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Front cover picture *Spirifer striatus* from Dove Dale (see page 43) Specimen 1971 305 XD in the J W Jackson fossil collection of National Museums Liverpool Photograph taken by Wendy Simkiss, copyright National Museums Liverpool

THE NORTH WEST GEOLOGIST
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CONTENTS

Editorial

Many thanks to all who have contributed to this issue of North West Geologist. Special thanks must go to Chris Arkwright who has found many of the articles and some new authors for this edition and to our regular authors who have taken time and effort to produce a variety of articles. What is most noticeable about this issue is the variety of locations for articles which vary from the centre of Liverpool to the Pennine areas, the full length of Britain from Scotland to the South coast of England and to the islands of La Palma in the Canaries and Tristan da Cunha in the South Atlantic.

Wendy Simkiss
August 2011

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,
Email: wendy.simkiss@liverpoolmuseums.org.uk

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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RECYCLED SEDIMENTARY HALOGENS PRESERVED IN THE TRISTAN DA CUNHA HOTSPOTSOURCE

By Lisa D. Abbott

View of Tristan da Cunha, taken from HMS Endurance's helicopter, 12th April 2007 (Image used with permission, www.tristandc.com)

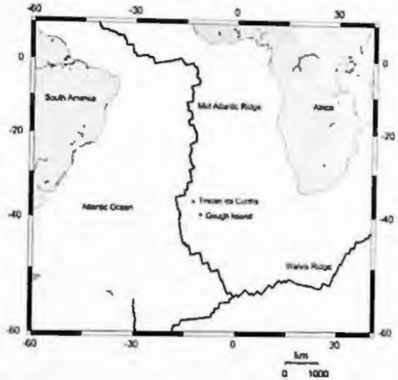

Figure 1
Location of the Tristan da Cunha group, east of the Mid-Atlantic Ridge (base map generated using Planiglobe - www.planiglobe.com).
Introduction

The Tristan da Cunha group comprises of three volcanic islands, Nightingale, Inaccessible and Tristan. The islands are situated in the southern Atlantic Ocean, 430 km east of the Mid-Atlantic Ridge (**figure 1**) (LeRoex et al., 1990). Tristan is still volcanically active, whereas Nightingale and Inaccessible are now in their erosional phases (Gass, 1967).

Tristan is the only populated island in the group, supporting a small population of around 300 islanders who all live in The Settlement, an area in the northern part of the island (Baker et al., 1964). The most recent eruption in October 1961 resulted in the evacuation of the entire population of the island, due to the close proximity of the volcanic centre to the village (Baker et al., 1964).

In late 1961, the Royal Society commissioned an expedition to the island to study the new volcano, and to assess its impact on the local flora and fauna (Baker et al., 1964). The expedition landed on Tristan on the 29th of January 1962 (Baker et al., 1964). During the following seven weeks a geological survey of Tristan was undertaken, and nearly 700 rock samples were collected from Tristan, Inaccessible and Nightingale (Baker et al., 1964).

A selection of nine basalts from Tristan (**figure 2**) and Inaccessible were analysed for their halogen content, specifically chlorine (Cl), bromine (Br) and iodine (I). Halogens are ideal tracers to search for recycling of subducted materials because they are concentrated in marine pore fluids, particularly in the case of iodine. This leads to their ratios (iodine/chlorine, I/Cl and bromine/chlorine, Br/Cl) being orders of magnitude different between the pore fluid and mantle. Thus, the aim of the study was to establish if there is a recycled halogen signature within the samples, providing evidence for the halogens being subducted deep into the mantle and eventually being returned to the surface via volcanism.

Data on the halogen content of ocean island basalts (OIBs) is scarce, particularly with respect to iodine; this is due to its low abundance (parts per billion levels) making it difficult to analyse.

Geological Setting

The Tristan da Cunha group of islands is thought to have formed due to volcanism associated with the Tristan mantle plume tail (Gibson et al., 2005). A mantle plume forms when anomalously hot mantle rises from the core-mantle thermal boundary. Due to density contrasts the plume ascends, forming a distinct head and tail, with the head eventually puncturing through the overlying crust. The head of the Tristan mantle plume is believed to have impacted Gondwanaland prior to 138 Ma, forming the Paraná-Etendeka flood basalt province (Gibson et al., 2005).

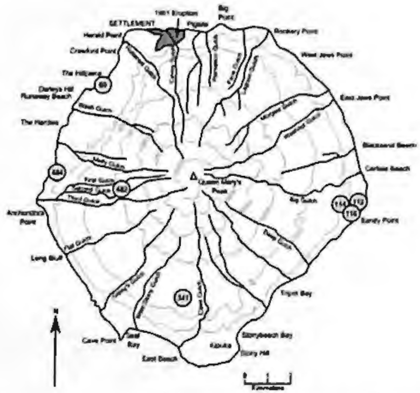

Figure 2
Locations of the Tristan samples (map modified from Le Roex et al. 1990; McDougall and Ollier, 1982).

All of the islands in the group are thought to have formed during the last 18 Ma, with Tristan being the youngest (Cliff et al., 1991). The main shield building phase of the Tristan volcano was short-lived, occurring between 0.2-0.1 Ma (McDougall and Ollier, 1982). In the past 15,000 years, volcanic eruptions have only occurred from parasitic vents (Baker et al., 1964).

The island of Tristan consists of interbedded layers of basalts and associated pyroclastics, ejected mainly from the central cone; the pyroclastics having formed due to the magma interacting with either a shallow water table, or a crater lake (Baker et al., 1964). The geology of Inaccessible Island is very similar, again consisting of interbedded basalts and pyroclastic material (Baker et al., 1964). Little erosion has taken place on Tristan, with the main areas of erosion being around the sea cliffs and on the upper slopes of the island (Baker et al., 1964).

Halogen Composition of the Earth and Meteorites

Whilst there is increasing information of the halogen concentrations and ratios within mid-ocean ridge basalt (MORB), data on ocean island basalts are scarce. No ocean island basalts iodine data has been reported in the literature. Br/Cl ratios have been derived for OIB ranging from (1.1-1.2) x 10^{-3} (mol/mol), with concentrations of 35-257 ppm and 0.09-0.69 ppm for Cl and Br respectively (Jambon et al., 1995; Schilling et al., 1978).

Estimates for MORB halogen concentrations are better constrained, with Cl ranging from 29-55 parts per million, Br from 60-1,300 ppm and I between 8-10 ppb; giving ratios of (1.03-1.11) x 10^{-3} Br/Cl and (15-25) x 10^{-6} I/Cl (**figure 3**) (Burgess et al., 2002; Déruelle et al., 1992; Jambon et al., 1995).

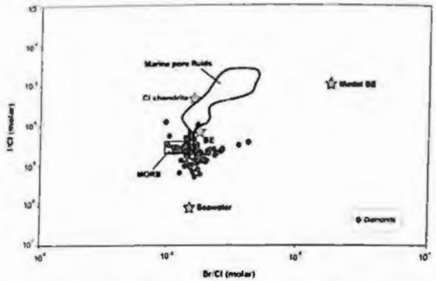

Figure 3
Halogen ratios for the Earth's reservoirs (data from Burgess et al., 2009; Burgess et al., 2002; Déruelle et al., 1992; Jambon et al., 1995; Johnson et al., 2000; Mahn and Gieskes, 2001; Martin et al., 1993; Schilling et al., 1978).

Estimates of the halogen ratios of the sub-continental lithospheric mantle (SCLM) and bulk Earth (BE) (Br/Cl 1.77×10^{-3}; I/Cl 72×10^{-6}) have been derived from diamond data, and a model BE value calculated from condensation temperatures of elements in the Earth-forming region of the solar nebula (**figure 3**) (Allègre et al., 2001; Burgess et al., 2009; Johnson et al., 2000). Halogen ratios have also been measured in primitive meteorites (CI chondrites); these are meteorites which have compositions considered to be representative of the bulk Earth. Although the I/Cl ratios between BE and CI chondrites are very different (**figure 3**) which may result from very limited meteorite sample analyses, a similar Br/Cl ratio (1.64×10^{-3}) to the BE values have been derived from mantle fluids in diamond (Burgess et al., 2002).

The concentrations of halogens within marine pore fluids have been measured using samples from the Ocean Drilling Program (ODP) (Mahn and Gieskes, 2001; Martin et al., 1993). Pore fluids show the greatest range of values, particularly with respect to iodine; I/Cl varies by three orders of magnitude (**figure 3**). These increased iodine concentrations are thought to be due to the degradation of organic matter from pelagic sediments, which are particularly iodine rich (Mahn and Gieskes, 2001).

Ultra-Sensitive Halogen Determinations

The halogen content of the samples was analysed using an extension of the Argon-Argon dating technique. Initially, the whole rock samples were crushed and olivine crystals hand-picked. The olivine crystals were then irradiated at the SAFARI-1 reactor, NECSA, Pelindaba, South Africa. During irradiation, the samples are subjected to a neutron flux and a small proportion (about one in every 10,000 atoms) of the halogens is converted into neutron-derived noble gases, via neutron interaction. Since noble gases are so rare on Earth,

they can be detected at very low abundance and this is what gives the technique its very high sensitivity.

The abundance of the neutron-derived noble gas isotopes produced during irradiation is directly proportional to the initial abundance of the halogens. This allows the noble gas content of the samples to be measured and used as a proxy for halogen abundance.

Post-irradiation, the samples were either crushed and, or step heated (600-1,600°C) in vacuum to release their trapped gases into a mass spectrometer. The MS1 noble gas mass spectrometer at the University of Manchester was used for sample analysis.

Thin sections of the samples were also examined to establish the mineralogy, texture and crystallisation history of the basalts.

Halogen Ratios

The iodine/chlorine values extend from 1.8×10^{-5} to 1.9×10^{-2} for the individual step heating and crushing steps, with the total releases ranging from 2.3×10^{-6} to 4.1×10^{-3} (**figure 4**). The highest values reported are for sample 446 from Inaccessible Island, ranging from 2.8×10^{-4} to 1.9×10^{-2} with an integrated value of 4.1×10^{-3}. Most of the samples have I/Cl between 10^{-4} and 10^{-2}.

There is less variation observed in bromine/chlorine ratio (**figure 4**), ranging from $(7.3\text{-}91) \times 10^{-4}$ for the individual steps, and $(7.9\text{-}34) \times 10^{-4}$ for the total releases. The largest range is again seen in sample 446, which extends from $(1.8\text{-}9.1) \times 10^{-3}$.

Marine Pore Fluid Signature

In **figure 4**, it can be seen that samples with lower bromine/chlorine and iodine/chlorine ratios extend almost to the mid-ocean ridge basalt field, and near to the value derived for bulk Earth from diamond analyses. The higher ratios extend well into, and beyond the field for marine pore fluids. The only known reservoir of material having high I/Cl and Br/Cl in the Earth are organic-rich sediments and marine pore fluids.

This trend from MORB and BE values to marine pore fluid values suggests that a mixing trend between a MORB or BE end-member and marine pore fluids, or iodine rich sediments, is being observed.

The high halogen ratios observed in the Tristan and Inaccessible Island olivines show a recycled halogen signature, and may therefore be explained by a marine pore fluid component within the Tristan da Cunha mantle source. This indicates that subducted marine sediments and pore fluids are mixing with the OIB source, with possible entrainment of MORB during magma ascent.

One sample from Inaccessible Island (446) reports a higher I/Cl ratio than is known for marine pore fluids, however Sumino et al. (2010) suggest that an increase in I/Cl may be due to additional iodine release during the dewatering of clay minerals and organic matter from sediment pores.

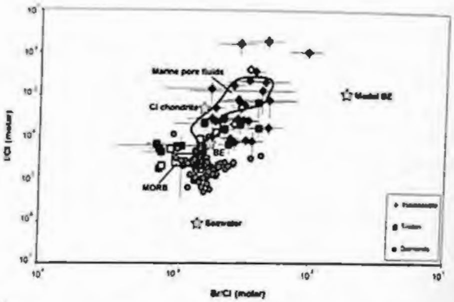

Figure 4

Tristan and Inaccessible samples (shown with error bars – closed symbols indicate individual steps; open symbols indicate total release; additional data from Burgess et al., 2009; Burgess et al., 2002; Déruelle et al., 1992; Jambon et al., 1995; Johnson et al., 2000; Mahn and Gieskes, 2001; Martin et al., 1993; Schilling et al., 1978).

If we assume a sediment iodine concentration of 15 ppm (Burgess et al., 2009), approximately 400 ppm of sediment would need to be present within the OIB source to give the highest I/Cl observed (sample 446, Inaccessible Island).

Conclusions

The Tristan da Cunha basalts show a strong overlap in their halogen ratios with marine pore fluids, suggesting that subducted sediments are mixing with the mantle source for the Tristan plume, deep within the mantle. Those samples with lower halogen ratios lie close to the values for the bulk Earth, and mid-ocean ridge basalts, suggesting a mixing trend between the bulk Earth or MORB range and iodine-rich sediments. Only 400 ppm of sediment would need to be present within the mantle source to provide the values observed. There is also some evidence to suggest that the Tristan hotspot source has changed chemically over time, as the samples from Inaccessible show higher halogen ratios than the samples collected from Tristan. The results of this study has implications for deep water recycling processes and may require a reassessment of the dominant transport mechanism and source of water in the Earth's mantle. In particular it is unknown whether it is possible for a free fluid phase to be subducted to the depth of the OIB source.

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Natural History Museum, London for providing access to the samples. Many thanks also to Richard Grundy, manager of the Tristan da Cunha website (www.tristandc.com) for photograph permissions. Thanks to Dr James Jepson (University of Manchester) for useful comments. Current research is being funded through a NERC scholarship.

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LACEWINGS AND SNAKEFLIES (INSECTA) OF THE LOWER CRETACEOUS OF THE WEALDEN SUPERGROUP, SOUTHERN ENGLAND

By James E. Jepson

Introduction

When most people think of the Cretaceous, they envisage a scene of giant roaming dinosaurs on the land and pterosaurs flying through the skies. They give little if any thought to the smaller animals, such as the insects. In the Cretaceous insects formed an essential part of the ecosystem, and it was at this time that a major diversification of insects occurred with many of the extant families evolving, partly related to the rise of the angiosperms (Grimaldi and Engel, 2005). Two groups of insect which had their 'Golden Age' in the Cretaceous are the lacewings and the snakeflies. Lacewings (Neuroptera) and snakeflies (Raphidioptera), along with alderflies and dobsonflies (Megaloptera) are holometabolous insects with distinct larval, pupal and adult stages that belong to the superorder Neuropterida. The first fossil record of lacewings is in the Permian and snakeflies in the Jurassic (Grimaldi and Engel, 2005). These insects are still alive today; in Britain there are 66 species, in six families of lacewings and four species in one family of snakefly (Plant, 1997). The extant fauna is considered to be relict, with their greatest period of diversity being around the time of the Wealden Supergroup in the Cretaceous.

Geological Setting

The Wealden Supergroup of southern England is Lower Cretaceous (140–125 Ma) in age (Gradstein et al., 2005) and is divided into two sub-basins, the Weald and Wessex (Allen and Wimbledon 1991). The Wessex Sub-basin has few fossil insect remains with mainly beetle wing cases known (Twitchett, 1994). In contrast the Weald Sub-basin has yielded many insect fossils (many hundreds of species have been recorded) and it is from here that the lacewings and snakeflies have been described. The Wealden Supergroup is divided into the Hastings Beds Group and Weald Clay Group (**Figure 1**); the rock types consist mainly of cycles of sandstone, clays and mudstones. The main outcrops of these rocks are found in various brickworks across the south-east of England (**Figure 1**). Fossil insects are found mainly in the fine grained rocks of the Weald Clay Group, the most productive locality being Clockhouse Brickworks. Few fossil insects have been recorded from the Hastings Group.

Lacewings and Snakeflies

The lacewing fauna of the Wealden consists of four families and 14 species; it is dominated by insects with many veins in their wings known as psychopsoid lacewings, which include the families Kalligrammatidae and Psychopsidae. The psychopsoid lacewings make up over 60% of the lacewing fauna (Jepson, 2010).

The oldest lacewing fossil from the Wealden is a kalligrammatid from the Hastings Group (**Figure 2**). The fossil is a fragment of wing, containing a beautifully preserved eyespot, similar to some butterflies and moths (Jarzembowski, 2001). Kalligrammatids are large insects which are thought to have had brightly coloured wings. These features have earned them the name of Butterflies of the Mesozoic. Another fragment of a kalligrammatid has been recorded in the Upper Weald Clay (Jepson et al., 2009), extending their range through most of the Wealden.

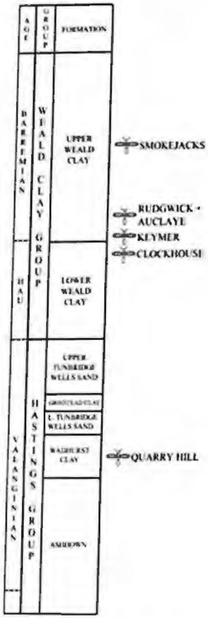

Figure 1
Stratigraphic column of the Weald Sub-basin (not to scale), showing insect localities with names of Brickworks (modified from Rasnitsyn et al., 1998).

The Psychopsidae or Silky Lacewings (**Figure 3**) are the most diverse and dominant group of lacewings in the Wealden; they are represented by four genera and eight species (Jepson et al., 2009). Many of these specimens

have colour patterns preserved on the wings. These have only been found in the Weald Clay Group. Extant Psychopsidae are found in restricted habitats in Africa, parts of Asia and Australia (Oswald, 1993), however, in the Cretaceous they were much more widespread.

Figure 2
Photograph of the oldest Wealden Lacewing *Kalligramma roycrowsoni* Jarzembowski, 2001, from the Hastings Group. Diameter of 'pupil' 8 mm (Photo: Ed Jarzembowski and Fred Clouter).

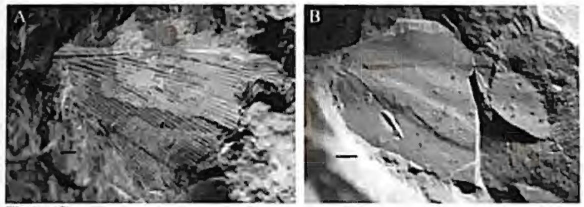

Figure 3
Photographs of two species of Psychopsidae from the Wealden. A. *Valdipsychops logunovi* Jepson et al., 2009. B. *Valdipsychops maculosus* Jepson et al. 2009 (scale bars both 1 mm)

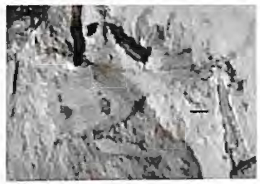

Figure 4
Photograph of a Wealden osmylid, *Protosmylina bifasciata* Jepson et al., 2009 (scale bar 1 mm)

The next dominant group of lacewings in the Wealden is the family Osmylidae (**Figure 4**) with two genera and two species known; osmylids are still present in Britain today.
An unexpected find in the fauna was the family Ithonidae, or moth lacewings (**Figure 5**). These lacewings are found today in Australia, south-western North America, Honduras and in Oriental regions (Makarkin and Menon, 2007). This fossil represents the first record of Ithonidae in Europe. Another surprise about the fossil is that it is from the same genus as a fossil described in the younger Crato Formation of Brazil (Makarkin and Menon, 2007), which suggests that the family and genus was much more widespread during the Cretaceous.

Figure 5
Photograph of Wealden Ithonidae, *Principiala rudgwickensis* Jepson et al., 2009 (scale bar 1 mm)

There are two species whose family affinities could not be deciphered, one is possibly related to the family Hemerobiidae, or brown lacewings, and the other may be related to the extinct family Brongniartiellidae.
Snakeflies (**Figure 6**) are rare in the Wealden, only three species in one family are known. The family in question is the extinct Mesoraphidiidae. Two of the species are members of the globally widespread genus *Mesoraphdia*, whereas the other is in the genus *Proraphidia* (Jepson and Jarzembowski, 2008; Jepson et al., 2011). The presence of *Proraphidia* in the Wealden extends both the geographical and geological range of the genus; previously it was only known in the Jurassic of Kazakhstan.
Along with the aforementioned specimens there are numerous very small wing fragments in museum collections; that unfortunately do not have enough diagnostic characters to describe to lower taxonomic levels. However, these fragments together with the described material give us a glimpse of the lacewing and snakefly fauna from this period of time, and from this we can deduce how and where they might have lived.

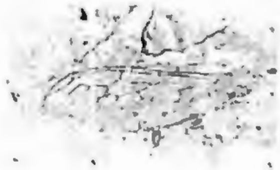

Figure 6
Photograph of Wealden snakefly, *Proraphidia hopkinsi* Jepson and Jarzembowski, 2008 (wing length 11.5 mm)

Palaeoenvironment and Taphonomy
The palaeoenvironment of the Wealden has been reconstructed as lacustrine-lagoonal with woodland bordering watercourses, and a distant forested area. The climate has been interpreted from sedimentological and palaeontological evidence as Mediterranean-like, sub-tropical to warm temperate, with seasonal rainfall (Allen and Wimbledon, 1991; Batten, 1998). Wild fires were a hazard in the drier seasons, being recorded by fossils of burnt plants and beetle elytra (Batten, 1998; Jarzembowski, 2003).
The lacewings, snakeflies and majority of insect fossils are preserved as disarticulated wings, many of which being fragmentary. The disarticulated state and fragmentary nature of the fossils can tell a story about two possible scenarios of events prior to deposition. The first scenario considers that the insect died on land, where the body was either eaten by predators, or decomposed, leaving just the wings. Any rain would have washed the wings into a watercourse transporting it down to the site of deposition. The second scenario is that the insect was washed into the watercourse either dead or alive; here it broke the water tension. If alive the struggling of the insect could cause the water tension to break, or if dead the action of raindrops could break the tension, causing it to sink.
When under water the body may have been eaten by aquatic predators, or become disarticulated due to attrition during transport in the water. In this scenario, if the insect died on the water surface it may have began to decompose there. The fragmentary nature of the wings suggests damage most likely by water transport and the more damaged, the further they have travelled. The fact that very little body material is found could be due to sorting by water (Jarzembowski, 1995; Jepson 2010 for more information on insect taphonomy see Martínez-Delclos & Martinell, 1993).
From the above evidence it can be suggested that the insects must have lived some distance from the site of deposition. Jarzembowski (1995) suggested that many of the insects lived in a distant forest on the south side of a large landmass, to the north of the Weald Sub-basin, known as the Londinia Massif. It is most likely here where the majority of the lacewing and snakefly fauna would have lived based on modern analogues; extant lacewings and snakeflies live in or around woodland areas (e.g. Duelli et al., 2002). The Osmylidae species could possibly have inhabited the woodland bordering the watercourses closer to the site of deposition, due to their larvae being semi-

aquatic, and therefore needing a source of water close by. This is further supported by their wings being better preserved and less fragmentary, indicating a shorter period of travel. **Figure 7** shows a schematic reconstruction of the Weald Sub-basin palaeoenvironment, also summarizing the taphonomy.

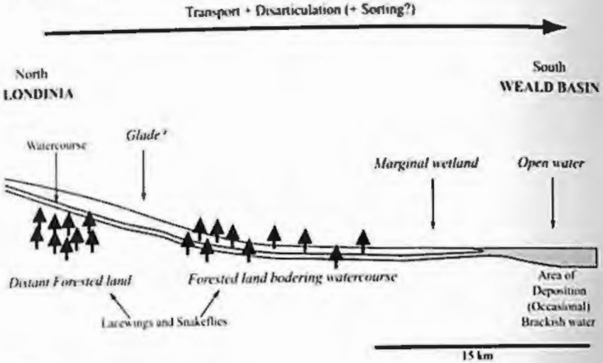

Figure 7
Schematic reconstruction of the palaeoenvironment of the Weald Sub-basin showing where the lacewings and snakeflies lived with regards to the area of deposition (modified from Jepson, 2010).

Future

The lacewings and snakeflies represent only two orders of insects from a much greater fossil insect fauna of the Wealden Supergroup. There is still a vast amount of work that needs to be completed on the insects from these rocks. Prior to my study on Wealden lacewings and snakeflies only one species had been formally described, now there are 17 known. This situation is going to be similar for many other insect groups in the Wealden, only lacewings (Jepson and Penney, 2007; Jepson et al., 2009), snakeflies (Jepson and Jarzembowski, 2008; Jepson et al., 2011), wasps (Rasnitsyn et al., 1998), dragonflies (e.g. Jarzembowski and Nel, 1996; Nel and Jarzembowski, 1998), grasshoppers and crickets (Gorochov et al., 2006) have been worked on in detail, others are yet to be studied. In museums there are numerous drawers of material waiting to be described, some collected yesterday, some collected over 100 years ago! The Wessex Sub-basin fauna is also in need of extensive study to build on the little work that has been done so far (e.g. Twitchett, 1994). The Hastings group also requires some intensive study of the clay bands to see what insects can be found. Although work on the insects from these deposits first began well over 100 years ago, with the work of Reverend P.B. Brodie (1845), and also the excellent work of Dr. Ed Jarzembowski in recent years, there is still much to be done to fully understand this fantastic fossil insect fauna.

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BURROWING BIVALVES AND SHUFFLING SHRIMPS; WHAT CAN TRACE FOSSILS TELL US ABOUT THE RATE OF SEDIMENTATION?

By Chris Arkwright

A summary of the lecture given by Peter Hardy about an investigation he undertook with the late Fred Broadhurst, which formed part of the MGA's Fred Broadhurst Memorial Lecture Day in November 2010.

Introduction

In the arenaceous sediments of the Upper Carboniferous there are very few body fossils, but relatively common occurrences of trace fossils which allow an interpretation of the palaeoecology. Some of these trace fossils indicate that the sandy sediments were often deposited very rapidly, as much as two metres of sand within the lifetime of one individual animal was observed, thus suggesting dramatic flooding. The critical factor which enabled this to be established was the recognition that many of the burrows were actually escape structures, made by animals which were being rapidly buried. In one example a sequence of seven or eight alternating coarse and fine bands is penetrated by a community of animals, showing that the entire sequence was laid down within one animal's life time. This suggested very strongly that the alternating cyclic units of sand and mud are of a seasonal, very probably annual nature.

There are many similarly cyclic units of clastic sedimentary rocks, in the Jurassic often accompanied by limestone horizons. These were also studied in an attempt to establish whether they too might have a seasonal control.

Upper Carboniferous trace fossils

An abandoned quarry on Billinge Hill, near Macclesfield, displays bivalve burrows, which were known as *Pelecypodichnus*, subsequently called *Lockeia*. These vary in depth from a centimetre or two, when they are classified as 'resting traces', to tens of centimetres, even up to a metre or more in some extreme cases. The depth of some of these burrows is not characteristic with modern bivalve behaviour, where no living species would normally dig down more than about fifty centimetres. This suggests that these structures are not really burrows in the usual meaning of the term, but are in effect upward moving 'escape shafts', made by animals under extreme stress during rapid burial.

Figure 1
Lockeia escape shaft, typically over 50cm in length, showing collapse of laminae as bivalve made rapid progress upwards to escape burial by sudden increase in sedimentation (photograph by F. Broadhurst)

Figure 2
Lockeia escape shafts with number of shafts diminishing upwards (photograph by F. Broadhurst)

Figure 3
Bivalve in escape shaft – Ravenhead Quarry
(photograph by P. Hardy)

Counting them at successive horizons in the rock revealed that numbers diminish upwards, which is difficult to explain for a colony of downward burrowers. The conclusion reached was that the animals started off at the bottom of any particular bed of sand and were buried, so that upward movement was their only hope of survival. Those which lived made it to the next pause in sedimentation, marked by a bedding plane, those which died were entombed and their traces finished.

Moreover, the shortest burrows, which are often well defined and closely resemble the shape of the animal shells, were obviously made by animals living in stable conditions, shallowly buried in the surface sediment, as are many modern bivalves, whereas the longest burrows, which tend to be poorly defined, were created as little more than a temporary disturbance of the sand as the animals passed through in their rapid upward escape from burial.

Further evidence of bivalve escape trails was seen in Ravenhead Quarry, at Upholland, near Wigan, when it was an active working brick pit (Broadhurst et al., 1980; Eagar et al., 1985). This site includes two coal seams which are separated by a wedge of sediment around 15 metres thick. The lower lithologies include muds and silts, with some bivalves and occasional plant fossils, then towards the middle of the sequence thin bands of sand begin to appear, just a few millimetres thick at first, but becoming up to 20-30 cm thick higher up, with thinner silt partings, culminating in several metres of sandstone below the next coal seam. These rhythmic units are repeated over a hundred times but the main interest lies in a few bands which have very obvious bivalve escape shafts penetrating them. The shafts are quite numerous in the lowest bands, but rather less frequent in higher ones, and in the seven or eight bands at the top none could be seen. The most

extraordinary feature of this sequence is that actual shells can very occasionally be found within the escape shafts themselves, and many more shells are seen on bedding planes in the silts in between the sand units.

It could be concluded that the shafts in successive rhythmic beds were made by the same individuals throughout the entire sequence. These animals were not successive generations, but individuals from one single successful brood which had colonised this area at the time of deposition of the lowest unit and had survived through around seven or eight episodes of burial, before they had been entirely wiped out. In other words, all of the sand/silt units which exhibited the escape shafts had been laid down within the lifespan of one living generation of bivalves. Whatever length that may have been, it clearly was not millennia, nor was it likely to have been centuries (although recent research in the cold North Atlantic waters has shown that perhaps the oldest living creatures on Earth may be bivalves, some with a lifespan of over 500 years). In all probability they might be expected to have grown to maturity in the warm equatorial waters of the Carboniferous in a few years and lived for maybe a decade or two.

It was further concluded that the sedimentary units were in fact seasonal, possibly caused by annual flooding, which is a well known phenomenon in modern equatorial regions. Thus seasonal sedimentation had been identified on the basis of trace fossil evidence.

These observations suggest that the entire 15 metre sequence between the two coal seams was possibly deposited within a century or two of the initial subsidence which buried the coal-forming forest on the down-throw side of the fault and created the deeper water basin. This is based on the extrapolation that each sandy unit represents one year and since they numbered in tens, or possibly low hundreds, the entire sequence represents at most a few centuries.

Upper Carboniferous environment

The Upper Carboniferous bivalves are known as 'non-marine', since they are almost invariably associated with sedimentary cyclothems in which coal seams are commonplace and river systems appear to have been the dominant environment. The marginal marine environment occasionally overtook some areas, leaving 'marine-bands' of fossils, which enliven the otherwise rather barren shales between the coal seams. The sea was apparently ever present at quite modest distance, but only dominated the region from time to time. It is probable that these marine incursions resulted from periodic subsidence after earth movements which suddenly deepened the faulted basins, allowing the distant sea water to flood in. Following this subsidence the basins were gradually filled, firstly by fine-grained mud or silt transported from the now further distant land mass.

As the basin shallowed the shore line extended, the waters became more turbulent and the sediment coarser. The earlier sediments in such a sequence contain the marine organisms which lived in the fully saline waters such as goniatites, orthocone cephalopods and scallop-like bivalves. The brachiopod *Lingula* usually occurs just above a marine band and represents the marginal brackish to saline conditions which followed. The non-marine bivalves could not survive in the most saline of the environments within this system, but once the waters became brackish or fresh they flourished in the muddier sediments where food, in the form of organic detritus, was abundant. They could not however survive in rapidly deposited thick sand units and most died if deeply buried. This made it clear that the most conspicuous rocks of the Upper Carboniferous throughout the region, such as the famous gritstone and sandstone edges, were probably deposited within a few days, certainly those in which bivalve escape shafts could be traced through metres must have been deposited very rapidly, after all, how long could a bivalve of two or three centimetres long survive under a metre or two of sand?

Lower Lias: North Somerset

Rhythmic alternations of sedimentary lithologies are also found in lower Jurassic sequences, although these cycles consist mainly of mudstone and limestone. Commencing with the lowest Jurassic (White and Blue Lias) in North Somerset, traces of upward escaping organisms, probably shrimp, are especially noticeable in the lime rich bands. Although the finest laminated shales are mainly devoid of any benthic fauna or traces, the paler lime-rich beds are often penetrated by trace fossils, including *Chondrites* a feeding tunnel system and protrusive vertical *Diplocraterion* burrows. Occasionally, horizontal U-shaped burrows, *Rhizocorallium*, are seen attached to the side of the vertical burrows, thus showing beyond any reasonable doubt that all of these u-shaped structures, protrusive or horizontal, were made by the same type of animals, or even the same individuals, depending upon conditions.

Thus we could demonstrate, through the variable morphology of this widespread and common trace fossil, whether the animal was actively moving around sideways in the sediment in search of food, in which case its burrow is called *Rhizocorallium*, or living in a fairly stable environment in its open-tubed vertical burrow, i.e. *Diplocraterion*. However, despite careful searching for sequential upward moving burrows, there appears to be no trace fossil evidence in North Somerset for the rate of deposition of the cyclic units.

Lower Lias: Dorset

The search was then extended to the Blue Lias of Dorset where *Diplocraterion* trace fossils are just as common as they are in Somerset, also associated with *Rhizocorallium*. Many examples of protrusive forms were found, with u-shaped tubes still open and disturbance (spreite) between them. Rarely the retrusive forms were seen, which are recognised by their tubes being absent with only the curving spreite seen in their place. It is clear that at times the shrimps had to burrow downwards to establish their 'homes' but at others they were required to migrate upwards or to perish. This evidence again failed to demonstrate any clear time scale for these banded units.

Middle and Upper Lias: Dorset

Moving up in the Jurassic succession, the Belemnite Marls (Middle Lias) are much less lime-dominated but still contain clear rhythmic units of dark, finely laminated shales, grading into paler lime-rich beds. Vertical trace fossil burrows were seen but with very little evidence of upward movement or rates of deposition.

However, it was noticed that the tops of the lime-rich bands had been eroded leaving lag deposits of shelly debris in topographical hollows. This indicates a regime of shallowing seas and increased energy during the development of the lime-rich sediments, and, in turn, implies a gradual infill of marine basins.

Therefore, the evidence seen in North Somerset and Dorset suggest that the whole Lias sequence represents a marine basin subject to repeated subsidence events (over millions of years) followed by gradual infilling with fine-grained clastic sediment, each sequence closing with lime deposition as the waters became more shallow.

Upper Jurassic: Dorset

The final stage in this investigation was conducted in the Upper Jurassic Corallian beds, which include sandstones, mudstones and various limestones. The laminated sandstones, known locally as the Bencliff Grit, are sufficiently lime-rich to include some nodular concretions known as 'doggers', many being more than a metre in diameter. The absence of many body fossils in this open textured sandstone is the result of redistribution of calcareous shell material. However, the abundant *Rhizocorallium*, seen as meandering flattened u-shaped tunnels on the bedding planes, and the vertical *Diplocraterion* are evidence that there had been animals living in this sand.

Some sections are dominated by retrusive *Diplocraterion* thus demonstrating the upward movement of the animals. This evidence combined with observations that the fore sets in the sand are up to a metre deep made it clear that they were deposited very quickly.

In contrast, the many oblique tunnels seen indicate more permanent settlement in burrows. Many of these are lined with organic debris and/or muddy sediment and named *Ophiomorpha*. Most start from the top of the sand units but can be found by downward penetration from the water interface or from an overlying more lime-rich bed. Some exposed tunnels show strong scratch marks made by the legs of the arthropod which created them. Clearly, the shrimps were living permanently within these tunnels. The shafts tend to be roughly triangular in vertical section, with distinct lateral projections at intervals up their sloping side walls. As the animals grew, incrementally shedding exoskeletons, the tunnels were enlarged by scratching away and widening the floor, leaving the lower corners of the earlier tunnels with a remnant of the lining material still wedged into the tunnel walls. The largest tunnel was their final home, and could be infilled either with unsorted sand or with laminated sand, probably dependent upon the speed of infill and on whether the backfill was made by the animal or by outside causes.

The Bencliff Grit is overlain by clays and nodular limestones, then a very distinctive coarse-grained pisolite and finally by a clean white oolitic limestone, the Osmington Oolite, less than a metre thick. The Osmington Oolite is characterised by the abundance of vertical trace fossils, commonly the vertical shafts are without bases and generally lack the 'spreite' (curving laminae) which characterise the retrusive form. These shafts are often lined with dark muddy sediment for stability, suggesting that the occupants lived in them for a while, rather than simply escaping upwards. In most cases they penetrate from a few centimetres to around 30 cm, often through an entire fore set within the bed of ooid grains, but others terminate within the unit at erosional breaks, so that the height of these shafts is very variable.

The evidence gathered over several metres of the exposure from three sample sites shows that the shafts are often restricted to individual fore sets, but usually commence within the muddier sediments at the base of the oolite. It was concluded that the entire oolitic bed had been deposited as a single continuous event, which smothered the established burrowing shrimp fauna by the advance of the ripple front. This either killed them by burial or they escaped to recolonise the upper layers of sediment. The benthic community clearly lived in very turbulent waters and was apparently buried by rapid sediment accumulation on more than one occasion

The Osmington Oolite was evidently deposited in a very short time (within the lifetime of one animal in any particular place) and clearly marked the end of an episode of prolonged infilling of a marine basin and the beginning of a shallow water stage, with active sediment movement but with little clastic input. Therefore, although the major Corallian depositional events (the Bencliff Grit and the Osmington Oolite) were rapid, probably only a few years in duration, they were in no way cyclic and, in common with other Jurassic sediments investigated, a definite time-scale could not be established.

Conclusion

It is possible to infer rates of sedimentation in the Upper Carboniferous by means of sequential upward-moving burrows or escape shafts of bivalves passing through cyclic sediments. However, this method is not possible with regard to Jurassic sediments either because of the lack of rhythmic cyclical sediments or sequential escape shafts.

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Chris Arkwright

THE EL TIME GROUP: A THICK SEQUENCE OF FLUVIAL CONGLOMERATES ON LA PALMA, CANARY ISLANDS

By Duncan Woodcock

In March 1854, Charles Lyell visited La Palma as part of his tour of Madeira and the Canary Islands. He was particularly keen to examine the Caldera de Taburiente (**Figure 1**), a large depression in the mountainous centre of La Palma that had previously been described by the German geologist Buch after his visit to La Palma in 1815 (Wilson, 1998). As well as the Caldera de Taburiente (**Figure 2**), Lyell was impressed both by a spectacularly deep valley, the Barranco de las Angustias (**Figure 3**), that runs South West out of the caldera and by a remarkable sequence of conglomerates that are exposed along the lower reaches of this barranco. Lyell included a sketch map of the caldera and the Barranco de las Angustias in the sixth edition of his "Principles of Geology", published in 1865 (reproduced as figure 5 in Wilson, 1998)

Figure 1
Sketch map of La Palma, showing locations mentioned in the text

Figure 2
The Northern wall of the Caldera de Taburiente with Pico Bejenado and the remnants of the Bejenado volcano visible in the middle distance.

Figure 3
View south west from the summit of Pico Bejenado into the Barranco de las Angustias.

The thick sequence of conglomerates that impressed Lyell is known as the El Time group (Roa, 2003). The sequence is up to 300 metres thick and contains mudstone and cross-bedded sandstone units in addition to the predominance of conglomerates. The El Time conglomerates are exposed in spectacular road cuts along the LP1; the main road along the western side of La Palma. The Barranco de las Angustias is a major obstacle that the builders of the LP1 had to overcome. Immediately west of Los Llanos the road begins its winding descent of 400 metres to the bottom of the barranco before climbing back up the northern wall. There are very few road cuts where it is safe to stop. It is considerably safer and more pleasant to examine the exposures within the barranco bottom upstream of the LP1 bridge where there is a convenient car park. **Figures 4** and **5** show details of an exposure at La Vina, towards the upstream end of the El Time outcrop where the shallow water facies are exposed.

Figure 4
The sedimentary sequence shown in rocks of the El Time group. La Vina, approximately 3km upstream from the road bridge in the Barranco de las Angustias. The lower conglomerate unit contains thin lenses of sandstone that attest to periods of slacker water. The upper sandstone unit contains thin cross-bedded and rippled units that indicate deposition in shallow water (Figure 5).

Figure 5
Details of the upper sandstone unit shown in Figure 4. The diameter of coin on the photograph is 20mm.

The deposition of a thick sequence of fluvial conglomerates and the erosion of an exceptionally deep barranco were unusual events during the development of a volcanic ocean island. They can be understood in the context of the development of La Palma, where sub-aerial volcanism began in what is now the north of the island with the growth of the Garafia volcano. This volcano was partially destroyed in a giant landslide and the Taburiente volcano developed within the collapse embayment. The Taburiente volcano in turn was partly demolished in the Cumbre Nueva collapse, leaving a collapse "caldera" that formed the nucleus of the present day Caldera de Taburiente (Carracedo et al. 1999).

A new volcano then developed within the collapse embayment. This volcano, known as the Bejenado volcano, grew rapidly and confined the drainage pattern to the northwest wall of the embayment, resulting in intense local erosion of the northern flank of the Bejenado volcano. The products of erosion were transported seawards and deposited in a large fan delta, known as the El Time group, that prograded offshore. Ongoing fluvial erosion has deepened the Barranco de las Angustias, which has cut down through the El Time sediments.

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LIVERPOOL GEOLOGICAL SOCIETY FIELD VISIT TO THE ARDNAMURCHAN PENINSULA 15-19 APRIL 2011

By John Iley

Introduction

Over the weekend of the 15-19 April 2011, the Liverpool Geological Society held a field session on the Ardnamurchan Peninsula. It was led by Professor Jeff Harris, who has studied this area for many years along with students from the University of Glasgow. The intention of the field visit was to get an appreciation for the local geology and to explore the three volcanic central complexes (known as AC1-AC3) in some depth (Gillen, 2003).

During the visit we stayed at the Sonachan Hotel [grid reference NM 454 664] which was well placed as a base for the field days. The group, nine in total have of a range of backgrounds from Earth Science graduates to amateur geologists. Prior to the trip, Jeff had issued an itinerary as follows:

DATE	ITINERARY
16 April	Geological mapping exercise near Loch Mudle to get an appreciation for the country rocks of the Moine (Precambrian), Mesozoic and Tertiary.
17 April	Explore the eastern side of Ben Hiant in AC1 to look at the igneous rocks and consider the relationship between these rocks
18 April	Visit Eilean Carrach (AC2), Mingary Castle (AC2), Sanna Bay (AC3) and Major Centre (AC3) to look at unconformities, faults, magma-mixed rocks, relationships between igneous and sedimentary rocks and a fossil locality in the Mesozoic sediments (near Mingary Castle)

Before reviewing the findings of the field visit it useful to consider why this area is so important geologically and to get an appreciation of previous studies.

Background

The Ardnamurchan Peninsula is part of what is known as the North Atlantic Igneous province (NAIP), which developed on thinned continental crust arising from rifting and sea-floor spreading and marked the opening on the North Atlantic Ocean. This process began 70 million years (Ma) ago and resulted in the separation of Newfoundland and Greenland from Europe. It is recognised that this process is driven by a mantle plume (Thordarson and Hoskuldsson, 2009) which is still active today and currently associated with Iceland. Iceland was born 25 Ma ago and its land mass is still increasing as a result of spreading of the mid-Atlantic ridge.

Intrusive and extrusive igneous activity which spanned the time interval 60.5 – 55 Ma is often referred to (Richey and Thomas, 1930) as the British Palaeogene Igneous Province (BPIP). Other parts of the province are west and east Greenland, the Faroe Islands, western Scotland and north eastern

Ireland. In western Scotland, central complexes have been recognised on Skye, Rhum, Mull and Ardnamurchan. They represent the roots of large Palaeogene volcanoes and comprise of a wide range of igneous intrusions and extrusive flood basalts.

Since the early twentieth century and up to the present day these central complexes have been studied in some detail (Brown and O'Driscoll, 2008) and interpretations of the geology has been revised and refined. One the most important researchers in this area was Richey who from the 1920s to the 1960s worked on various palaeogenic centres. More specifically he identified three successive intrusive centres on Ardnamurchan (Richey 1932).

- Centre 1, the oldest, is mainly basic cone sheets and associated outcrops of fragmental rocks.
- Centre 2, is mainly basic cone sheets and a number of large ring intrusions.
- Centre 3, the youngest has a feature attributed to magma chamber collapse and ring-dyke intrusions. The largest intrusion associated with Centre 3, the Great Eucrite, forms an elevated ridge which dominates the Ardnamurchan landscape (**Figure 1**).

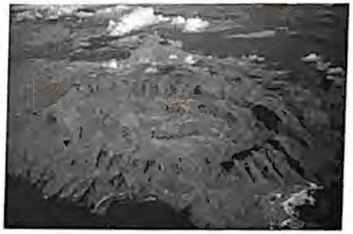

Figure 1
Aerial view of the Ardnamurchan Central Igneous Complex
(© Patricia & Angus Macdonald/Aerographica/SNH)

Richey also made important contributions to the theories of ring-dyke and cone sheet emplacement; magma chamber subsidence and produced detailed maps.

More recently, the models for ring-dyke and cone sheet emplacement have been refined by (O'Driscoll, 2007), who suggested that the Centre 3 intrusion is a lopolith with a funnel shaped geometry. A lopolith is a concordant igneous intrusion (Anon, 2008) that has a saucer shaped form. Collapse of a volcanic crater due to emptying of a large magma chamber or cauldron can result in formation of arcuate fractures. These fractures can fill with magma

taking the form of cone sheets and ring-dykes. A cone sheet is a dyke having a cross-section like a cone which dips inwards towards the igneous body feeding it with magma. Ring-dykes are cylindrical sheet intrusions which dip outwards towards the igneous body. Further work (Brown and Bell, 2007) on the Centre 1 cone sheets has suggested that emplacement of the Ardnamurchan Central Complex (ACC) with magma caused uplift, doming and faulting. This resulted in catastrophic gravity-driven events in which slabs of basalt, dolerite and sandstone (some up to 30m across) were transported as megablocks. These episodes were interposed with lower energy periods during which lacustrine-fluvial processes produced volcanoclastic siltstones and sandstones in an upland landscape of mature pine forest and streams draining into lowland areas of swamp-filled valleys.

The following sections summarise the outcome of the field visits associated with the three volcanic centres and the surrounding country rocks. In order to identify specific locations OS grid references are given which refer to OS Explorer Map 390.

Rather than refer to detailed geological maps the group was encouraged to infer the stratigraphy by observation and mapping. However, in preparing this article, reference has been made to the BGS geological map (UK North, scale (1:625 000)) and handbook (Stone, 2008). Also, a useful BGS App (iGeology) which runs on an iPhone or iTouch provided geological maps at a scale of (1:625 000) and (1:50 000). The App relies on a network connection (WiFi or 3G) to obtain the maps and other information. The scale of (1:50 000) provided sufficient geological information to help underpin stratigraphy, geological structures as well as information on rock types.

Geological Mapping Exercise

This locality was near Loch Mudle and Jeff helped us to identify various rock exposures and take strike and dip measurements of the various stratigraphical units. At the first location [NM 548 654] we indentified pepperite which consists of fragments of volcanic rock supported in a matrix. Alongside the pepperite were Precambrian Moine basement rocks of psammite (metamorphosed sandstone) and pellite (metamorphosed shale).

After walking around a spur we looked at outcrops visible in two almost parallel steep sided valleys occupied by streams. The streams merged before draining into Lochan Gruagaich. Here we identified outcrops of Jurassic limestone lying unconformably on top of the Moine rocks. Further upstream we encountered basaltic lava flows on top of the Jurassic limestone. At higher topographic levels dolerite cone sheets emplacements were identified which stood out as ridges on the landscape. Dykes, cutting across the valleys were also evident and a reverse fault where basalt of Palaeocene age lay unconformably on top of the Moine rocks. A possible explanation for this was upthrow of the Moine rocks followed by erosion of the limestone and subsequent arrival of basalt lava. Jeff pointed out fossils confirming the limestone was of Jurassic age.

Ben Hiant (AC 1)

This field day centred on the south eastern side of Ben Hiant and took us to a waterfall, Richey's Gully and other localities of geological interest.

At the base of the waterfall [NM 542 623] folded Moine psammite was observed and the psammite was intruded by a dolerite plug which forms the steep crags of the waterfall.

In Richey's Gulley [NM 540 621] Mesozoic sedimentary rocks overly Moinian psammite. Amygdaloidal basalts lie on top of the Mesozoic rocks, for example, basalt containing large quartz agates was noted at the base of a nearby waterfall. Several dykes cutting the lavas were observed and some display well developed columnar jointing. At a higher level (approximately 250m) in Richey's Gully close to Stallachan Dubha [NM 540 622] a pod of andesite pitchstone was identified. On the eastern side of the gulley the pitchstone displays spectacular fan-shaped jointing. Columnar-jointed dolerite sheets cap Stallachan Dubha. Dolerite sheets also form the summit area of Ben Hiant. Unfortunately, as a result of the weather closing-in and poor visibility it was unsafe to walk to the summit.

Eilean Carrach (AC2)

The main point of interest at this locality [MN 425 676] is the Sgurr nam Meann ring-dyke which outcrops in an arc over a distance of c.6km to the south of Sanna Bay. The ring dyke is identified in the field guide as a hybrid intrusion of dolerite mixed with microgranite and felsites. It is suggested in the guide that mixing of hot basic magma (c.1200 °C) with cooler silicic magma (c.900 °C) resulted in rapid cooling and solidification of the basic magma. As a result, angular and crenulated clasts of dark dolerite can be seen embedded in a matrix of pale silicic material (**Figure 2**).

Figure 2
Magma mixing in Sgurr nam Meann ring-dyke at Eilean Carrach

Close to the ring-dyke a localised zone of pegmatite with coarse pyroxene crystals up to 5cm across were observed (**Figure 3**)

Figure 3
Localised zone of pegmatite containing coarse pyroxene crystals up to 5cm across

Our next stop gave us the chance to visit the Ardnamurchan Lighthouse which is located [NM 416 650] at the most westerly point on the Scottish mainland. The lighthouse was designed and built in 1849 by Alan Stevenson, uncle of the author Robert Louis Stevenson. It is built of Ross of Mull granite and stands robustly on top of dark coloured gabbro volcanic rock. It is 36m high and built 55m above sea level. Egyptian influences can be seen in the entrance to the tower and the arches (corbel) at the top of the lighthouse tower beneath the balcony (**Figure 4**).

An excellent exhibition of local geology associated with the Lochaber Geopark can be seen at the Lighthouse Visitor Centre. The exhibition traces the volcanic activity and ice ages that have shaped the Lochaber landscape.

Figure 4
Ardnamurchan Lighthouse

Figure 5
Mingary Castle and associated igneous and sedimentary rocks Mingary Castle (AC2)

Mingary Castle [NM 503 631] sits on top of an igneous intrusion (**Figure 5**). The underlying Mesozoic sedimentary rocks close to the shore are highly fossiliferous. Assemblages of *Gryphaea* sp. (**Figure 6**) confirmed that the rocks are of Jurassic age. These fossil oysters are also known as 'Devil's toenails' (Palmer and Cockburn, 2008) due to their curved shape and layered structure. In this location the Palaeocene igneous rocks lie on top of the Jurassic sedimentary rocks.

Figure 6
Assemblages of *Gryphaea sp.*

Sanna Point (C2)

At this locality [NM 440 701], igneous intrusions of hypersthene-bearing gabbro are evident (**Figure 7**). Structures known as 'augen' (derived from the German word for 'eyes') were observed in the hypersthene gabbro (**Figure 8**). The intrusion dips at an angle of c.15 degrees towards a focal point to the South East.

Figure 7
Looking across Sanna Bay towards Portuairk

Figure 8
Augen structure in hypersthene gabbro, Centre 2

Major Centre (AC3)

This short excursion gave us an appreciation for the igneous intrusions and topography associated with this major volcanic centre. The walk took us from the outer rim across to the centre. The first location [NM 472 665] was at the parking area on the road side close to Achnaha where we identified gabbro (**Figure 9**) as the outer rock type. This cross-referenced with the geological map as an outer unlayered gabbro. We then walked towards the centre [NM 470 666] and stopped to look at tonalite rocks and in the centre quartz monzonite.

Figure 9
Gabbro associated with the periphery of Centre 3

Figure 10
Group photograph in the middle of Centre 3

The overall structure of centre 3 has been interpreted as a lopolith or funnel shaped body (O'Driscoll, 2007), whose mineral fabrics and magmatic layering are attributed to central directed sagging. Having reached the centre a team photograph was taken (**Figure 10**) which also shows the outer elevated rim of Centre 3.

Summary and Comments

In summary, the field visit gave us an appreciation of the geological events which have shaped the distinctive landscape of the Ardnamurchan Peninsula. The landscape has not only been altered by vulcanism and emplacement of igneous bodies but also significant erosion as a result of glaciations and weathering processes. Hence, all that is now remaining are the roots of ancient volcanoes and associated structures. Interpretation of these structures i.e. ring-dykes, cone sheets and as to how they came about is subject to much debate. Currently, it would appear that Centre 3 is interpreted (O'Driscoll, 2007) to be a lopolith arising from a collapsed magma chamber.

Of great interest was the range of intrusive igneous rocks associated with the various centres. In one example, slow cooling rates resulted in pegmatite with coarse pyroxene crystals of several centimetres in size.

Centre 3 had the best preserved igneous emplacement structures and contains mainly coarse grained igneous rocks with mineralogy which changes from the outside to the inside of Centre 3. Mineralogy was reflected by the different proportions of plagioclase, silica (quartz) and alkali feldspar and can be understood by cross-referencing the BGS publication (Gillespie and Styles, 1999). Outer rocks were coarse grained gabbro, a basic rock. Moving towards the centre we came across tonalite, a granitic rock; and in the centre, quartz monzonite, a syenitic rock.

In summary, the field visit helped improve our mapping skills and gave us an understanding of how different structures and petrology can arise from magma mixing, magma cooling rates, magma emplacement and contact of hot magma with surrounding rocks. Viewing faults, unconformities (time and structural) and fossil localities pointed out by Jeff also helped us make connections between the various units of stratigraphy. Finally, it is worth mentioning that we all appreciated Jeff's commitment to ensuring this was a valuable learning experience as well as injecting good humour along the way to make it a memorable and enjoyable three-day trip.

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THE FIRST MANCHESTER GEOLOGICAL ASSOCIATION FRED BROADHURST MEMORIAL FIELD TRIP

By Jane Michael and Sue Plumb

Dovedale, 4th September 2010

On a sunny day about 20 people gathered in the car park at Dovedale for the first Fred Broadhurst Memorial Field Trip. Fittingly, it was based on one of Fred's Rocky Rambles (No 7), adapted and led by Jane Michael. It was lovely to have the company of Rosemary Broadhurst and other members of Fred's family on this occasion.

Jane gave us an introduction to the geology of the area, which is early Carboniferous reef and bedded limestone, altered by relatively recent glaciation. The knoll limestones are Milldale Limestone and therefore some of the oldest Carboniferous rocks in the Peak District. Limestones of the Lower Carboniferous comprise marine shell debris although, as we found, there are areas where discrete fossils can be found. These are usually in a good state of preservation and thus identifiable and include corals, brachiopods and crinoids. Whilst there is evidence of volcanic activity in the Peak District, none was seen during this trip.

Crinoids and Brachipods in the Stepping Stones

After watching the arrival of the refreshment kiosk, which looked like a stone building, pulled by a tractor into the car park, we walked upstream along the River Dove, past the Gauging Station which measures river flow. The path skirts Thorpe Cloud which was ascended by part of the party later in the trip until the Stepping Stones across the river were reached at a left hand bend in the river. These stones, polished by numerous boots and shoes, show crinoid and brachiopod remains. A crush stile also has many fossil remains and the party spent several minutes investigating these two sites.

The valley at this point is more of a gorge with steep sides, well wooded

Dovedale

This owes its origin, according to Fred, to a time during the last Ice Age (Pleistocene) when all subsurface water was frozen and melt waters at the surface were able to deeply erode the actual limestone surface. This makes for a very impressive valley with several 'towers' – limestone pinnacles. One of these, Dovedale Castle, on the opposite side from our path was partly obscured by vegetation.

The path leading upstream was generally gently rising until we reached steps leading up to Lovers Leap. These steps are a palaeontologist's dream, as we investigated the many crinoids and some brachiopods in the steps, which we hoped were constructed using local stone! A few blocks were of a much darker colour and we wondered about the environment of deposition for these, and mentally compared them with the Ashford Marble. At the top of the steps, the limestone pinnacles known as the Twelve Apostles could be viewed from Lover's Leap, but we were hard pressed to spot all twelve due to the vegetation. At this point, it was noted that the trunks of some of the trees were curved. This demonstrated growth on unstable ground.

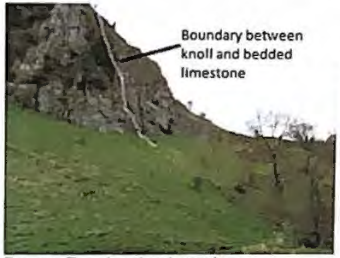
Group at Lovers Leap

We continued up Dovedale, past Tissingston Spires – reef knoll limestone where the shape of the 'towers' is controlled by joints. Some members of the group spent time looking at the remains of a water-powered pumphouse – water was raised up to the top of the cliff to irrigate the fields above during periods of low rainfall, although this did not appear to have happened for some considerable time. We passed several caves in the cliffs whilst looking, unsuccessfully, for Reynard's Cave. Ilam Rock and Pickering Tor were the next landmarks, both in knoll reef limestone.

Dove Holes Cave

Dove Holes Cave was our lunch destination. This is a large formation comprising two linked caves; their bases standing probably five metres above the river. The largest cave is 60 feet high and 30 feet wide. It was worth the

scramble to get inside and to the back. There did not appear to be a way out at the rear of the cave although at one stage there may have been.
Our final locality Ravens Tor appeared on the opposite bank. This is where the contact between knoll reef and bedded limestone could be seen – the bedded limestone was probably deposited in deeper water.



Ravens Tor showing boundary

Reynards Cave Arch

Walking a little way further brought the group to an exposure of the bedded limestone. It is easily distinguished from the 'reef' limestone although it was rather dusty. There were no obvious fossils.
Whilst Fred Broadhurst's original walk returns using a high route to give views up and down the valley, Jane decided it was better on this occasion to return along the same route. This did enable us to find Reynard's Cave and the natural arch in front of it – how did we miss it on the way up Dovedale? There was a lot of vegetation though. Several members of the party climbed up the steep path to investigate this amazing formation and the cave which lay beyond.
Jane took a small group up Thorpe Cloud to look for stromatolites on the top.

Thorpe Cloud

After a steep climb and a couple of stops to look for brachiopod fossils, they arrived on top. After much searching, Tali Broadhurst finally found some telltale concentric circles which the group agreed could be the missing stromatolites.

Stomatolites at the top of Thorpe Cloud

Since Fred originally wrote the book, thousands of feet plus the weather have eroded the limestone making these ancient algae very difficult to find. The views from the top were excellent were worth the ascent. In addition to brachiopods (and the stromatolites), Fred had indicated that trilobites, bivalves and gastropods could be found – a unique assemblage associated with carbonate mounds or knoll reef limestones. Unfortunately very few fossils were found on the top at all.
The sun shone as we strolled back to the car park and a most welcome ice cream or cup of tea.

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Sue Plumb and Jane Michael, September 2010

ROCK AROUND WILLIAM BROWN STREET, LIVERPOOL

By J.D. Crossley and H.E. Clark

Ten years after the original publication of *Rock Around Liverpool* it seemed to be a good idea to produce a new, revised edition particularly as the Liverpool One complex had just been completed. However, the building, cladding and paving stones of Liverpool One, lack variety, meaning that any additional material would be negligible! Instead, it was thought better to follow up the very popular Guide to Liverpool Airport leaflet (which was out of print in no time) with a series of similar leaflets. These would not only encourage visitors to the city to appreciate the fascinating variety of geological phenomenon to be found, but would also arouse their curiosity about the natural world surrounding them.

To put the geological content into a Liverpool context, the Street formerly known as Shaw's Brow was renamed after Sir William Brown M.P. (1784-1864) who was born the eldest son of a Belfast linen merchant in Ballymena, County Antrim. After a "good middle class education" he joined his father's business in Baltimore before returning home and then moving to the main port of entry for American exports, Liverpool. Moving out of the linen business into cotton and ultimately into merchant banking he helped to establish the Bank of Liverpool in 1831. For Liverpudlians his main claim to fame was that he gave the money for Liverpool's first public library and museum (opened 18th October 1860 – just after the LGS was formed) which was named after him. In 1862 "in recognition of his eminent commercial position and generous conduct towards the public of Liverpool" he was made the first Baronet Astrop. He died at his home on Richmond Hill, Anfield and is buried in a vault on the East wall of St James' cemetery, adjacent to the Anglican Cathedral.

There are at least three very good reasons for writing about William Brown Street. Firstly, the assemblage of superb neoclassical Victorian buildings is testament to the former wealth and greatness of the City of Liverpool. Secondly, is the presence of beautifully displayed, diverse minerals, rocks and fossils in William Brown Street. Thirdly, dominating the lower part of the Street is the World Museum where people can handle geological specimens in the Clore Natural History Centre.

An additional consideration was that people with a prior interest and knowledge of geology would be likely to visit the World Museum where these leaflets will be displayed. It is also hoped that the leaflet will be available in the Walker Art Gallery, the Central Library (on its completion) and St George's Hall.

It seemed appropriate to start the William Brown Street trail with the most spectacular feature – the 132ft (40m) Wellington's Column. Wellington's statue (allegedly composed of melted down cannon from the Battle of Waterloo) is perched on top of a Doric column of Carboniferous Darley Dale (Derbyshire) "Millstone Grit" sandstone. The plinth is composed of Aberdeen Granite and exhibits many interesting features (see below).

The leaflet concludes at the World Museum where not only are there wonderful floor slabs but also *Quetzalcoatlus northropi* which was the last and the largest of the pterosaurs with a wing span of 12 metres which is somewhat greater than that of the iconic World War II fighter plane - the Spitfire.

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The Wallace Pitcher Prizes

With the death of Wallace Pitcher, the eminent and much respected Jane Herdman Professor of Geology at the University of Liverpool who was also a long standing supporter, member and trustee of the Liverpool Geological Society (LGS), the LGS Council decided to celebrate his contribution to both the science of geology and to the LGS. In view of his lifelong interest in fieldwork, annual cash prizes for 'fieldwork' have been established.

The LGS Council hope that readers may be able to spread the word, particularly to Schools at Primary and Lower Secondary level but also to those centres doing GCSE, AS and A Levels and University Departments. A brief summary of the criteria follows while full details may be found on the LGS website www.liverpoolgeologicalscoiety.org.uk or obtained from the Honorary Secretary Joe Crossley lgshonsec@gmailcom

Criteria for the Wallace Pitcher Prizes

Essentially, the prizes are for fieldwork in NW England/N Wales OR fieldwork anywhere by educational establishments/individuals/groups resident or working in NW England/N Wales.

Category 1:
A submission arising out of investigative fieldwork at University undergraduate or postgraduate level.

Category 2:
Similar to Category 1 but by persons not currently studying at University

Category 3:
Primary, Secondary or Sixth-Form/College. This award is intended to be much more open ended and may be

- Done as part of normal curriculum, or (e.g.) Duke of Edinburgh
- Individual or group work
- A written report (depending on level of student(s)) with input in any medium or mix of media (video, photo, painting, modelling)
- Written element: Primary max 500-600 words, Secondary max 1500 words. The length and quality of work would be appropriate for high achievement at the relevant age, allowing for the actual ability of the student.

Entry forms may be downloaded from the LGS website www.liverpoolgeologicalsociety.org.uk and entries must be submitted by March 1st each year. Prize money will vary, according to quality and number of entries received at the discretion of the Society.

Mike Collins, President Liverpool Geological Society

Joe Crossley, Hon. Secretary Liverpool Geological Society.

9. The World Museum forecourt, entrance hall and atrium are floored with cut slabs of rock formed by violently explosive volcanic eruptions. The grains thrown out from ancient volcanoes to form these fragmental *ashes* and *tuffs* from the Elterwater region of the Lake District. In many cases they were moved around by flowing or wave disturbed water to produce ripples on the top of layers (a), best seen in cross section by the giant spider crab in the corner of the atrium. On occasions, the force of the water washed away some of the earlier underlying volcanic material producing uneven bottoms to the layers. In many cases these were accentuated by the weight of the coarser sediment causing it to sink into the underlying rather sloppy mud, to form load casts (b

To explore and learn more about minerals rocks and fossils go to the Clore Natural History Centre on the second floor of the World Museum, William Brown St

http://www.liverpoolmuseums.org.uk/wml/earth/

The Liverpool Geological Society

In December 1859, a small group of ordinary men met and agreed to form the Liverpool Geological Society. Today the Society flourishes, still composed overwhelmingly of ordinary people who have an interest in geology in all its many aspects—from volcanoes to floods, deserts and seas, mountains and glaciers, minerals, rocks and fossils.

The Liverpool Geological Society, ever since its first open meeting on 10th January 1860, has invited the knowledgeable and famous to come and tell all those interested in the wonders of the world and its even more amazing history, beginning some 4,600,000,000 years ago

Trips to sites of particular geological interest have also been a long standing feature of the Society. Much more recently, practical sessions in the laboratories of Liverpool John Moores University have enabled those wishing to gain hands-on experience, to apply a range of fascinating techniques to a wide variety of specimens and samples.

For more information about the Society please visit the web site

Joe Crossley spent his 42 year career as a Geology teacher and lecturer, latterly at LJMU. He has been the Honorary Secretary of the Liverpool Geological Society since 1969 and was President of the Society between 1983 and 1985

Hazel Clark works in Earth Sciences at LJMU and teaches night school classes for Continuing Education at the University of Liverpool. Hazel was President of the Society from 1997-1999

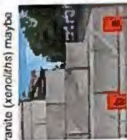
Liverpool Geological Society

http://www.liverpoolgeologicalsociety.org.uk

ROCK AROUND LIVERPOOL

William Brown St

1. The rock forming the plinth of Wellington's Column was a very hot molten mixture (*magma*) which cooled deep in the Earth's crust. It has only been exposed at the surface after hundreds of millions of years of weathering and erosion. Containing a high proportion of silica (SiO_2) this granite from Aberdeenshire is made mainly of crystals of white feldspar (the commonest mineral in the continental crust), grey, glassy quartz and black biotite. Thin sheets or veins of aplite (a) and quartz occupy former cracks in the granite mass and represent the last part of the cooling fluid. The dark inclusions (b) in the granite (*xenoliths*) maybe inclusions of either the surrounding country rock into which the fluid magma was intruded or earlier solidified parts of the magma itself



Other Publications

Liverpool Geological Society

The Geological Journal

Rock around Liverpool

Rock around Wirral

Rock around Chester

The William Smith map

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

Contact: Bob Bell, 5 Brancote Gardens, Bromborough, Wirral CH62 6AH (telephone 0151 334 1440)

Michel Levy Charts*

Stereographic Projections*

*Contact Mr N C Hunt, Department of Earth Sciences, University of Liverpool, PO Box 147, Liverpool L69 3BX or email: scfc@liv.ac.uk

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 (£1.50)

Geology Trail of Knutsford's Buildings and Cobbles (£1.50)

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

A Building Stones Guide to Central Manchester

Available from Rosemary Broadhurst, 77 Clumber Road, Poynton, Stockport SK12 1NW

2. On the surface of the steps a series of very narrow and shallow ridges and furrows, called *primary current lineation*, are formed in fast flowing water, parallel with the ancient current direction.

3. The bollards surrounding Wellington's Column are composed of a nodular limestone of Lower Carboniferous age (about 350 Million years old) from North Wales. **On the fountain side of the 5th bollard on the right of the steps (2)** is a large, *solitary coral*. Such corals grew vertically towards the light in clear, shallow, tropical seas; being unable to fix themselves to the bottom of the sea they tended to gradually fall over. The corals always resumed growing upwards and are therefore curved

4. On the fountain side of the 5th bollard on the left of the steps (2) *Colonial corals* originated from a single corallite which then branched over and over again to produce a small, tree-like mass

5. On the fountain side of the 5th bollard on the left of the steps (2) *Brachiopods* consist of two shells (valves) one of which in this case is strongly convex and in juveniles, sat on the muddy sea floor. Then as the brachiopod grew, the convex valve was gradually buried by accumulating sediment; the other valve formed a concave 'lid' on top of the animal. One end of both valves grew much more quickly to remain above the accumulating sediment.

6. Contrasting with the light coloured granite of 1. much darker crystalline rocks are formed by the partial melting of rock below the crust of the earth. They contain much denser elements (such as iron and magnesium) than the granitic rocks of the continental crust. *Basalt* is black, *dolerite* is grey with very small (<2mm) crystals while *gabbro* is a mixture of coarse black and grey crystals. These rocks can be seen in the **cobbles and kerbstones outside the Walker Art Gallery**

7. Adjacent to St Georges Hall *Rhizocorallium* is the name given to horizontal U-shaped feeding burrows formed within the sediment, parallel with the sea floor, by shrimp-like creatures. As no body part of the animal is preserved, these are trace fossils.

8. The trace fossil *Arenicolites* is a vertical U-shaped living burrow produced by filter feeding, ragworm-like animals. These are preserved as pairs of rounded lumps on the surface of paving stones, as seen on the **pavement outside the Central Library**.