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Front cover picture: Storeton South Quarry, Wirral, Merseyside. Picture taken by E. Newell in October 1886 with G.H. Morton pointing out the footprint bed. Photograph is from the H.C. Beasley archive. Archive held by National Museums Liverpool.

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Editorial

Many thanks for all the interesting articles received covering such a broad range of geological subjects of both local and regional interest. Some are new topics from authors who have not written for North West Geologist before whilst others are continuing articles which have appeared in several instalments. These are proving very popular. I am particularly grateful for the contacts in other societies and would especially like to thank Fred Owen from the MGA as this is the last issue for which he is the MGA contact. I would also like to welcome Christine Arkwright who will be taking over the post. We already have a few articles for the next issue, but I would like to renew the request for a suitable photographic image for the front cover. Please keep sending articles and images. I have also received some details of other interesting geological papers which appeared in other publications, including a paper on William Smith's mining report on the Tarbock Coalfield on Merseyside - written by Iain Williamson and published by the Northern Mine Research Society, indicating that research interest in geology is not only scientific but also historical.

Wendy Simkiss

Notes for Authors

Articles and suggestions for future issues are most welcome and should be sent to either Chris Hunt, Department of Earth Sciences, The University, Liverpool L69 2BX or Wendy Simkiss, Earth Sciences, World Museum Liverpool, William Brown Street, Liverpool, L3 8EN,
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Articles should preferably be emailed, or if very large files, be presented on disk in MS Word. They may be up to 3,000 words in length. Figures should be designed for reduction to fit a maximum frame size of 180 mm by 125 mm.

Cover pictures can either be photographs or digital images and must include the name of the photographer or owner, the society to which they belong and information about the image including the location. The cover picture will be around 92 mm by 72 mm and, if sent as a digital image must be at least 300 dpi.

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LOCKEIA, PELECYPODICHNUS, ESCAPE STRUCTURES AND A TRACE FOSSIL 'COVER UP'

By Stephen K. Donovan

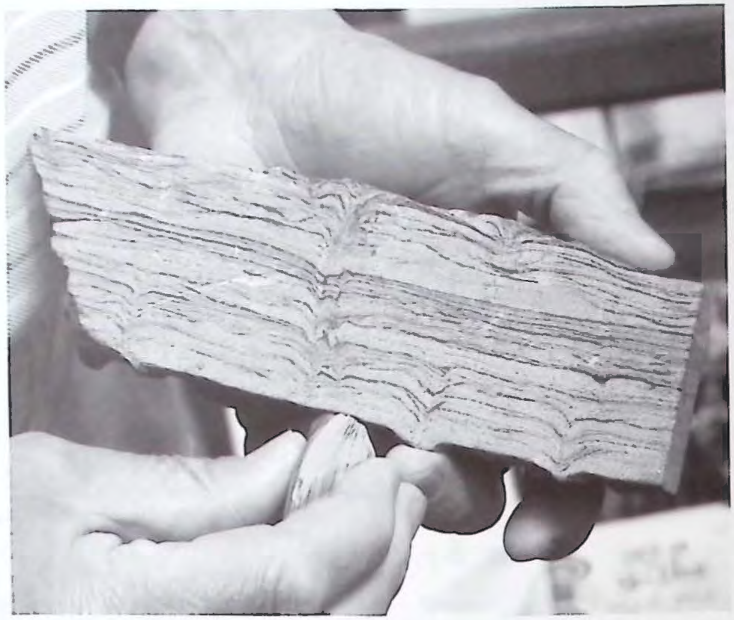
Trace fossils are a great fascination for geologists of all persuasions and have considerable value in studies of, for example, palaeoecology, but their classification can cause some confusion. Consider, for example, the cover of *The North West Geologist* no. 13 (Rankilor, 2006). It was delightful to see such a fine group of escape structures in laminated sandstone, but things went awry in the caption. 'Pelecypod ichnus' should have been one word and italicised, being an ichnogeneric name erected by Seilacher (1953). To be more accurate, *Pelecypodichnus* isp. would indicate that it is an ichnospecies of *Pelecypodichnus* left in open nomenclature (following Bromley, 1996, page 162).

But even that fine tuning could be improved upon, for *Pelecypodichnus* (Seilacher 1953) is, in fact, a junior synonym of *Lockeia* (James1879) (see Häntzschel, 1975, page W79 and Pickerill, 1994, page 20). In particular, Maples & West (1989) discussed this synonymy in great detail and firmly demonstrated that, whatever the beauty of the name *Pelecypodichnus* for trace fossils that we commonly consider to be formed by infaunal bivalve molluscs, known as pelecypods, is the wrong one to use.

Yet it is even questionable on morphological grounds whether *Lockeia* is the correct name for the structures figured on the cover of *The North West Geologist*. Häntzschel (1975, page W79) diagnosed this ichnogenus as follows:

> "Small almond-shaped oblong bodies preserved in convex hyporelief ['on the under surface of psammitic beds;' page W20]; tapering to sharp and obtuse points at both ends; surface commonly smooth; mostly symmetrical; length varying from 2 to 12 mm" (also see Seilacher, 1953, page 105).

The specimens illustrated by Rankilor (2006) appear to be escape structures seen in section, with a morphology typical of those known to be formed by infaunal bivalves and, perhaps, certain other invertebrates, but *Lockeia* refers only to "Almond-shaped, convex hyporeliefs" (Maples & West, 1989, page 695). It is defined as a structure seen on bedding planes. Similar traces may be related to the vertical burrow *Monocraterion* (Torrell1870) (see Crimes *et al.*, 1977, figure 7) or may even have an inorganic origin such as water escape structures outlined by R.K. Pickerill (in written communication, July 2007). Therefore, the structures figured so beautifully by Rankilor (2006) should more correctly be referred to as 'Probable escape structures, possibly produced by bivalve molluscs, seen in section perpendicular to bedding.'



Probable escape structures, possibly produced by bivalve molluscs, seen in section perpendicular bedding. Photographed by Dr Peter Rankilor, displayed by and property of Mr Fred Owen, Manchester Geological Association.

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The encyclopaedic knowledge for the literature of trace fossils of Professor Ron K. Pickerill (University of New Brunswick, Canada) gave me title and authorship of some of the principal references used in this note. His comments on an early draft were most supportive.

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CHIROTHERIUM AND THE QUARRYMEN

By Geoff Tresise

The hand-like footprints known as *Chirotherium* ('Hand Animal' in Greek) appear on the cover of '*The North West Geologist*'. When they were first discovered in the 1830s, they aroused great interest since the Triassic sandstones in which they were found contained no skeletal remains of the animals that had left them. For more than a century, *Chirotherium*'s identity remained a mystery but the prints are now believed to be those of thecodonts – an extinct group of reptiles which were the ancestors of both crocodiles and dinosaurs. These footprints were first found in Germany in 1833 and were described and illustrated by William Buckland of Oxford University in 1836. Two years later he would be shown similar footprints in the sandstone quarry on Storeton Hill near the village of Higher Bebington on the Wirral.

Credit for identifying the Storeton footprints must go to John Cunningham, a Scottish-born architect who was a member of the Liverpool Natural History Society. In a letter to Richard Owen, written 20 years later, he described what happened:

> "In the spring of 1838 I went across to Storeton Quarry to select some blocks of stone... I pointed out to the Foreman several beds or seams of clay between the strata and requested when he lifted the strata reposing on the clay beds he would examine the under surfaces of the slabs that rested on the clay beds and if he found any impressions of vegetables or animals he would immediately communicate to me the circumstance. In the course of 10 or 12 days after I had made the request he sent a person over to my office in hot haste with the intelligence that he had found the impressions of 'a man's hands and knees'. I of course lost no time in getting over to the Quarry and was much gratified with the spectacle presented by the slab which I saw at once were the impressions of the animal called by Professor Kaup the cheirotherium similar to those found at Hilburghausen."

Realising the importance of the discovery, Cunningham persuaded the quarry owner, John Tomkinson, to donate the finest slab to the Liverpool Natural History Society. It was put on display in the Liverpool Royal Institution where the Society held their meetings.

By July 1838 the working floor at Storeton Quarry had reached a second footprint-bearing bed, 2 feet [0.6 metres] below the first. *Chirotherium* prints were few at this lower level which instead showed a mass of smaller footprints of many different kinds. Three slabs from this lower footprint bed were also acquired for the Royal Institution Museum.

The following month, a lecture on the footprints was given to the Liverpool Mechanics Institute by Robert Grant, Professor of Zoology at University College, London. Storeton Quarry was also visited by William Buckland who was en route to the British Association for the Advancement of Science meeting in Newcastle on Tyne, where he reported the find. He persuaded Cunningham to write a paper on the prints which Buckland read to the Geological Society of London in December 1838.

Meanwhile the Liverpool Natural History Society had produced a set of four lithographs of the Storeton finds, together with two plaster casts, one showing the trackway then in the Royal Institution Museum and the other a selection of the small footprints from the lower bed. Thirty sets of these casts and lithographs were presented to museums and scientific societies.

The Liverpool Natural History Society rightly claimed credit for so astutely publicising the Storeton finds. However, contemporary accounts and correspondence make it clear that the Storeton workforce, along with the site foreman and quarry owners, also played a significant role in determining which specimens survived and which did not.

Cunningham, in his 1858 letter to Richard Owen gave no hint of this although he would later admit that:

> "The Storeton footprints had been exposed to the gaze of the quarrymen for 15 or 20 years before he gave publicity to them."

Francis Archer, the President of the Liverpool Natural History Society, confirmed this in his own account of the discovery:

> [Mr Cunningham]"being in the neighbourhood of Storeton happened to hear that there had been blocks of stone turned up in the quarry with the impressions of men's hands upon them; these had been ascribed in the simplicity of the workmen, to some antediluvian members of our race who, attempting to escape from the influx of the waters, had thus left their track upon the rock, the smaller marks being ascribed to the hands of children. Mr Cunningham immediately visited the spot... and gave such directions as secured the specimens from mutilation. Had it not been for his activity, the probability is, that these slabs would have shared the fate of many others which had been previously raised, and which were afterwards found built up in the stone fences of the neighbourhood."

However, the most crucial evidence came from Robert Grant in his lecture of August 1838:

> "In Storeton Quarry there are two distinct strata of these footmarks, about 2 feet [c. 0.6 metres] from each other, and the workmen believe that there is a third stratum of the same impressions a very little lower in the rock; but I have been able to examine only the two upper strata of these remarkable impressions."

Other authors followed Grant in regarding the existence of a third footprint bed as unproven and the literature refers only to an "upper" and a "lower" footprint bed. It was not until Liverpool Geological Society member Henry Beasley began his detailed investigations of the Storeton quarries at the end of the nineteenth century that it was confirmed that there was indeed a third footprint bed some 10 inches (0.25 metres) below the "lower" bed, just as the quarrymen had claimed.

It is clear from Grant's account that the quarrymen had not just noticed the footprints and explained them to their own satisfaction, but had pinpointed the levels at which they were found. The probability is, therefore, that when he visited the quarry in the spring of 1838, Cunningham (in Archer's words) "happened to hear" from the quarrymen of these strange relics of Noah's flood and was also told that the current working floor was now very close to the levels at which they were found. Hence his request to George Forrester, the quarry foreman, to "examine the under surfaces of the slabs that rested on the clay beds", far from being the inspired guesswork that his 1858 letter to Richard Owen seems to suggest, would have been based on the precise information which the quarrymen had given him. It is fitting therefore that, at their meeting of 3rd July 1838, the Liverpool Natural History Society agreed that:

> "Twenty shillings be placed at [John Cunningham's] disposal to distribute among the workmen of the quarry".

The minutes of this meeting also report that:

> "The proprietor of the quarry had presented the Society with the most perfect of the slabs, and had offered to place it free of charge in the museum of the Royal Institution".

In fact, John Tomkinson brought to Liverpool not just the slab he had promised to the Royal Institution Museum but at least three other slabs from the upper footprint bed. He was in partnership with his brother William, and the head office of their business was in Liverpool. It may be that the brothers felt that displaying some of the Storeton slabs in their office would help publicise the firm and bring in new business. Whatever the reasons, it was to prove a most fortunate action.

For several months after Buckland's August visit to the Storeton quarry, he and Cunningham were in regular correspondence. It is clear from Cunningham's letters that John Tomkinson had agreed to present footprint-bearing slabs to both the British Museum and Oxford University. It also appears that, when Buckland reported the discovery to the British Association for the Advancement of Science meeting in Newcastle, a number of Association members expressed an interest in acquiring specimens. However, when Cunningham was informed of this, his reply of 5th September 1838 was not overly optimistic:

> "I will if possible procure for the Societies and Museums you mention slabs containing footmarks... but Mr Tomkinson has of late become so very careful of them that I am afraid they will be obtained with considerable difficulty."

However, there was to be a more serious problem than Tomkinson's reluctance to part with the slabs. Following Robert Grant's lecture, visitors were coming to the quarry in search of souvenirs and the foreman, no doubt in exchange for a coin or two, was happy to accommodate them. In the weeks that followed, Cunningham's letters to Buckland and to Charles Konig, who had charge of the geological collections at the British Museum, show his increasing concern. Eventually, on 16 November, he was forced to tell Buckland that the promised slabs would not be forthcoming:

> "The cause is simply this: Mr Tomkinson would neither allow them to be taken from the quarry, nor would he bring them himself... You can easily conceive my consternation and anger when I beheld them broken in pieces after the precautions I had taken to preserve them whole."

Over the next week, Cunningham must have brought all the moral pressure at his command on John Tomkinson. It is not difficult to imagine the thrust of his argument: Cunningham had, with Tomkinson's consent, promised footprint slabs to Buckland and Konig, but all the slabs from the lower footprint bed left in the quarry were now broken up and useless. However the slabs from the upper bed which Tomkinson had brought to Liverpool in July remained intact.

Figure 1. Natural History Museum specimen R729 showing the trackway of *Chirotherium storetonense* crossed by that of *Chirotherium sickleri*, from the upper footprint bed at Storeton.

Whatever arguments Cunningham used, they were successful and on 26th November he was able to write to Buckland with better news:

> "Mr Tomkinson has at length come to the magnanimous resolution of allowing me to fulfil my promise to you but not with the slabs from the bed you wished. The slab I have selected is one of the originals which contain the most distinct impressions of any yet obtained. The others being all broken in pieces, I had no alternative left. I trust, however, that you will be pleased with it. Another of the originals will be forwarded this week to the British Museum."

In the end, despite Cunningham's fears, things had worked out well and it is gratifying to note that both slabs are currently on display – Buckland's is in the Oxford University Museum while the British Museum slab can be seen in the centre court of London's Natural History Museum alongside the *Diplodocus* skeleton.

After the slabs had been sent to Oxford University and the British Museum, one of the slabs depicted in the Liverpool Natural History Society lithographs still remained in the Tomkinson brothers' possession. In 1842, at John Cunningham's instigation, this slab was presented to the Royal Geological Society of Cornwall. At this time, Triassic footprints were again in the news, thanks to a new discovery at Lymm, a mile or so east of Warrington. Unfortunately the Cornish society, mislead by this, recorded their Storeton slab as having been "found near Warrington". It was not until 1989 that its true place of origin was recognised.

Figure 2. Oxford University specimen G55 showing the trackway of *Chirotherium storetonense* from the upper footprint bed at Storeton.

Figure 3. Royal Geological Society of Cornwall slab showing *Chirotherium* prints from the upper footprint bed at Storeton.

Figure 4. Sedgwick Museum slab showing trackway of *Chirotherium storetonense* from the upper footprint bed at Storeton.

There is one further slab that certainly came from the upper footprint bed at Storeton. It is on display in the Sedgwick Museum of Cambridge University but there is no record of how or when it reached the museum. This too may be an 1838 specimen. Grant, in his lecture to the Mechanics Institute, noted:

> "The workmen have traced these large footprints in a continuous single line, produced by the walking of one animal, for 20 or 30 feet [6 or 9 metres] over the surface of the rock."

It is possible that John Tomkinson brought *five* slabs from this six metre trackway to Liverpool. Of four we can be sure since they were figured in the Liverpool Natural History Society lithographs but there could also have been an unillustrated fifth slab which Tomkinson later presented to the Woodwardian Museum (as the Sedgwick was then known).

However, it is also possible that the slab was excavated at a later date. By the middle of the 19th century, the huge North Quarry was the main commercial supplier of Storeton stone although operations still continued in the older South Quarry on a smaller scale. In 1860, J.H. Mitchener described his visit to Storeton to the newly-formed Geologists' Association. It was in the South Quarry that:

> "Capital casts of [footprint] impressions are found, which find their way into the various museums of the country. By far the best specimen the writer has yet met with might some little time since have been seen on the top of a pig-sty belonging to one of the workmen. No geologist that visited Storeton Quarry but was dragged up its steep and rugged sides to view this unique scientific gem on its inelegant setting."

Even if it was not the Sedgwick slab itself which once roofed a pig sty, it is clear from Mitchener's account that footprint slabs were still being raised from the South Quarry in the middle of the 19th century, and that these might "find their way into the various museums of the country".

Contemporary accounts record that ten specimens were collected from Storeton in 1838. The four slabs from the upper footprint bed figured in the Liverpool Natural History Society lithographs are now in museum collections in Southport, London, Oxford and Penzance. Two of the three slabs from the lower footprint bed obtained in July 1838 are also in the care of Sefton Museum Service at Southport along with fragments of the third, broken while on display in the now-closed Bootle Museum. Three more specimens were obtained for the Royal Institution Museum in September 1838; two of these are now held by the National Museums Liverpool, but the fate of the third is unknown.

Figure 5. Bootle Museum slab number 10 showing the trackway of *Chirotherium storetonense* from the upper footprint bed at Storeton.

Figure 6. Bootle Museum slab number 9 showing small footprints from the lower footprint bed at Storeton.

Eight of the ten 1838 specimens thus survive intact, along with part of a ninth; only one appears to have been lost. Credit for their rescue and preservation is largely due to John Cunningham and the Liverpool Natural History Society, but this is not the whole story. If Cunningham had not "happened to hear" the quarry workers' tales of the victims of Noah's Flood, the 1838 discoveries might have gone unnoticed by the scientific community. Following their recognition, it was the quarry owner who decided to bring to Liverpool the slabs he would later present to four (or possibly five) museums. Even the quarry foreman could be said to have played a positive role, despite allowing casual visitors to break up the trackway slabs at Storeton. Because all available slabs for the lower footprint bed had been destroyed in this way, the slabs sent to the British Museum and Oxford University came from the upper bed with its more spectacular trackway. For good or ill, the quarry workforce played an important part in the rescue operation and, on balance it was overwhelmingly for good. More than a century and a half later, recognition of their role is long overdue.

Acknowledgements. An extended version of this paper was published in ICHNOS (vol. 10, pp. 77-90) in 2003, abridged here by permission of the editor. For details of the sources of the material quoted, please refer to the ICHNOS article.

Figures 3 and **6** are from the Beasley photographic archive owned by the Liverpool Geological Society but in the care of National Museums Liverpool. The other illustrations are under copyright and are reproduced by permission of the institutions listed: **Figure 5** National Museums Liverpool; **Figure 2** Oxford University Museum; **Figure 1** Natural History Museum, London; **Figure 4** Sedgwick Museum, Cambridge University.

THE STORY OF LIVERPOOL SPA – ITS HISTORY AND HYDROGEOLOGY

By John D. Mather

Towards the southern end of Hope Street, in Liverpool, wonderful views of the Anglican Cathedral open up to the west. Between the street and cathedral lies the long disused St. James' Cemetery which occupies the site of an old and extensive freestone quarry (Wedd et al, 1923). In the eighteenth century this belonged to Liverpool Corporation and supplied the stone for many of the city's public buildings and elegant houses as well as material for the construction and repair of the docks.

Waste from the quarry formed a spoil heap to the west which was known as Quarry Hill or Mount Sion. In 1767 a terrace was formed using this waste

> "....when the poor people, in a season of great scarcity and a severe winter, were employed in making it" (Brooke, 1853 p145).

By 1773 this terrace was described as

> "A noble and extensive gravel walk, interspersed with clumps of trees" commanding "a most delightful prospect of the town and its harbour" (Worthington, 1773 p9).

The walk was known as St. James' Walk (Enfield, 1773) and Quarry Hill as St. James' Mount, perhaps because of an association with the construction of St. James' Church, opened in 1775 on Upper Parliament Street to the south. Much of St. James' Mount is now occupied by the Anglican Cathedral of Christ in Liverpool, the foundation stone for which was laid in 1904.

By the early nineteenth century the usable stone in the quarry was exhausted and the Corporation decided to use the quarry as a cemetery. The long eastern face was remodelled into a series of benches, lined with catacombs cut into the rock face and the floor was laid out with trees and winding paths. The cemetery was in use for some 100 years with the last burials in the 1930s. Over the following years it fell into disrepair, and became overgrown, until in 1968 most of the gravestones were moved and the grounds were laid out as a garden. St. James' Cemetery Gardens were opened in their present form in 1972 and are now a valuable green space near the city centre. Entry at the northern end is via a tunnel, close to the north end of the Cathedral, which was probably excavated originally to access this end of the quarry in the eighteenth century.

In the eastern wall of the old quarry, below Hope Street and close to the Huskisson Mausoleum standing towards the centre of the Gardens, a small stream of water issues from the rock face. This was once known as the Liverpool Spa and achieved brief fame in the 1770s for its "chalybeate" waters, containing iron salts. The area around the spring has been renovated by the Friends of St. James' Gardens and water now emerges from a 2.5 cm diameter hole into a pool the sides of which are formed by old gravestones (**Figure 1**). This paper charts the history of the spa and examines the source and chemistry of the mineral water.

Figure 1. The present mineral spring in St. James' Cemetery Gardens.

The early years of the spa

The presence of a mineral spring in the quarries of this area of Liverpool is recorded by the Sheffield physician Thomas Short who made several journeys to visit such springs in the midlands and north of England in the middle of the eighteenth century. He comments that

> "At the top of Quarryhills, on the South end of Liverpool, from the bottom of a Stone Delph [Quarry], ouzes out off a very hard coarse freestone, an exceeding slow spring of slight chalybeate" (Short, 1740 p38).

Hembry (1990) suggests that Bath interests may have encouraged the development of a spa at Liverpool. The Bath builders/architects, Messrs Wood, directed the building of the New Exchange using stone from the quarry and Samuel Derrick, who became master of ceremonies at Bath, visited the city in August 1760. However his three letters written from Liverpool make no mention of visiting a mineral spring (Derrick, 1767).

The mineral water begins to be designated as a spa, or spaw, in published accounts dating from 1773 (Enfield, 1773, Worthington, 1773; Houlston 1773). Enfield describes the quarry noting that

> "There is found here a good chalybeate water, which appears upon trial to be little inferior to many of the Spaws." (Enfield, 1773 p.65).

Both Worthington and Houlston wrote medical treatises publicising the merits of the water; Worthington's account anticipating Houlston's by a few months.

James Worthington was a Liverpool surgeon and carried out nine separate experiments on the water (Worthington, 1773) He described it as having a strongly ferruginous taste noting that it threw down an ochrous earth as it trickled over rocks away from its source (Worthington, 1773). He bemoaned the fact that there was no cover for those that frequented the spring or to

> "....shelter the fountain from the sun's influence, and the dilution of the water with the rain, which are consequences that ought ever to be avoided, as they both so manifestly injure the virtues of these kind of waters" (Worthington, 1773 p14).

He thought that spring or autumn were the best times to drink the water and that drinkers should begin with small doses leading up to three or four half pints, taken at half hour intervals, interspersed with gentle exercise. Before starting a course of the water he recommended

> "....that the patient should lose some blood and then open the body with any general laxative...." (Worthington, 1773 p26).

He noted that many people were drinking the water "in too considerable quantities and at improper hours" which had produced "disagreeable consequences", although what these were, is not stated!

Thomas Houlston was an eminent medical figure in Liverpool. Appointed one of the physicians at the Liverpool Infirmary in 1774 at the age of 29, he became interested in resuscitating persons apparently dead from drowning or hanging. After several failures he revived a drunken cow-keeper who had been taken out apparently dead from George's Dock and his next five cases were all successful. He also wrote on the prevention of death from excessive drinking (Bickerton, 1936). His essay on the spa water is more substantial than Worthington's pamphlet and includes an appendix on the accidental use of lead.

The spa spring was one of several in the quarry, used because it contained more iron than the other springs. At this time water trickled into an irregular basin, which held about four gallons, and to which a small iron ladle was attached. Houlston carried out 19 experiments on the spa water, reporting that:

> "It is naturally limpid [completely clear], tho' frequently found otherwise, owing to the ochre, which it deposits on the escape of the fixed air [carbon dioxide], and as it is exposed to the air and weather exhibits different appearances, and different proportions of mineral contents at different times. Its taste is at first cool and refreshing, afterwards austere and inky, and it does not lose the irony taste by long keeping in open vessels, though it soon deposits a quantity of ochre" (Houlston, 1773 p26).

Houlston recommended drinking the water when the stomach was empty, in the morning or an hour or two before dinner. The dose recommended was half a pint, or a pint, at the start, gradually increasing in some cases, to four or five pints a day. The summer season was considered best for drinking and he advised drinking it at the spring rather than at home.

If there were some years of prosperity for Liverpool Spa these certainly did not last long. William Moss in his *Medical Survey of Liverpool* dated 1784 records that the spring water was suspected of producing

> "....unfavourable and even fatal effects; which, if really the case, most probably happened from its too indiscriminate and injudicious use...." (Moss 1784 p71).

Perhaps because of this it had fallen into disrepute and was now totally neglected. If already weak and sickly patients followed some of the recommendations given for taking the waters, i.e. loss of blood, use of a general laxative followed by four or five pints of iron-rich water, it is perhaps not surprising that fatalities occurred!

Years of neglect

Over the next 200 years the spring continued to flow and, although no longer recommended by the medical profession, was probably still used by local people. According to Brooke (1853) the original spring was lost when part of the rock face in the quarry was cut away but was replaced by another close by. This new spring was incorporated into the design when the cemetery was laid out in the quarry in 1825. On the lower level of the cemetery there are five large arches and the middle and grandest of these is centred on the spring (**Figure 2**).

In the 19th Century about a dozen workers were active in researching the hydrogeology of the Permo-Triassic sandstones which underlie Liverpool (Tellam, 2004) but there seems to have been little interest in Liverpool Spa. The Honorary Secretary of the *Liverpool Geological Association*, Mr D. Clague, visited the cemetery in 1887 on a field excursion with his students and took a sample of the water. The results of the analysis were reported by Tate (1889) and are reproduced in **Table 1**.

Figure 2. Looking across the old quarry from the eastern side of the Cathedral showing the spring occupying the central arch.

Source	Tate	Jones	Estimate
Date	1889	1924	1773
Species			
Ca	123	153	80-100
Mg	52	63	30-50
Na	59	30	20-100
K	9		4-5
HCO_3	224	242	350-550
Cl	57	64	20-40
SO_4	288	323	5-30
NO_3	15	13	0
SiO_2	2	5	10-12
Fe			1-5

Table 1. Analyses of samples from the mineral spring in St. James' Cemetery Gardens and an estimate of the original composition of the water of Liverpool Spa. Concentrations in mg/l.

George Highfield Morton, a founder member of the *Liverpool Geological Society*, mentioned the mineral spring and Houlston's pamphlet in the second edition of his memoir on the geology of the country around Liverpool (Morton, 1891). However, he gave no description remarking merely that the supply to the spring had nearly ceased.

Little attention was paid to the spring during the 20^{th} Century. Ramsay Muir in his *History of Liverpool* (Muir, 1907) makes no mention of the one time existence of a spa at Liverpool. Likewise the *Geological Survey Memoir* (Wedd et al, 1923) does not refer to the spa or to a mineral spring in St. James' Cemetery, although the geological sections in the old quarry faces are described. However, on 1st August 1924 a report appeared in a Liverpool newspaper on the mineral spring and the subject was taken up by local historian R. Saunders Jones (Jones, 1924). He visited the spring and took a sample of water which was analysed in September 1924. The results are presented in **Table 1**. At this time water issued from a pipe, as a small jet, into a pool enclosed by a semi-circular iron railing and the spring had a very dilapidated appearance. According to Jones the water

> ".... had a reputation all over Lancashire and Cheshire for curing inflammation and weakness of the eyes: and on my recent visits to the spring, several people were also drawing water" (Jones, 1924 p22).

At the back of the spring, attached to the rock face, there was a tablet with an almost obliterated inscription which is reproduced in **Table 2**.

By the end of the 20th Century the spring was sadly neglected, the iron railing was long gone and litter was strewn around the spring pool.

After Jones (1924)	Present inscription
Christian Readers, see in Me	Christian reader view in me
An emblem of True Charity,	An emblem of true charity,
Who, truly, what I have Bestow	Who freely what I have bestow
From beneath as seen to flow,	Though neither heard nor seen to flow,
Will have to look to Heaven	And I have full return from heaven
For every cup of Water given.	For every cup of water given.

Table 2. Inscription on the sandstone tablet above the spring as recorded today and in 1924.

Fortunately the formation of the Friends of St. James' Gardens early in the present century has led to increasing interest in the enhancement and use of the old cemetery. The spring has been one of the first features to benefit, broken stones have been replaced, litter removed and information on the spring included on the Friends website. On a visit in July 2007 the spring was readily located flowing into a shallow pool (**Figure 1**). As described by Jones (1924) an inscribed tablet, made of sandstone, was fixed to the rock face above the spring. However, the inscription differs from that which he recorded in 1924 (**Table 2**). Either he incorrectly transcribed the verse, or it was subsequently modified when the tablet was replaced during the intervening 80 years.

Hydrogeology

The mineral spring emerges from sandstones which underlie thinly-bedded shales. According to Wedd et al (1923), in the old quarry there is a sharp line of demarcation between these two units but at the spring site the contact has been covered by brickwork and is not exposed (**Figure 1**). The sandstones are well sorted, coarsely-bedded and unfossiliferous. There are large cross-bedded units which have been interpreted as indicating deposition as sandbars within a seasonal river system in a semi-arid setting (Howard et al, 2007). These rocks were known formerly as the Keuper Basement Beds but modern mapping assigns them to the Helsby Sandstone Formation at the top of the Triassic Sherwood Sandstone Group (Howard et al, 2007).

The overlying shales consist of red, grey and yellow interbedded mudstones, siltstones and fine-grained sandstones (**Figure 3**). They are highly micaceous and their old name, Keuper Waterstones, originated because of the shiny white mica which gave bedding planes a watery sheen. They are now assigned to the lowermost beds of the Mercia Mudstone Group. Designated as the Tarporley Siltstone Formation they were formed in an estuarine or lacustrine setting subject to periodic desiccation and sheet floods (Howard et al, 2007). The rocks in the quarry dip towards the east at an angle of 10° and over much of the old quarry the Tarporley Siltstones would have been stripped off to expose the underlying sandstones. It would have been this waste material which formed the bulk of the original Quarry Hill in the 18^{th} century.

Figure 3. The Tarporley Siltstones exposed above the spring (Photograph by Jane MacDougall).

A cross section (**Figure 4**) from the Cathedral in the west to Hope Street in the east, based on the recently published British Geological Survey Map Sheet 96, shows that the Tarporley Siltstones crop out on the western downthrown side of a north-south trending fault which runs along the eastern side of Hope Street. Sandstones are again mapped to the east of the fault such that the siltstones form a narrow wedge parallel to the fault.

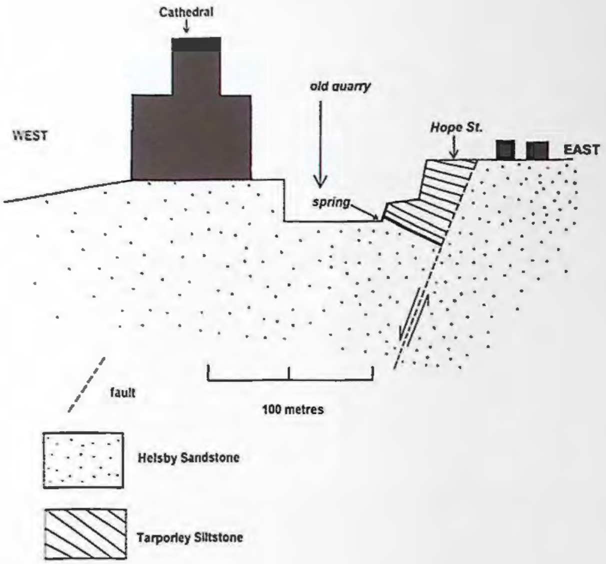

Figure 4. East-west cross-section through the old quarry showing the position of the spring.

The sandstones of the Sherwood Sandstone Group form the principal aquifer of the Liverpool area. The Helsby Sandstone, exposed at the site of the mineral spring, is the most strongly cemented and forms the best building stone. However, the cement means that intergranular porosity is reduced and fractures tend to be regularly distributed, leading to comparatively low formation permeabilities. In addition, recent research suggests that movement of groundwater across faults in the area is substantially reduced by fault plane infill (Seymour et al, 2006) and the Tarporley Siltstones are likely to restrict recharge to the underlying sandstones immediately to the east of the quarry. Thus, although from first principles groundwater movement at the main water table beneath the quarry might be expected to be westwards towards the River Mersey, the distribution of faults and tunnels and outcrops of the Tarporley Siltstones mean that local variations are likely to occur.

The chemical analyses given in **Table 1** have been recalculated from the hypothetical mixture of salts given in the published analyses. The methodology employed is outlined by Lloyd and Heathcote (1985). The analyses are very similar, particularly considering techniques available to analysts at that time. The hydrochemistry is characterised by rather high concentrations of nitrate (NO_3), chloride (Cl) and sulphate (SO_4), suggesting pollution, and significant bicarbonate (HCO_3) concentrations, suggesting the dissolution of carbonate cement within the sandstones. A major study of the hydrochemistry of the Permo-Triassic Sandstone aquifer system in the Lower Mersey Basin, to the east of Liverpool, has been reported by Tellam (1994). Although sulphate concentrations are somewhat higher, the Liverpool Spa analyses lie within Tellam's water type 1B. This includes waters which have been recharged recently enough to be affected by urban pollutants, such as de-icing salts, sewage and industrial chemicals but which have been in contact with the sandstone for a period of time sufficient to achieve partial saturation with respect to calcite.

The samples were taken in the period during which the quarry was used as a cemetery and the old quarry faces were lined with catacombs cut into the rock face. The breakdown of cadavers within these underground galleries could also have contributed to the pollutant load as chlorides and sulphate concentrations up to several 100 mg/l have been reported from groundwater in close proximity to graves (Young et al, 1999). However, it is interesting that both Tate (1889) and Jones (1924) comment on the satisfactory organic purity of the spring and Tate (1889 p64) notes

> "....but perhaps the most noticeable feature is the very small amount of impurity from organic sources, notwithstanding that the spring is in a closely inhabited region".

Unfortunately the available water analyses are likely to be totally unrepresentative of the 18th century spa which was in use before the area became urbanised and groundwater affected by the pollution characteristic of later centuries. Contemporary descriptions of the spa water talk about its "irony taste" and the deposition of ochre when it was exposed to air (Houlston, 1773). Evaporation to dryness of a weak water, collected after heavy rain yielded 28 grains of solids in a gallon of the water, which is equivalent to a total dissolved solids concentration of around 400 mg/l of which eight grains (about 110mg/l) were ochre. There seems no doubt that the water was strongly impregnated with iron which could be observed

"..on the surface of the rock down which the water trickles from its source" (Worthington, 1773 p15).

In contrast the deposition of ochre close to the modern source is not mentioned by either Tate (1889) or Jones (1924) and there is no deposition of ochre at the spring today.

It is suggested that the original composition of the spa water was close in composition to water type 4 as designated by Tellam (1994). These are waters which are still largely confined beneath areas of glacial till, a situation comparable to that in the old quarry where groundwater in the sandstone was probably confined beneath the Tarporley Siltstones and lateral flow restricted by the fault to the east. Such waters would have been characterised by saturation with respect to the calcite forming the sandstone cement, low concentrations of chloride and sulphate, reduced nitrate and iron in solution. A probable compositional range for this original spa water is given in **Table 1** based on the work of Tellam (1994).

Conclusions

Liverpool Spa was the name given, somewhat pretentiously, to a chalybeate spring first noted around 1740 in an expanding stone quarry in what are now St. James' Cemetery Gardens. On the assumption that the original spring was close to that existing today, it discharged from the Helsby Sandstones just beneath their junction with the Tarporley Mudstones.

The spa water was probably derived from a fracture in the sandstones discharging into the quarry void. This was fed by slow recharge through the siltstones and/or lateral flow within perched water bodies in the sandstone above the main water table. Transit times were such as to yield a mature groundwater containing iron in solution but no hydrogen sulphide, which would have been recorded by early writers.

Continuing stone extraction destroyed the original spring which was replaced by another close by. Further quarrying, urbanisation, and the use of rock around the spring as an underground cemetery, changed the recharge pattern resulting in decreased flows and changes in water quality. The more recent analyses show a hard groundwater characteristic of those occurring in industrial and urban areas of the Permo-Triassic Sandstone which would have been unrecognisable to our 18th century forebears.

Acknowledgements

Many thanks to Hugh Torrens and Alan Bowden for their help with references, Jane MacDougall who visited the cemetery when the sun was shining and took photographs for me, Pat Johns who drew figure 4 and to John Tellam who first brought the existence of Liverpool Spa to my attention nearly 20 years ago.

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STRESSED AND SWEATY IN FUERTEVENTURA: SHALLOW LEVEL PARTIAL MELTING IN THE CONTACT AUREOLE OF A MAFIC PLUTON

By Duncan Woodcock

Abstract

Shallow level partial melting of alkaline mafic host rocks has occurred in the contact aureole of a mafic pluton within the Basal Complex of Fuerteventura, Canary Islands. The resulting migmatites are particularly well displayed in the Barranco de las Arenas, where they typically occur in patches of closely spaced millimetre scale leucocratic veins. The orientation of the veins was controlled by stresses generated during the emplacement of the pluton.

Introduction

The western upland area of Fuerteventura contains exposures of a "Basal Complex": rocks that pre-date the voluminous basaltic lavas that characterise the "shield building" phase of activity on the island. These Basal Complex rocks comprise Mesozoic turbidites of the original ocean floor together with rocks from the "seamount phase": pillow lavas, volcaniclastics, a basaltic dyke swarm and a number of mafic intrusions.

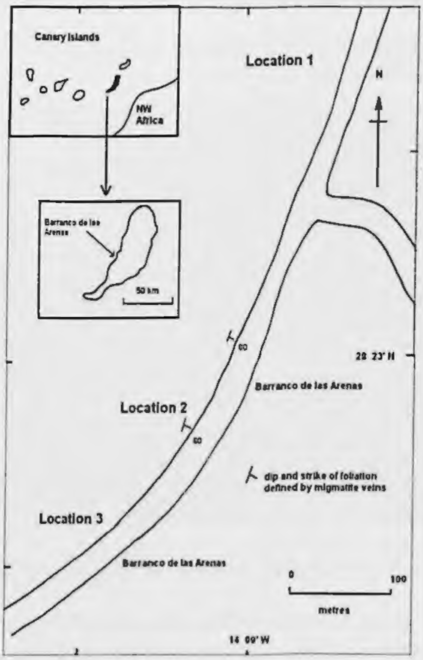

Figure 1. Edited field sheet for the Barranco de las Arenas area. Based on a GPS survey of 25 January 2007. GPS datum: Pico de las Nieves.

The mafic intrusions include some that were sufficiently hot when intruded to cause partial melting in the host rocks marginal to the intrusion. This note describes one location where partial melting has resulted in the development of leucocratic veining in the marginal hornfelsed alkaline basaltic rocks. This location is described briefly in a recent field guide to the geology of the Canary Islands (Carracedo & Day 2002) and in a paper by Hobson *et al* (1998).

Figure 2. Late stage basaltic dyke cutting migmatites Location 1 on Figure 1. Diameter of coin c.20mm.

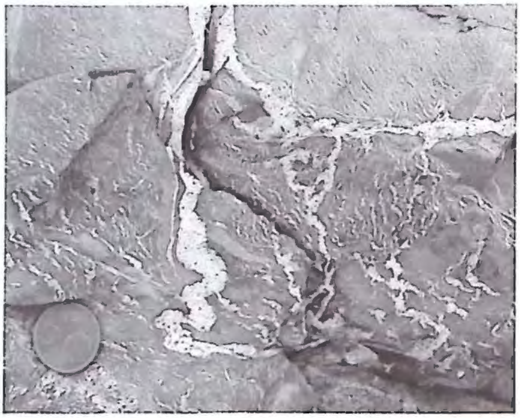

Figure 3. Irregular migmatite veins Location 2 field observations.

Figure 1 comprises a sketch map of the part of the Barranco de las Arenas that contains the field location. The barranco is a dry river valley that has been eroded by water from infrequent but intense rainstorms that occasionally sweep the island. The location lies around 1.5 kilometres south of the coastal village of Ajuy; it can be reached by walking south along the Barranco de Aulagar as far as a large earth dam and then by following the southern branch of the barranco for a further 500 metres.

The most northerly exposure of the migmatites is situated at **Location 1 (Figure 1)**, where the veining is cut by a later, unveined basaltic dyke (**Figure 2**) which has clear chilled margins against the veined host and contains a fragment of the veined host.

The migmatites are best displayed at **Location 2** in a continuous exposure around 20 metres long in the west bank of the barranco. **Figure 3** shows a somewhat irregular development of veining: this is relatively unusual – in most places the veins tend to be thin, sub-parallel and restricted to quite distinct areas of the host rock (**Figures 4** and **5**). In some places the parallelism of the veining is so well developed that it produces a foliation. Where measured (**Figure 1**) this foliation dipped steeply to the east and had a strike running approximately NNE. Hobson *et al* (1998) suggest that the orientation of the sub-parallel veins is controlled by shearing along the margins of the intrusion at the time of emplacement.

The most southerly migmatite location is at **Location 3**, where a pervasively veined area is in sharp contact with an area that contains a network of fewer but thicker veins (**Figure 6**).

Petrography

Figure 7 is a photograph in plane polarised light, of part of a thin section produced from a typical hand specimen of the veined rock. The leucocratic veins are typically 1mm wide and taper towards their ends.

Between crossed polars at higher magnification, the leucocratic veins can be seen to comprise tabular grains of plagioclase feldspar that are orientated at right angles or slightly oblique to the vein margins (**Figure 8**). In addition, the veins contain smaller grains of clinopyroxene, a brown pleochroic amphibole and an opaque mineral. The darker inter-vein material is fine grained and comprises clinopyroxene, brown amphibole and opaque minerals. In some places, polygonal grains with triple point contacts are well developed. Occasional larger clinopyroxene grains, probably originating as phenocrysts, show exsolution laminae of an opaque mineral. A single high birefringence grain, possibly originally an olivine phenocryst, displays a corona of radiating elongate opaque grains in a matrix of clinopyroxene.

Figures 7 and 8 were produced from digital photographs of the thin section, using the techniques described in Peter Rankilor's inspirational contribution to the North West Geologist (Rankilor 2006).

Figure 4. Sub-parallel migmatite veins at Location 2.

Figure 5. Sub-parallel migmatite veins, Location 2

Figure 6. Pervasively veined area in sharp contact with an area that contains a network of fewer but thicker veins, Location 3

Figure 7. View of thin section in plane polarised light. Field of view 20 mm by 20 mm.

Figure 8. View of thin section between crossed polars. Field of view 4 mm by 5 mm.

Discussion

The mineralogy, petrology and geochemistry of the migmatite veins and their host rocks were studied by Hobson *et al* (1998). They consider that partial melting took place at 2-3 kilobars and temperatures in excess of 800 °C. Partial melting was possible under such shallow conditions because of the high temperature of the pyroxenite intrusion and the alkaline composition of the mafic host rocks.

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TAKE 3D PICTURES WITH YOUR DIGITAL CAMERA

By Peter Rankilor

This is part three of a series of short articles on how you make your digital camera more versatile; how to get more out of it, and how to make your geology more interesting by using your digital camera in conjunction with your computer.

In the last two articles, I described how the digital camera lends itself to the microscopic examination of rocks, fossils and mineral samples, and how it can be very cheaply converted into an effective 'polarising mineral microscope'.

In this third article, I want to point out a scientific 'truth' about geological photography, and expand that point to encompass three-dimensional images.

The scientific 'truth' that I want to discuss is that photography in connection with a science such as geology, differs from domestic 'holiday photography' in that the scientific photograph is taken with a view to acquiring and recording scientific data. The domestic photograph records a scene or event, which we wish to remember. The geological photograph may well record a scene, but it is almost inevitably the data contained within the scene that are important to us, and not the scene as an artistic or historical rendition.

My earlier two articles followed this theme in that they described the ability of the digital camera to reveal hidden, microscopic detail in the camera image. Details of crystals, fossil forms or revealed by polarised light form data that are invisible to the naked eye. We might call that 'micro-data'. This article, on the other hand, shows you how to extract 'macro-data' from a site visit, by the use of a digital camera and a computer back at home, or in the local pub if you have a laptop!

Taking stereoscopic photograph pairs

I believe that everyone must be aware that humans view the world through both eyes, producing a three-dimensional image within the brain. That is how we see everything. I also believe that most of us don't think of the wonder of that procedure, which takes place in the brain; nor do we think a great deal about the significance of the three-dimensional image in our daily lives. Nonetheless, without it, we would not be able to play tennis, football, or most team sports well. We would not be able to judge the distance of the ball away from us, or the relative positions of the other players. The vast majority of us would also become much more dangerous as car drivers, without our stereoscopic vision. What we don't think about is that, consequently, our brains are processing considerably more data than that presented by one eye alone. Viewed simplistically, each eye seems to see the same scene. Close one eye and then close the other, the scene looks virtually identical. But what the brain sees, and miraculously processes, are the tiny differences in the scene as viewed by the two different eyes. These tiny differences are processed at amazing speed – what is known in computer circles as 'real time' to provide us with an ongoing stream of visual information.

Now here is the significance to us as geologists: when we take a single photograph of an outcrop, a fossil, or a mineral, we store, for our future benefit, a single, flat image with very little three-dimensional information. Such three-dimensional information that is stored, is in the form of hints: shadows, relative size of objects that we know to be the same size in reality, and so on. Look at **Figure 1**, for example:

Figure 1. Photograph of mountains with a lake in the foreground.

Figure 2. Photograph of a volcanic rock.

In order to assess what we are looking at in **Figure 1**, we extract a lot of hidden information from our experience of life. We notice that the ripples on the water are large at the bottom of the photo and get smaller upwards until they disappear: we interpret this as representing a large distance, because we know that in our day-to-day view of things, they do not disappear unless they are very far away. Then we look at the people who are large in the foreground and get smaller upwards: this supports our inferences from the ripples and gives us a second scale to assess the size of the lake. We glance up and see that there are houses at the top of the water that are smaller than the people in the image: we therefore judge that the top of the water represents the far shore of the lake at a substantial distance. This is not a pond – it is a large lake. We notice the way that the trees become smaller upwards and attribute this to distance perspective. We notice that the mountains at the top of the picture are slightly hazy and a blue colour: we attribute this, from our experience, to distance. And so on. We infer a great deal from these hints from our day-to-day experience. That is fine if this were a holiday shot, since it contains sufficient information for our purpose. We admire the nice photograph.

But what if we are looking at a scientific photograph, where there is insufficient information for us to make an inference? For example, we can look at **Figure 2**.
This photograph is much more difficult for us to interpret. In the first instance, there is no scale indication anywhere on the photograph, so it could be half of a cliff face, or it could be a patch of rock 10 cm across. A good photograph, taken with a good depth of field, gives no hint as to the size of the subject being photographed. The first lesson, although not directly connected to the subject of this article, is to always provide a scale indicator whenever possible. Anything is better than nothing: a pen, a coin, or a person on a large scale subject scene. Use of a scale indicator is ideal, a measured rule of any kind, increasing in size to a full surveying stave for larger subjects.

Apart from scale, the photograph gives little hint as to the depth of the surfaces and objects within, or their three-dimensional relationships. To provide such information, it only requires taking one additional photograph. The taking of a second photograph can produce a 'stereoscopic pair' which contains not only many times the information of one photo, but the information it contains can (if necessary) be mathematically analysed to derive numerical information on the objects photographed. Of course, that would not be necessary in the vast majority of cases, but for professional researchers, it could be vitally important. For example, stereoscopic pairs of photographs, taken over time, could reveal the rate of retreat of a glacier.

So, how should stereoscopic pairs of images be taken? In the simplest terms, we need to take a pair of photographs, looking at the same spot, but separated by approximately the distance of the human eyes apart or a little more – say 20 cm. Looking on the internet will show you lots of specialist cameras and gadgets made for the purpose[1] - for example, the camera in **Figure 3**. However, there are few digital cameras made to take stereo photos, and some are woefully lacking in digital size, whilst others are very expensive. Checking on the internet should produce some – hopefully with a minimum 5Mb image size – for those who are inclined to go down this route.

Figure 3. A film camera for taking stereo photos.

Some people have approached the concept by fixing two digital cameras to a frame, as shown in **Figure 4**. This is good, but quite expensive, requiring the purchase of two cameras and a frame. It also requires the arranging of a simultaneous firing action, and necessitates carrying the mounting frame everywhere. However, a simultaneous

Figure 4. A pair of digital cameras fixed to a frame, for taking stereo photos. This is a useful apparatus, because the separation of the camera lenses can be controlled and measured accurately.

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[1] To get an informative look at this subject, go to www.google.com on the internet, then using 'images', enter 'stereo photography' for your search. The resulting images and online sources are amazing.

firing of the cameras avoids one of the shortcomings of the easy method I am describing below: that is the fact that it is unsuitable for moving subjects – but fortunately fine for geological ones. Most of my geological subjects haven't moved for quite a long time!

Whereas the fixed–distance lens separation is useful for mathematical accuracy in rare cases, it is not essential for the obtaining of stereo images. What can we do to take stereo pairs cheaply and more simply? We take the first photo with our camera in the normal way, and then move our camera sideways before taking a second one. That's the essence of it and **Figure 5** shows the simple guidelines.

Here are the step-by-step instructions for taking a good pair of stereo photos.

1. Make all the standard adjustments to the camera for taking a photo at the site.

2. Stand upright as if about to take the photo, and then lean about 10 cm to the right. (It is not essential, but there is a useful reason for leaning to the right first, which will be explained at the end of this article, when I describe how to view a stereo pair.)

3. Before taking the photo, look carefully at the viewfinder image and make a note of exactly where the centre of the lens is pointed. I usually centre the image on some recognisable rock or other feature. Then take the right photo of the pair.

4. Now stand straight and then lean over about 10 cm to the left and take the second photo of the pair, remembering to centre the photo on the same object as before.

That is all there is to it. You have just taken a stereo pair that will allow you to view your object in considerable detail and which will remind you of the site details much more accurately than a single flat photograph.

It is useful to know that the wider apart the photographs are taken, the greater will be the apparent impression of depth when viewed stereoscopically. You can make use of this by taking the photos further apart when, for example, you are looking at a fairly flat subject, such as a rock surface; it is also useful to do when taking a photograph of very distant objects, to enhance the '3D effect'. There is no limit as to how far apart the pair can be taken. In fact, what I sometimes do is take three or four photos at increasing distances apart starting at the right hand side and moving further and further to the left. Then, when I view the scene, I always use the right hand side image, and select which of the left hand side images gives the best visual result.

There is a further interesting thought, in that photographs of the same object, taken from a moving car will, if not taken too far apart, form a stereo pair (or pairs if more than two photos are taken). So, when you are snapping scenes from your car, remember to take more than one photo and enjoy a 3D view! Whether you extend this visual treat to views of your relatives is a matter entirely for your discretion!

Figure 5. Take a stereo pair by taking two photographs consecutively, first to the right, and then to the left.

Viewing stereoscopic images

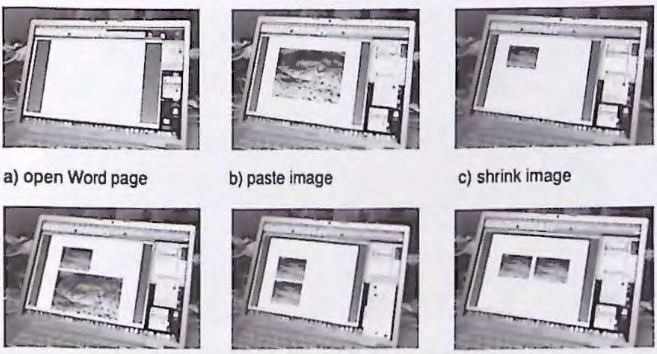
If you feel up to it, you can make your own viewer along the lines that the Victorians did over a century ago, but the benefit of having digital photos is that they can be viewed directly on the computer screen.

How, exactly can you view a stereo pair on a computer screen?
If you have a laptop computer, you can view a pair of photographs directly on the screen using a simple, portable viewer, as shown in **Figure 6**.

In this case, when using a viewer, you must be sure to put the LHS image on the left, and the RHS image on the right. Otherwise, when you view them, everything will be wrong – things that should stick out will sink in, and vice versa. Reduce the centre separation of the images to approximately that shown in **Figure 6**, which is about 6 to 7.5 cm, and then view as best you can. You could turn the images upside down and put your screen flat on the desk, or any other variation that comes to mind.

Figure 6. Viewing a stereo pair directly on your computer screen.

Figure 7 gives a step-by-step suggestion for how to put your stereo pairs onto the screen for viewing. It involves saving them in a word-processor file such as a Microsoft Word document – which is handy for archiving as pairs.



a) open Word page   b) paste image   c) shrink image

d) paste next image   e) shrink image   f) put images in line

Figure 7. Assembling a stereo pair in a Word document.

How to Assemble a stereo pair in a Word document

a) Open up a Word .doc file or any other word processor file.

b) Using the menus at the top of the page - Insert / Picture / From File – locate and paste in one of the pair of images. If you are going to view the images through a stereoscopic viewer, then paste in the left hand image. If you are going to view the images with the naked eye as described below, then paste in the right hand image first.

c) Click on the image, which highlights it, and select the bottom right hand side handle, dragging upwards and to the left to shrink the photograph. When it is about the size shown on **Figure 7c** it is about the right size. Next, type in two spaces and two carriage returns, so the next paste will come two lines further down.

d) When the second image is pasted (using the – Insert / Picture / From File – menus), it is large, which is why we put in the two carriage returns.

e) Click on it and shrink it, as before, until it is the same size as the first image.

f) Click just to the left of the second image and delete the two carriage returns. The image will now move upwards and relocate itself to the right of the first image. That is how you need them to view them.

A pair of images, at about the right size for a small viewer, is shown in **Figure 8**. They are the right size for a small hand viewer because the centres are about 6 cm apart.

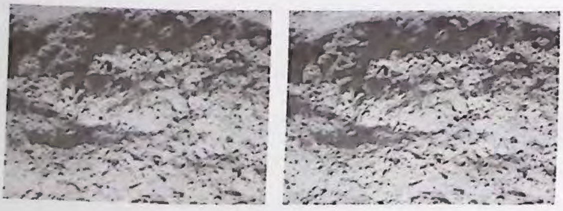


Figure 8. A stereo pair ready to be viewed using a small hand viewer (LHS image is on the left).

If you are going to view the images through a viewer, then the LHS image (as photographed) needs to be on the left. If you are going to view them with the naked eye, then the LHS image needs to be on the right.

However, viewing directly on screen with a small viewer is rather unsatisfactory because of the poor pixel resolution of the screen when viewed through magnifying lenses. You will see the image rather in the same way as when viewing a newspaper photograph as if the image is comprised of many small square dots. The three-dimensional effect is there, but the lack of resolution spoils it.

So what can you do to overcome this? The most obvious solution is to print out your stereo pairs at higher resolution onto paper. You can then see the images through the viewer with a much more satisfactory effect. A resolution of 300 dots per inch (dpi) or higher should do the job just fine. You could, if you had access to a large stereoscopic viewer, enlarge the photos as well, when the results become spectacular. The effect can be breathtaking!

The problem with this solution is that not everyone can get access to a large stereo viewer. If you know of a local geology university department, or other teaching department, then they are sure to have a viewer, but otherwise, buying one could be expensive.

So, finally, there is a solution which costs nothing, and which produces very good results, but it involves mastering a skill. So the question is do you have the perseverance to practise and master the technique? This is a technique that is sometimes taught at university in geology departments, where viewing of stereoscopic images is commonplace.

What is this marvellous technique that allows us to see images stereoscopically? It simply involves crossing your eyes and this is how it is achieved.

If you place two stereo images side by side (but in this case with the LHS image on the right and vice versa for the RHS image), then you will be able to view them as a stereoscopic image if you can cross your eyes. It can be difficult at first for some people, but with practice it becomes so easy that you don't think about it.

Let's start with a couple of small images. The next two, in **Figure 9**, look like those in **Figure 8**, and are actually the same images, but reversed in their order on the page.

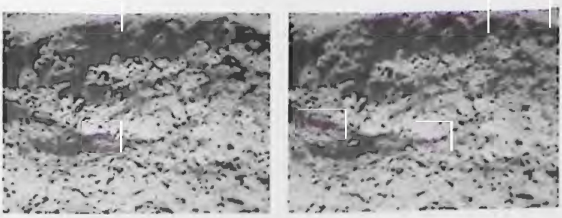


Figure 9. A stereo pair ready to be viewed with your eyes crossed (LHS image is on the right).

It does not matter if your eyesight is good or bad, as long as you are wearing appropriate spectacles, lenses, or bare eyes, as the case may be. **Figure 9** has been arranged with the LHS image on the right, so it is intended for use by eye-crossing and not through a viewer.

The first thing that you will find is that, because you are not using a viewer, there are two images in front of your eyes. So you must sit back from the computer screen (or page) a distance of about 50 cm, concentrate on looking at the white gap between the two images, exactly in the centre of the gap and start to cross your eyes very slowly.

You will see a thin, central image forming between the two outer ones. Practise achieving this and holding it for a second or two. The image will not be clear at first because it will not be properly formed. Go on increasing the extent of your eye-crossing and slowly, you will find that there are now three full images in front of your face. Keep concentrating on the central one, and move your head around slightly until, suddenly, the central image becomes a startling 3D image.

From this point on, you don't need a clumsy viewer, to see your shots; you can see them in full resolution with your own eyes! Further, as shown in **Figure 10**, you can view larger images than is possible with a small viewer. The more you can cross your eyes, the bigger the images you can view! Look at the amazingly realistic effect of **Figure 10**!

If you cannot seem to get the two images to be exactly the same size, in a Word document, you can right-click on an image and use Format Picture in the resulting options menu box, to specify the size of the image. The two in **Figure 10** have been scaled in Word to each be 8 cm wide. The height stays proportional and therefore does not need to be specified.

Now we come to the reason why you should photograph the RHS view of an object first, and then the LHS one.

When you are looking through your computer, at your slides, no matter which program, you will almost inevitably be presented with a thumbnail array, as shown in **Figure 11**.

Because I took my RHS image first and the LHS second, they have come in the array with the RHS image first (on the left) and the LHS image second (on the right). So they are immediately laid out correctly for cross-eyed viewing. Thus, when you have mastered the cross-eye technique, you can view all of your stereo images directly in the thumbnail layout, and see the effect immediately. This helps you to enjoy your images, and helps you to select appropriate pairs for your different purposes.

Apart from creating sensational three-dimensional images for your enjoyment, stereo pairs hold large quantities of data that could, if required, be numerically analysed. So, for the sake of taking one extra, free photograph of a site, mineral, or fossil, you could be storing information that could be valuable to you or another researcher at some future date.

Perhaps, as time goes by, we shall see more stereo pairs of all kinds of subjects printed in technical publications, for the better enjoyment and education of their readers.

Figure 10. A larger stereo pair ready to be viewed with your eyes crossed (LHS image is on the right).

Figure 11. An array of image thumbnails, with a stereo pair at 5330 (RHS image) and 5331 (LHS image). Look at the pair cross-eyed to see the 3D effect.

JAN'S ROADSIDE ROCK SESSIONS – NO. 3: IGNEOUS INTRUSIONS OF THE OGWEN VALLEY (PART 2 OF 3)

By Jan Heiland

I hope that you enjoyed our last little ramble where we looked at some of the sedimentary geology in the lower Nant Ffrancon valley.

This time, we are returning to the same area so that we can look at some of the intrusive igneous rocks and see how they have affected the earlier sedimentary rocks.

We are going to return to the old coach road that runs along the opposite side of the Ogwen valley to the A5, which you can easily get onto near Idwal Cottage car park and its convenient tea stall. I am going to mention several easily-accessible roadside sites along the first mile of this road as it descends the hillside to the valley floor. You can chose for yourself whether or not to try to reach each part by car, or to walk down the entire hill and then back up.

The sequence of the rocks in this area is widely argued, but generally coarse Glanravon (Caradoc) slates are giving way uphill into rhyolitic ash tuffs, with many varied strata and intrusions along the way. The top of the falls approximate to the point where the lower Ordovician sedimentary rocks end and the upper Ordovician volcanic ashes take over.

To begin with you may like to refresh your memory, and take a quick look at the brachiopod fossils in the sandstones of the Cwm Eigiau formation. They can be seen by crossing over the A5 bridge, climbing carefully over the slate style, and looking for the crescent-shaped cavities where the brachiopods have weathered out. If you consider the dip of these fairly uniform beds which themselves suggest calm water, you will quickly realise that they must strike roughly SW, under the A5 bridge (with its rustic companion). Wander back over the bridge, and with care you can see that the line of the fossil beds continues. If you are really adventurous, you can carefully ford the river and make your way up through the lovely stand of Scots Pine, following the strike of the bedding as you go.

When you pick up the old road, follow it down over a cattle grid, and pause at a line of old war-time blocks that were built as tank-traps, as this valley is full of old defensive positions from that troublesome time. If you observe the cliff face on the uphill side of the road, you will see that the sandstone beds are now marked with superb and quite large cross-stratification. Although we are still in the same Eigiau beds, by just moving a short distance we have come to an area of fairly high-energy water movement, compared to the flatter bedding on the other side of the A5. There is plenty of scope for you to pass a pleasant half-hour or so, as the next 100 yards of exposure demonstrates the cross-stratification in all its various sections. Hopefully, we can run a field trip to the Ogwen valley at some point, when we can try to interpret this bedding in more detail.

However, to find our next point of interest, we must wander further down the road, past Hafod hostel, until we enter a small but very distinct road cutting (grid reference SH 643 605).
For now, you need to be in the middle of the cutting, so that you can inspect the sidewall as it is exposed in a large bowl on the SW (uphill) side. Disregard the loose debris, and look for a nice solid exposure of reddish-grey Ordovician rock, which is roughly 450 million years old, with a coarse slate-like cleavage at the top of the cutting.

Now look down at your feet – you should find that you are standing on some rusty-brown nodular rocks, which appear to be noticeably vesicular. This is a rare local exposure of a Tertiary dyke, dated to about 55 million years old using potassium-argon dating (Fitch 1969). This is one of those nice quirky sites where you can easily lean on the rock face and have a gap of around 400 million years between your hands and your feet! It is quite likely that the old road-builders chose to cut away the soft dyke to give them this easy cutting for the road to pass through. The exposure of the dyke is small, you could cover it with a tablecloth, so please do not extract specimens.

A Tertiary dyke is exposed to the right of the road, low down and just out of sight in the curve of the cutting in this photograph.

Our dyke here has been identified as olivine dolerite and is on the usual NW-SE trend. Note that the small holes you can see are not actually vesicular, but are the remaining cavities where the olivine and other mafic minerals have weathered out. So far as I know the only other Tertiary dyke in the valley is reported in a stream bed high up in Bwlch Tryfan (at about grid reference SH 658 591), but while it lines up nicely with our dyke it is thought to be slightly older.
Incidentally, Dr Rob Crossley has looked at this dyke with me, and has suggested that it represents a late stage of the dyke's emplacement, and

could be seen as a containing solidifying clasts still cooking within the last of the magmatic fluids, a bit of an "Irish Stew" of a mixture in lay terms! Hopefully, he may be able to expand on this early opinion at a later time.

The Tertiary dyke lies under this road and extends from the cutting at the right to the little bridge just before the trees.

Scree with cordierite-spotted hornfels is found opposite the road junction on the bottom left of the photograph. The feature in the centre is a dyke.

However, now that we know what to look for – let's do some investigative geology and try to trace this dyke a little further. From the cutting it runs NW (downhill) beneath the road for about 100 yards before striking off up the hillside as a shallow depression, running at 315° from the little bridge at SH 642 606 which is marked as a private water supply (please respect this). Let's walk up this depression for about 10 paces and start digging close to its edge. If we are right, then a few inches down we should uncover more of the brown decaying material and a few inches deeper we should come to more solid Tertiary dolerite. Try it, and see if you can prove the course of this illusive dyke. When you have finished, please put everything back tidily before you leave.

The course of this hard-to-find dyke was marked on the old geological maps, and you can see it marked on the 25,000 scale Special Sheet of Central Snowdonia, last revised in 1972. However, this was based on early work done by Williams and Ramsay, who would have seen the dyke before the road was hard-surfaced. The later British Geological Survey 25,000 map (Sheets 65 & 66) of Nant Ffrancon & Llanberis, prepared by Howells et al in the late 1970s, misses it out completely, and I suspect that they may not have been able to find the dyke. Its route beyond the little bridge has never been mapped, so please feel free to indulge in some fresh research.

From the little bridge, walk a little further downhill until the road levels out for a short stretch opposite the upper entrance to Blaen-y-Nant (SH 641 609). Carefully examine the scree on the uphill side of the road, and you will find excellent samples of light-grey hornfels, with dark spots of cordierite, representing the local slates that have cooked in contact with the hot Cywion granitic intrusion.

The steep cliffs above you mark the edge of this substantial granite body, which melted its way upward through the earlier rocks, arriving some time after all the earlier volcanism and folding had ended. The road passes very close to the boundary, and at many points you can see how the molten rock has intruded through the local slates. Here, closer to its edge, the intrusion is closer to a rhyolite, which has been argued as a slightly later phase of the intrusion. If you were to climb the entire mountainside, you would see the rhyolites change to felsite, and then to the microgranite core of the intrusion.

The Cywion intrusion has long been noted for its excellent mineralogy, which includes, among others, garnet-biotite, almandine-spessartine garnet, microcline, brookite, fluorite, gibbsite, molybdenite, pyrosmalite; its first UK occurrence; and topaz (Bevins 1994).

If you have the time and the energy, continue walking down to the bottom of the hill, where you will come to another cattle grid. In the hillside just above you are the traces of some old mines (SH 640 612). These are reported to be pre-1800 trials for molybdenum which is sometimes found around the edges of a major intrusion (Hubback and Bevins).
These have recently been fenced off from the road, but I inspected them some time ago and there were no mineral traces evident, so please don't annoy the farmer by climbing all over them. Incidentally, the farmer here is a very keen dry-stone wall builder and his impressive handywork is visible on

the valley floor area. He has mentioned that he can always tell a rock that has come from the mine area by its great density!

Our final interest at this point is to look up at the steep debris cone which descends at this point from Cwm Coch. When seen from across the valley, this is a very substantial cone, steeply banked due to the angular nature of its component debris. You may notice that there is a fresher-looking debris cone part-way up the gulley. A hill-side farm and a cottage were actually buried when this cone settled and are only two of around half-a dozen homes that are know to have been destroyed in this valley in the same way.

In our next walk we will look at another debris cone, a little further down the valley, which in complete contrast to this one is very wide and flat as it is constructed of slate fragments. We will also look at evidence for the deposition of iron, and consider the past flora of the valley, when it contained two lakes.

For now though, it is time to work your way back up the road to the Idwal car park, where I strongly recommend the veggie cheeseburger with a nice cup of Earl Grey. Look forward to seeing you next time!

Jan Heiland, North Wales Geology Association.

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*William Williams of Landegai

SUN, SAND AND SHELLS (BUT NO SEA)
FIELD TRIP TO THE JURASSIC OF RUTLAND 3 AND 4 JUNE 2006

By Peter del Strother, Fred Owen and Jane Michael

Manchester Geological Society Vice President Joe Macquaker led members on a two day trip to investigate the Jurassic sediments of the East Midlands.

Castle Cement Quarry, Ketton

Peter del Strother, Technical General Manager and Chief Geologist for Castle Cement, and also a MGA member, arranged for the group to spend Saturday afternoon at the Castle Cement Quarry at Ketton investigating the Mid-Cimmerian unconformity and the Great Estuarine Series. After a thorough safety briefing and the allocation of high visibility jackets and goggles, Peter showed us round the Cement Works and gave us a potted history of the quarry. It seems that until he appeared on the scene, the company did not use the ready supply of ironstone to provide the iron required in the cement making process. He changed the operational procedure to utilize this resource, with obvious economic benefits for the company.

Our first exposure was the Mid-Cimmerian unconformity, which Peter had found in a railway cutting to one side of the site. Joe outlined where it appeared in the succession: between the Whitby Formation, which we had seen the previous year on the Yorkshire coast, and the Northampton Sand and Ironstone formation. This put us in the middle Jurassic. The contact was a dark grey, somewhat wavy, erosion surface and dipping from top right to bottom left of the photograph below.

Mid-Cimmerian Unconformity (photograph by Fred Owen.)

Below were the organic rich muds, containing fish teeth and bones, of the Whitby Mudstone. A layer of nodules, indicating a break in sediment deposition, also marked this regional unconformity. A high energy, shallow or sub-aerial, transgressive marine surface was present. There had been some movement, as the railway line which ran alongside the exposure, followed the line of a fault. On the opposite side from the unconformity, many large selenite crystals, a fibrous form of gypsum, were found. These were formed by pyrite oxidizing to ferric oxide and sulphuric acid which then reacted with calcium carbonate to give the calcium sulphate.

Discussion took place about the formation of the Northampton Sand and Ironstone Formation as this was of marine origin and not formed in freshwater. In freshwater settings, where biologically available organic carbon is oxidised by iron-reducing bacteria, iron carbonate cements are commonly precipitated. In contrast, in marine settings the concentrations of sulphate are so much greater that sulphate-reducing bacteria typically cause pyrite to precipitate. However, Joe's hypothesis is that under certain marine conditions, particularly where organic matter is already highly degraded, iron-reducing bacteria are able to extract more energy from organic carbon than sulphate-reducing bacteria. Iron-reducing bacteria compete better than sulphate-reducing bacteria for the available food and iron carbonate cement precipitates as a result. During deposition this process reduced iron from its ferric to ferrous state. However, recent weathering has oxidized the ironstone again sending it back to the ferric state. The result is brown, iron-rich sandstone. As well as the iron carbonate it also contains glauconite and berthierine and is similar to the Frodingham Ironstone. The uppermost surface of the Ironstone Formation showed burrowing marks and harder layers, which also suggested breaks in sedimentation prior to deposition of the overlying unit.

The next formation was the Grantham Formation which was a rooted horizon of a terrestrial mix of sand and silt. Above this was the base of the Lower Lincolnshire Limestone. This had a sandy bottom, limestone concretions and sandy partings. Some layers were well cemented and some not so. It contains around 25% silica.

We moved then to the main body of the quarry where, initially, we saw Northampton Sand and Ironstone, Grantham and Lincolnshire Limestone formations again, though at this location we saw some very fossiliferous blocks. The fossils included oysters in-situ, which indicated the rock was cemented already to form the 'hardgrounds' on which they live. There appears to have been very slow sedimentation rates, with at least two ammonite zones found. Overall this pattern suggests that little accommodation was available and there was lots of evidence of relative sea-level change. Again the Grantham Formation showed two rootlet horizons. In one or two places, the top of the Ironstone was also rooted. The lower part of the Lincolnshire Limestone was fine grained, burrowed and contained gastropods and serpulid worms; its dark grey colour was probably caused by the presence of very fine disseminated pyrite.

We then moved to look at the Rutland Formation at the top of the main quarry face. This comprised the Stamford Member overlain by six 'rhythms', which appear to represent coastal cycles of regression and transgression. The photograph of the quarry face overleaf clearly shows layering. The layers varied in colour from white to grey though greens and brown to black.

The Stamford Member changes from silt with rootlets above, gypsum and limonite nodules through pyritic clay or silt to dark carbonaceous clay interbedded with pale silt laminae. Rootlets were in evidence in the topmost layer.

The various rhythm boundaries were marked by truncated rootlets; within the rhythms were coloured horizons such as olive green clay with ferruginous nodules, black clay which were almost coal-like and green clay. There were shell beds in most of the rhythms although we were not able to get at the different levels due to the steepness of the face and danger of falling rocks. It is possible that what is represented is a succession from marine to fresh water. Nodules had formed around roots in some places. The oxygen isotope signatures of these nodules suggest that their formation was linked to iron reduction processes that occurred during subsequent marine flooding, rather than in fresh water at the time when the plants were living.

Joe pointed out that sequence boundaries occurred at the levels of the truncated roots. He also considered that the area was probably like present day machair geomorphology in the Western Isles of Scotland. These are coastal areas, which are episodically flooded by both seawater and loch freshwater. Apparently the same iron-reducing and sulphate-reducing bacteria are seen in this environment, which also has variable concentrations of organic carbon and sulphate. Recent lab research has shown that iron-reducing bacteria can form iron carbonate cements in these conditions (Adams *et al.*, 2006).

Lingula, which is a fully marine brachiopod, is found in the first rhythm. Oysters are found in rhythms 4 and 6. Generally all the rhythms comprise silt, fine sand and clay at their bases and are dominated by clay towards their tops. However, rhythm 5 has clay at the base and calcitic mud above.

Near the top of the Lincolnshire Limestone is the Ketton Freestone. We moved to another part of the quarry to get a better look at this. The blocks we saw were mainly oolitic in what was known as the Inferior Oolite. It is not cemented at all and looks almost 'welded'. The question was asked whether this was what it was like originally or whether some later process has changed it. It is freestone and carves easily. It has a porosity of between 25 and 40% which makes it fairly frost- proof and suitable as a building stone.

The Lincolnshire Limestone contains *en-echelon* faults that form a series of ridges and valleys across part of the quarry and so it was difficult to see what was happening to the geomorphology. The top of the Blisworth Limestone contains cone-in-cone structures. These appear to be the result of pore water overpressure and occur when the pore water pushes the limestone apart precipitating calcite into the free pore space.

Above the Blisworth Limestone was the Blisworth Clay. As the photograph below shows, it is quite spectacular.

The lower layers are very shelly; include ostracods and a layer of ferruginous nodules. Above this in turn is the massive Cornbrash with its large bivalves, brachiopods and ammonites. The Kellaways Formation of clay and sand overlaid these and was just visible in the quarry due to the faulting. Above this was the start of the Oxford Clay – our topic for the second day of the trip.

Rutland Formation (photograph by Fred Owen.)

Faulting in the Blisworth Clay (photograph by Fred Owen.)

By this time, we had climbed up quite a long way above the quarry floor and this gave us a spectacular view across to the Cement Works which ended our first day.

View of Cement works (photograph by Jane Michael.)

Bradley Fen Clay Pit from the entrance (photograph by Jane Michael.)

Bradley Fen Clay Pit, Whittlesey

Bradley Fen Clay Pit is very close to the River Nene between Peterborough and Whittlesey and as we approached it, looked very grey.

We were escorted to the pit by Andrew Mortlock, an employee of Hansons. He told us that it had been open for five or six years and was producing half a million tons of brick clay per year. The bricks themselves are made about a mile away at Star Pit. They are currently producing around 2.5 million bricks per year; a mind-boggling figure.

The pit is in the Upper Jurassic Oxford Clay but there are pods of sand and gravel overlying the Oxford Clay, there is a lot of organic matter, essential for making bricks and plenty of coccoliths and foraminifera. Joe told us that he had produced a series of thin sections at 10 metre lateral intervals around a nearby quarry and that the material was highly variable even at the same height and within the same beds. This data suggested that individual units visible in the field were probably parasequences and that during deposition of this succession there had been many changes in relative sea-level. However, there are no layers of concretions as we had seen the day before except at the bottom of the succession. There was a hiatal surface. The unit is 30 to 40 metres thick and it is considered that it has only been buried to a depth of 0.5 km.

There are also very few large fossils in the Oxford Clay locally those being mainly marine reptile Ichthyosaurs, including the massive one found by Dave Martill on the other side of Peterborough. There are however layer upon layer of shelly fossils such as ammonites e.g. *Kosmoceras jason*, many species of *Gryphaea* and a great number of belemnites, some over 20 mm in diameter.

Bradley Fen Belemnites (photograph by Jane Michael.)

We spent much of our visit trying to sort out the bedding and trying to decide what had happened to form it. Some of the beds were obvious to follow including orangey coloured pyritic beds. Even though the formation is called 'clay', 10-15% is calcium carbonate in the form of coccoliths. The remainder is a mix of clay and silica foraminifera with some pyrite arising from diagenesis in anoxic pore waters. The shells we found were often very thin and probably lived on the bottom in oxygen-rich conditions. However, only a few millimetres below that, the 'surface' conditions were anoxic.

Where carbonate nodules formed it would appear that all material came in as 'clay' in water alive with benthic fauna to a depth of approximately 30 to 50 metres. This was below storm wave base, on the East Midlands Platform. The material was the product of a very mature hinterland, which did raise the question of where all the quartz had gone. Much of the sediment may originally have been deposited as organo-minerallic aggregates that are also known as "marine snow".

We did reach the bottom of the formation and found a layer of concretions. These represented a long break in sedimentation. There were also shell concentrations and we found a life assemblage. The *Kosmoceras jason* is found just above these concretions and we did see one or two examples showing a pearlescent lustre in the impression of the creature. They were very fragile however.

Bradley Fen Ammonites (photograph by Jane Michael.)

Our visit to the Brick Pit had been very interesting and a contrast to the previous day's mix of rock types. The weekend had proved as educational as ever and a good pre-cursor to the trip to Skye in September.

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BOOK REVIEW: TWO LEAD MINING NOVELS

By Iain A. Williamson

Adam Brunskill (1952) Armstrong, Thomas; Collins

Few novels have been written about the geology, working methods and many rich characters associated with British lead mining. Undoubtedly the most noteworthy is *Adam Brunskill* by Thomas Armstrong in 1952, which, probably by reason of the slight degree of geological knowledge required of the reader, never attained the popularity of the author's previous novels including *The Crowthers of Bankdam* and *Dover Harbour*. However, anyone interested in the geology and lead mining history of the Yorkshire Dales and Swaledale in particular, will still find it an enjoyable read. The geology is good the characters portrayed life-like, and there is indeed evidence to suggest that story is based on competition between mining companies which actually took place.

King Charles' Mine (2000) Thornber, Titus; Pentland Press, Edinburgh, ISBN 1-85821764-4, 272 pp.

Since Adam Brunskill we have had to wait half a century for another such novel. Whilst *King Charles' Mine* by Titus Thornber (2000) is a somewhat lighter read than Armstrong's it is nevertheless recommended. Much of it is based upon the records of the Thieveley Lead Mines on the north-western edge of the Cliviger Valley near Burnley. The mines were worked by the appointed commissioners for Charles I during the working period between 1629 and 1635. The book details problems at the time with disease, due to the plague in the area and pollution caused by mining, together with drainage which was partly sorted out by the digging a long drainage sough and use of a series of rag and chain pumps to remove water. With the hardships of mining as a background, based on actual conditions at the time, the story concentrates on the characters and their lives. Events like the happenings at the local inn at Holme in Cliviger, a place still frequented by parties of Lancashire geologists, are colourfully described and add to the most interesting mining, geological and historical content.

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Williamson, I.A. (1999) The Burnley Coalfield, *British Mining* no.**63**, The Northern Mine Research Society, Sheffield, pp.5-27

Other Publications

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The Geological Journal

Rock around Liverpool

Rock around Wirral

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The William Smith map

A field guide to the continental Permo-Triassic rocks of Cumbria and North West Cheshire

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Stereographic Projections*

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Manchester Geological Association

A Lateral Key for the Identification of the Commoner Lower Carboniferous Coral Genera (£2.25) available from Niall Clarke, 64 Yorkdale, Clarksfield, Oldham, Lancashire OL4 3AR

Geology Trail of Styal Country Park, Wilmslow (£1.25)

Geology Trail of Knutsford's Buildings and Cobbles (£1.25)

Available from Fred Owen, 29 Westage Lane, Great Budworth, Northwich, CW9 6HJ