1821. Darwin's personal copy of this book survives in Cambridge University library, complete with his marginalia annotations, which amount to 2500 words. At the bottom of page 341 he sketched a three-dimensional diagram illustrating the principles of dip and strike of strata, quantitative measurements of which require a compass-clinometer (Secord, 1991).

In 1831, when practical field geology was on Darwin's agenda, he ordered a compass-clinometer made to a Henslow modified design (Fig. 5). This was constructed by the London instrument makers George and John Carey Ltd at the cost of 25 shillings (just over £130 in modern currency). Almost two decades later, Darwin contributed a section on 'Geology' to a scientific handbook sponsored by the British Admiralty (Darwin, 1849). This book went through four successive editions during 1851–1886. In his essay he gave a concise description of a clinometer 'it consists of a compass and spirit level, fitted into a small square box [mahogany], in the lid there is a brass plate, graduated in a quadrant of 90 degrees, with a little plumb-line to be suspended from a milled head at the apex of the quadrant'. After his death in 1882, the instrument was inherited by his first son William Erasmus Darwin, who, although a banker by profession, was also a Fellow of the Geological Society of London and Lincolnshire estate owner (Worsley, 2017). It was loaned by William to the Darwin Centenary exhibition held at Christ's College in 1909. Currently it is on display at Down House in Kent, Darwin's final home, which is now cared for by English Heritage / Historic England, but is erroneously stated to have been bought by Darwin to take on the *Beagle* voyage. This assertion was repeated by Brindle (2017). However, the hand-written label on the instrument correctly records 'used by CD on Beagle'. At the time of purchase, he had absolutely no inkling that within weeks he would be signing-on for a round-the-world voyage under the command of Captain Robert Fitz-Roy.

***Figure 5**. Darwin's compass-clinometer made to a modified design by Henslow in mid-summer 1831. It is currently on display in Down House, Kent. This was subsequently taken by Darwin on* H.M.S. Beagle *(photo: English Heritage).*

Mid-summer 1831 in Shrewsbury

Having met the outstanding residency requirement for formal graduation, on June 16, Darwin ended his undergraduate career and finally left Christ's College Cambridge bound for his birth place and family home at The Mount in northwestern Shrewsbury (Figs. 1 & 6). His widowed father, Dr Robert Waring Darwin, was living there, in the company of his two unmarried daughters Susan and Catherine. Although keen on developing his new geological interests, his long-term prospect was to return to Cambridge in the following autumn to start the reading necessary for ordination and later assignment to a parsonage. His father supported this, an essential prerequisite for guaranteed funding. Darwin knew that many country parsons were active naturalists, as indeed was his cousin William Darwin Fox. A church career could be accommodated within his natural history expectations.

No diary of the eight weeks prior to August 4 has survived, and a chronology for this period must be reconstructed from the few surviving dated letters and other indirect sources; not all of these agree. After taking delivery of his new compass-clinometer at The Mount, it is understandable that Darwin was keen to use it for the first time. On July 11, he reported to Henslow - *'I put all the tables in my bedroom, at every conceivable angle & direction. I will venture to say I have measured them as accurately as any geologist going could do'* (Darwin, 1831, p125). One source claims that he bought the compass-clinometer in London on the journey from Cambridge to Shrewsbury (Desmond & Moore, 1991).

Henslow saw the desirability of enhancing both Darwin's capability and confidence in field geology. He knew that Sedgwick was planning to initiate a field research programme in North Wales later that summer to investigate the stratigraphy of the so-called 'Greywacke (Transition) Group' which was thought to lie below the Old Red Sandstone and above the primary (Precambrian) rocks known in Anglesey, thereby extending his just completed work in Cumbria (Rudwick, 1985). Henslow had the foresight to enquire if Darwin might accompany him. Sedgwick was amenable, thereby demonstrating that he endorsed Henslow's view of Darwin's potential as a geologist. Knowing that he was the grandson of the famed Erasmus Darwin and Josiah Wedgwood the potter, probably did his case no harm. Sedgwick's work schedule meant that he could not commit to a specific date. A major problem for him was the revision of a paper on the eastern Alps which he had written jointly with Roderick Murchison. Although he had recently concluded two years as President of the Geological Society in London and 'exchanged dignity for liberty', the Council of the Society insisted on changes to the paper prior to publication (Sedgwick & Murchison, 1835). In addition, University and national politics rose to the fore as the Great Reform Bill was introduced into Parliament, causing him to remain in Cambridge in the immediate future.

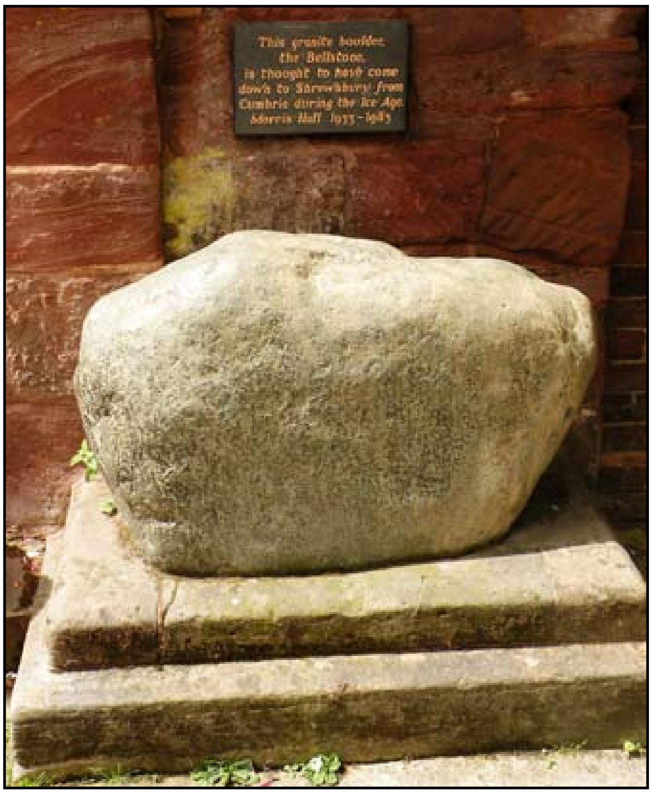

__Figure 7__. The Bellstone, a glacial erratic displayed beside the Morris Hall in central Shrewsbury. The rock identification on the plaque is incorrect; rather than being a granite, it is either a volcaniclastic or an altered andesite. In 1832 Adam Sedgwick took a sample that is now displayed at the Sedgwick Museum, Cambridge, (accession number 145218).

***Figure 6**. The Mount, Frankwell, Shrewsbury, the home of Dr Robert and Susannah Darwin. On February 12, 1809, Darwin was born in the first-floor room to the left of the portico. After leaving Cambridge in mid-June 1831, Darwin was based at The Mount until shortly after he received the invitation to join the* Beagle.

Darwin's first attempts at geological mapping were none-too-successful (Roberts, 2000). Herbert & Roberts (2002) have transcribed his notebook entries, estimated to date from mid-July to early August, and attempted to identify four of his field study sites. The immediate area around Shrewsbury is not ideal for a young bedrock geologist because of the extensive and thick cover of superficial sediments (drift). Indeed, the area displays excellent examples of hummocky glacial terrain with numerous kettle holes (Worsley, 2005). In 1831, the drift blanket was regarded as diluvium, a deposit resulting from a Noachian-type deluge/ catastrophic flood. It would be almost a decade before Louis Agassiz would startle the British geological community by declaring that Britain had been subject to land ice glaciation. Within Shrewsbury, bedrock outcrops are rare.

In his early teens (c.1822), Darwin was familiar with The Bellstone, a celebrity glacial erratic long displayed in central Shrewsbury (Fig. 7). Some 50 years later in his autobiography, he recalled how in c.1823 'an old Mr Cotton in Shropshire who knew a good deal about rocks' had told him that 'there was no rock of the same kind nearer than Cumberland or Scotland'. Cotton had also declared 'that the world would come to an end before anyone would be able to explain how this stone came to where it now lay'. This challenge, Darwin felt, helped prepare him for a philosophical treatment of geology (Barlow, 1958). Richard Cotton (1790-1839), came from an old Shrewsbury family and after making his fortune in London, in 1812 settled at Woodfield House, Claverley, east of Bridgnorth. When Cotton joined the Geological Society in London he was described as 'a gentleman partial to the study of geology' (Torrens, 2008). It was appropriate that he was laid to rest in Claverley All Saints churchyard, as he had funded the restoration of the church.

***Figure 8**. An exposure in the Welsh Quarry [SJ643177] of well-bedded and jointed limestone. The black arrow indicates the horizon of one of the thin ash beds (see Figure 9).*

Sedgwick finally became free at end of July and he travelled in his gig (a light two-wheeled carriage pulled by one horse) to North Wales from Cambridge via Dudley and Shrewsbury. From correspondence with Murchison, it appears that Sedgwick stayed at The Mount for two nights (Clark & Hughes, 1890). However, his journal (Sedgwick, 1831), reveals that he spent two days examining the district around the small coalfield some 10–15 km west of Shrewsbury (Fig. 1), but we do not know whether Darwin accompanied him. There is no doubt, however, that on August 5 the two set off for Llangollen in Sedgwick's gig on the first stage of their North Welsh field research venture. Sedgwick in the company of Darwin might have visited Llanymynech *en route* since he records that the limestone outcrop there extended a mile beyond the limit shown on Greenough's geological map.

Darwin at Llanymynech

When Sedgwick was planning his North Wales fieldwork, he received a letter, dated June 6, from John Hailstone (1759-1847), his immediate predecessor as Woodwardian Professor. Hailstone advised 'I think that you ought not to omit Llanymynech as the extensive Limeworks there have laid bare the beds to a great extent' (Lucas, 2002). Clearly in the Cambridge geological community the locality had some renown and bearing in mind Henslow's role as mentor, it is possible that Darwin was appraised of the importance of the Llanymynech exposures before he left Cambridge (this was ten days after Hailstone had sent his letter to Sedgwick). Therefore, it is probable that Darwin selected Llanymynech for clinometer practice knowing that the outcrops there consisted of well-bedded and jointed limestone affording three-dimensional exposures (Fig. 8). According to Roberts (1996), he went there early in July, hence very shortly after receiving his new compass-clinometer. As part of his intended geological mapping programme, Darwin had prepared four hand-drawn base maps and one of these covered the Llanymynech area. Curiously, no geological data were transposed onto it, despite his Llanymynech investigations (Roberts, 2000).

An additional factor may be that for several years, he had frequently visited Woodhouse [SJ364288], a mansion that was the family seat of the Mostyn-Owens, for field sports, socialising and flirting with Fanny Owen. Indeed, in 1828 he wrote '*Woodhouse to me is a paradise, about which I am always thinking*'. Showing his priorities, Woodhouse was marked on the Llanymynech area sketch map. The route from Shrewsbury to Woodhouse was along the A5, then a new toll road designed by Thomas Telford. This affords fine views of the Welsh borderlands' scarred hillside, and plumes of steam from the lime kilns at Llanymynech would have been visible from it.

In 1772 a turnpike road eastwards from Llanymynech (now the B4398) had opened and intersected the A5 at Knockin Heath. Access to Llanymynech from Shrewsbury

***Figure 9**. An intraformational argillaceous ash bed of the kind identified by Michael Roberts; these represent distal ash falls. Scale is in centimetres.*

was therefore easy. Because Darwin examined the geology of a working quarry, the available exposures in July 1831 were later destroyed. In his analysis of Darwin's Llanymynech observations, Michael Roberts admitted to being baffled by one critical aspect. The essence of the problem is that Darwin recorded '*great cracks passing straight through the rock now filled with clay*', a statement which on face value suggests that he encountered ***vertical*** cracks penetrating the limestone. Roberts correctly states that the notes do not specify whether the cracks were vertical or horizontal. However, since Roberts himself was unable to find 'obvious vertical cracks' at the locality, he concluded that Darwin must have been referring to what Roberts described as 'thin bands of reddish clay …. lying between thicker beds of up to 10 feet of limestone' …. which could 'be traced over much of the rock face'. These thin bands of clay recognised by Roberts were ***horizontal*** and he gained confidence in his 'horizontal bed hypothesis' since, when with Sedgwick in North Wales, Darwin had examined a similar Carboniferous limestone outcrop near Abergele [SH960775] and described as containing '*very ferruginous clay seams in the rock itself*'. This observation appears to have strengthened Roberts's belief that the Llanymynech Hill cracks were horizontal features, 'recognising them as interbedded with limestone and not a later infilling' (Fig. 9).

Geology of Llanymynech Hill

The hill attains 223m OD and forms the rather abrupt southern termination of a cuesta of Lower Carboniferous limestone extending many kilometres to the north, although it is not a continuous landform due to outcrop offset arising from east-west faults. North of Llangollen it includes the well-known Eglwyseg escarpment, which displays classic rhythmic sedimentation. At Llanymynech, the scarp face is to the west, and the dip slope descends eastwards to be overlapped by Permo-

Llanymynech 16 miles NE [NW] of Shrewsbury; to the north of the village about ½ of mile in an extensive quarry of Limestone. On the road to it, passed over a hillock of soft slaty rock, some of the Strata were crumbling away by exposure to the air. Strata very distinctly inclined at 78°. Direction ESE & WNW. The quarry is worked in the escarpment of a range of carboniferous Limestone facing S by W. On the Eastern side & high in the hill where the stratification is better marked the rock more compact & of redder colour, the general D is NR b N 14°. To the Westward & lower down D of strata is more NW & the angle less. *In the centre there of quarry are several great cracks passing straight through the rock now filled with clay*. To this line the strata on each side are inclined on each side from [E crossed out] W 10° 7 from [W crossed out] E 15°. It gives the strata the appearance of curves. The stratification of the whole western side appears to be less than regular than that of the East. At one place I observed a series of strata having D ENE 10° - The lowest Strata of Limestone that are worked consist of rocks of a softer texture, marked in patches by a brightish red, called by the Workmen 'bloody veined'. Beneath there is the Delve consisting of a very argillaceous Limestone, soft & wasting away on exposure to the air. It is not worth being burnt for Lime – The Workmen have never gone beneath this.

Transcription of Darwin's field notes, by Michael Roberts; in these notes, Darwin uses the letter 'D' as an abbreviation for the dip of a stratum.

Triassic red beds within the Shropshire basin. It is likely that the limestone outcrop once extended further to the south since, 12 km southeast of Llanymynech, the Permian Alberbury breccia is dominated by Carboniferous limestone clasts. Sedgwick (probably with Darwin) visited an active quarry at Alberbury [SJ353143] on August 3, 1831 (Fig. 10).

***Figure 10**. The Permian Alberbury breccia at Alberbury [SJ362131]. The angular clasts consist of Carboniferous limestone like that at Llanymynech. The matrix is carbonate-rich making the rock suitable as a feed to lime kilns. These rocks were examined by Adam Sedgwick on August 3, 1831, almost certainly in the company of Charles Darwin. Scale in cm.*

C.B. Wedd made the first examination of Llanymynech Hill area as part of the six-inch-to-the-mile mapping programme by the Geological Survey (Wedd *et al.,* 1929). While innocently mapping in 1914-5 at the start of the First World War, Wedd was arrested as a suspected German spy. He identified a Carboniferous succession of <c.27m of ‘Basal Shales’ overlain by ‘Lower Limestones’ <c.64m thick. Toghill (2006) recognised a ‘Whitehaven Formation’ that essentially equates with the ‘Lower Limestone’ of Wedd. More recently the British Geological Survey has revised the classification of the Carboniferous stratigraphy in the North Wales region by erecting the Clwyd Limestone Group (Waters *et al,* 2007; Howells, 2007). Within this, the ‘Basal Shales’ become the Pant Formation and the ‘Lower Limestone’ is allocated to the Leete Limestone and Loggerheads formations.

The Pant Formation consists of mudstone, siltstone and sandstone deposited as alluvial and lagoonal sediments along a platform margin. It lies with angular unconformity on the ‘Allt-Tair-Ffyonnon Formation’ of Caradoc (Ordovician) age. In the banks of a lane extending north westwards from Llanymynech village towards ‘The Hill’ [SJ265213], Wedd recorded ‘… about 250 ft. of indurated olive-grey sandy shales with shaly sandstones and mudstones; they contain a few brachiopods’ (Wedd *et al,* 1929, p52). Darwin almost certainly approached the working quarries via this lane as his notes record his first outcrop measurements of dip and strike in the banks of a lane (Fig. 11).

The Pant Formation is overlain, with gradational contact, by the Loggerhead Limestone Formation, which largely consists of massive, thickly bedded, pale grey shelly, limestone; this represents peritidal, shoaling-upward cycles that are commonly capped by palaeokarstic surfaces with calcretes. Intraformational thin bentonitic clay seams correspond to subaerially-deposited, distal volcanic ash falls. These are likely to be the sedimentary features discussed by Roberts.

Figure 11*. The steeply dipping Ordovician mudstone exposed in the road cutting on the west side below Pen-y-Foel (Pen-y-fron) Hall [SJ26552129]; the inset shows the plaque fixed to an adjacent outcrop. Scale in centimetres.*

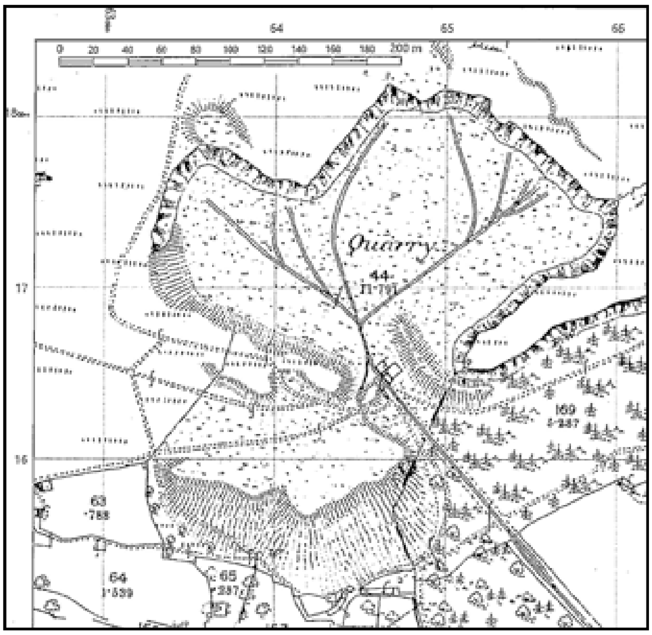

Figure 12*. Ordnance Survey map of the Welsh Quarry (Chirk Castle Estate) at Llanymynech Hill, published in 1874 at 1:2500 scale. The top of the cable-worked incline is at the drum house (square outline). Tramways (two-foot gauge) within the quarry lead to the incline top. The large flat-topped tip of waste material below the main working floor, south of the quarry entrance, is visible in the landscape today.*

History of quarrying

Underground mining of metalliferous lodes within the limestones commenced in the Bronze Age and was continued by the Romans. The ores contained copper in chalcopyrite and minor malachite, with subsidiary galena and zinc. Mining was reactivated in the mid-18th century and continued for about a century, latterly on a small scale. Quarrying of limestone, primarily for making lime for agricultural purposes, ante-dated 1753, when it was reported that ‘a great number’ of limekilns were active. Land ownership of The Hill was divided by the north-south trending national boundary with the Chirk Castle Estate (Earl of Powys) owning the Welsh side and the Bridgman (later Lord Bradford) Estate the English side. Quarry operators leased their land from the estates. The Welsh quarry was probably the older of the two.

A branch of the Ellesmere Canal (Shropshire Union system) was extended southwards from Lower Frankton and reached Llanymynech in 1796 with the primary objective of tapping the limestone traffic potential. Just beyond Llanymynech, the new canal was linked to the Montgomery Canal in the following year and by 1821 had reached Newtown. Canal traffic also included the distribution of coal for the limekilns. The nearest coal resources were at the southern limits of the small Oswestry Coalfield, less than 4 km away. Initially these were worked from bellpits. Gronwen-Nant-y-caws Colliery [SJ282269], with a shaft 64m deep, was active in 1802 less than 5 km to the north and linked to the canal via a horse-drawn tramway. The advent of the railway at Llanymynech in 1862 led to a drastic reduction in canal traffic (Hadfield, 1966).

A major operational problem was that the quarry floor lay 80m above the level of the canal and c.700m distant from it. This was solved in 1806 by Davies, Cartwright and Jebb who were the quarry lessors. From the edge of the Welsh Quarry, a double-tracked, self-acting incline was built and fed into a tramway to a new wharf on the canal (Fig. 12). This replaced horse-and-cart transport. A similar incline from the English Quarry to the canal was built about 1810, and ultimately this became the main route out of both quarries until closure in 1914. From 1827 the western quarry had become part of the Ruthin Castle Estate and in that year the Ruabon based company 'Exuperius Pickering and Co' held the lease. The latter company was probably working the quarry when Darwin visited it (Jones, 2004).

Genesis of the 'great cracks'

The current quarry geomorphology relates to abandonment c.1920. Comparison of Ordnance Survey maps shows that between c.1870 and 1920 the main face retreated between 0 and 60 m. As it is now impossible to examine the exposures that Darwin saw, accounting for the 'giant cracks' must be speculative. However, processes related to the Quaternary geology rather than those of the Carboniferous could hold the key to the crack conundrum. Three principal hypotheses appear worthy of consideration.

Hypothesis 1. Karst terrain is developed within the limestones. Fissures and cavities are formed where percolating rain water is concentrated along structural discontinuities such as joints, lithological boundaries and bedding planes. At Llanymynech, the south facing wall of the Welsh quarry exposes a dissolution feature, infilled with fine red sediment, that would be analogous to a 'great crack'. It trends oblique to the plane of the face, is about a metre across and exposed over 7m of depth, and possibly exploits a minor fault (Fig. 13). High in the quarry face, it is not readily accessible.

Hypothesis 2. The Llanymynech area was glaciated many times during the Quaternary, most recently during the Devensian Last Glacial Maximum c.20 ka BP when much of Shropshire was glaciated. During this event, ice flows from Welsh sources were dominant in the region, and in the Tanant Valley, immediately west of 'The Hill', ice flowed generally from west to east. Striations on a keratophyre (soda trachyte) intrusion trend between 075° and 125° west of Blodwell Hall farm [SJ262227] (Wedd *et al,* 1929). Hence the basal Welsh ice was deflected around The Hill, with the southern slope of the limestone cuesta subjected to intense erosion. After deglaciation, this slope would have been de-stressed, causing dilation joints to develop. A comparable glaciated limestone escarpment at Griersville Rock in Ontario, Canada, has exposures revealing deep, in-filled, dilation cracks (Straw, 1966).

Hypothesis 3. A hillside formed of a succession of incompetent clay or shale overlain by competent limestone or sandstone may be subject to instability, especially in a periglacial environment. Fluvial erosion of the incompetent beds, forming the lower slopes and valley floor, frequently induces movement towards the valley of the overlying competent rock, in the process of cambering. The cutting walls of the Cirencester by-pass (A419) expose competent White Limestone that is fractured and dipping valley-ward where it overlies Liassic shale (Worsley, 2004). The strike of the fractures are parallel with the contour and taper with depth. Normally they are infilled by superficial sediments, and are known as gulls. At Llanymynech, the appropriate combination of strong and weak beds occurs with the Leete Limestone overlying the Pant Formations, so gull development is highly probable. Potentially, gulls were exposed in 1831 when the quarry face was closer to the former natural hillslope. If so, in section they would have appeared as deep wedge-shaped cracks with unlithified infillings derived from materials upslope. Due to the advance of the quarry face, any cracks present close to the former hillslope, would have since been destroyed.

As the 'great cracks' observed by Darwin no longer exist, these proposed hypotheses of formation cannot be tested against field evidence. Hypotheses 2 and 3 are potentially related, with each possibly contributing to 'great crack' formation in the outer parts of the south-facing slope. However, it is suggested that all the hypotheses are realistic and provide satisfactory mechanisms for crack genesis. Most importantly, they eliminate the need to question the accuracy of Darwin's observations.

***Figure 13**. The karstic fissure at SJ655185, infilled with unconsolidated sediment, just below the top of the south-facing wall of the Welsh Quarry. This is some 50m north of the working face shown in Figure 12.*

Implications for Darwin as a geologist

The period January to August 1831, immediately before the offer of a place on H.M.S. *Beagle's* projected surveying voyage, was significant because it allowed Darwin to develop his geological skills that were to be vital during the next five years when working as a field geologist and naturalist. If he had not had to meet the residential rules for graduation by remaining at Christ's College for a further two terms, he would have missed the stimulating tuition given by John Stevens Henslow. Further, there would not have been the personal contacts that led to him accompanying Adam Sedgwick on his field research in North Wales. It follows that the incentive to (a) purchase his own compass-clinometer, and (b) commence original geological fieldwork in Shropshire may not have occurred. Rather he would probably have given priority to field sports, as was his custom, and pursued his friendship with Fanny Owen of Woodhouse Hall. After a leisurely summer he would have returned to Cambridge to commence theological studies, leading to ordination in the Church of England and assignment to a country parish in the footsteps of William Darwin Fox. Undoubtedly his natural history interests would have flourished, but whether geology would have featured in these is uncertain. However, this scenario did not happen and at his first land-fall from H.M.S. *Beagle* in the Cape Verde Islands, he was able to tackle the unknown geology of Quail Island, as a fast-learning and increasingly competent geologist.

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