Farnham Geological Society

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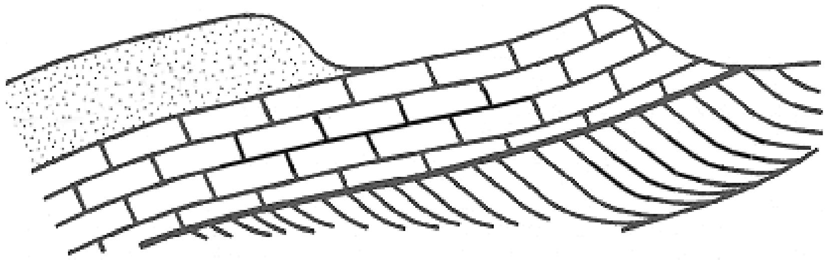

A local group within the GA

Vol. 13 No.3 **Newsletter** October 2010

Issue No: 76

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Editorial

This Newsletter seems to be dominated again by our 40th Anniversary Celebrations - the day of lectures and exhibits and the splendid Celebration field trip to the volcanic island archipelago of Madeira, which I felt deserved a full, unedited report. It was written by several of the members and compiled by Graham Williams. The newsletter can only fit in a few photographs of the various aspects of the Anniversary day and field trip, so I plan to upload more photographs onto the *Field Trip Photo Album* section of the Society's website. Also, and most importantly, FGS gratefully acknowledges financial support from the JAPEC Fund of the Geologists' Association for the 40th Anniversary Celebration event.

There seems to be a very igneous theme this time (unintentionally) as I have included the summary of the April Field Trip to Charnwood Forest in the East Midlands, which explored the Precambrian igneous province of that area and followed on perfectly from the previous day's lecture on the Santorini Supervolcano. Also included in this issue is a summary of the July lecture, given by one of our members, Dr Alan Witts, on the influence of geology on the development of narrow gauge railways in North West Wales. Space limitations have meant that the summaries of the April (Santorini) and June (Theron Mountains) lectures have been held over to the next Newsletter

Sadly, the Charnwood trip was the last one made by David Martin, an enthusiastic, well respected and ever-present member of FGS, who made a valiant effort throughout the whole Charnwood trip despite being so unwell.

FGS 40th Anniversary celebrations, June 26th 2010

Lyn Linse's comments echo those of the members and non-members who attended the FGS 40th Celebrations this summer. '*Sue Williams did an excellent job in organising the event and everybody who attended had a wonderful time. The speakers in the morning sessions at the Maltings were very good and everyone enjoyed wandering happily down memory lane whilst looking through the lovely photographic display of our field trip adventures. A lot of work had gone into the displays of the rocks and fossils, which proved of interest to all. The weather was very warm and sunny for the picnic lunch on the Hog's Back and the pleasant walk around the area afterwards. The whole event was rounded off by great fun at the evening party in Joan Prosser's garden. The many delicious contributions of food complemented the lively music provided by the Prossers and together made for a perfect evening and ending to the whole excellent event'*.

Marybeth Hovenden agrees - her life '*has been enhanced by FGS membership and its camaraderie since 1980'*.

Clockwise from top left:
1. Peter Luckham (Treasurer) views the fossil collection;

2. The display of rocks, minerals, and their petrogenesis;

3. Enjoying a relaxing lunch and then 4. A walk around the Hog's Back;

5. The evening celebrations kick off with Joan Prossser's band;

6. Graham presides over the celebration cake, and last but by no means least;

7. The morning's well attended lectures on Climate Change.

Climate and Getting Older – a Comment on the Birthday Celebrations by Janet Phillips

Those big birthdays – 30th, 70th etc are always slightly depressing. The way to cope is to thank God that you are not dead and then to have a party. So, for FGS's 40th birthday we had a party. Only, an oil geologist on the committee thought we would enjoy the party more if we had done some intellectual and physical work first!!

So our birthday on 26th June passed very happily. We gathered at the Maltings and viewed a display that included photographs from the last 40 years, fossils and rocks. Susan Williams had done the lion's share of the work and I am sorry for anyone who missed it. Luckily, many FGS members made it, together with an impressive number of visitors from other clubs together with our friends from Harrow and Hillingdon, Horsham and LOUGS (a total of 71 attendees, mostly from FGS but others from Harrow & Hillingdon, Horsham, Mole Valley, Reading, and West Sussex Geol Societies; of these, 55 joined the field trip and 50 stayed to party).

Then the lectures started: Prof Susan Marriott 'Late Silurian and early Devonian Climate as revealed by the Old Red Sandstone of South Wales'; Prof Malcolm Hart 'Was the Cretaceous greenhouse world always so warm?' and Dr Danielle Schreve 'Quaternary climate change and fossil mammals.' Notice -

a. these were first class lecturers who gave up their Saturday and came miles to educate us;
b. we were helped with a grant to pay their travel expenses – thanks GA Curry Fund;
c. the lectures were given in chronological order – impressive I thought;
d. the climate theme is topical and guaranteed to start a fight in our society - always fun.

We then leapt into our cars and gathered on the Mount in Guildford for a mass picnic lunch. As usual Graham had arranged good weather. It was so congenial that it took a little time to gather everyone for the field trip. Dick Selley came as joint leader. They proved a knowledgeable team, and we were treated to an interesting journey from the Guildford chalk back in history to the Atherfield Clay. By the end everyone could take an educated guess at what rock lay beneath the lovely views around them.

At last, we were allowed to party - eating strawberries and cream, a glass of while wine in hand, whilst listening to the Prossers' Band and talking to friends in a pretty garden on a warm June evening.

Finally, we would all like to thank all those who grafted. In particular Graham Williams for making it happen and Sue Williams and Joan Prosser for a huge amount of work.

FGS Field Trip to Charnwood Forest, East Midlands.

Led by Drs Steve Booth and John Carney

The localities visited lie to the N and N-W of Leicester. The sites visited on day one (Mount St Bernard Abbey, Charnwood Lodge, Warren Hills and Bardon Hill), led by Dr John Carney, and on day 2 (Bradgate Park), led by Graham and Liz in Keith's absence, were dominated by the Charnian Supergroup rocks of late Precambrian (possibly to early Cambrian) age. The rocks are igneous volcanic rocks (intermediate lavas – dacites and andesites - and intrusive diorite bodies, and ignimbrites - welded ash flows) and sedimentary rocks (mainly formed of clasts from the same lavas, called volcaniclastics), and included tuffs and tuffaceous sediments, agglomerates and slump breccias.

Cambrian-aged sandstones were examined at Bradgate Park and slates at the Swithland Wood Slate Quarry. This sequence of Precambrian-Cambrian strata form small outcrops on the tops of hills which jut through a younger blanket of thick Triassic mudstones (such outcrops are called inliers, i.e. where older rocks are surrounded by younger rocks). These red Triassic sediments were visible underfoot as we trudged down to and along the valley of Bradgate Park.

The last day was spent touring the offices and laboratories of the British Geological Survey (BGS) at Keyworth, led by Dr Steve Booth. This was a very interesting and informative visit viewing 3-D models and new methods of mapping, but space prevents description of this part of the trip in this newsletter. However FGS would like thank the BGS for their kind assistance that day and for their kind permission to reprint various photographs used in this article.

In late Precambrian times (ca. 600Ma), the British Isles were situated in the southern hemisphere but in two distinct areas. Scotland and the northern half of Ireland were located at about 60°S, on the southern edge of 'Laurentia', then still part of the supercontinent Gondwana. By contrast, England, Wales and the northern half of Ireland lay on the northern margin of 'Avalonia', a continental fragment that was splitting away from Gondwana and situated about 30°S of the Equator (Figure 1).

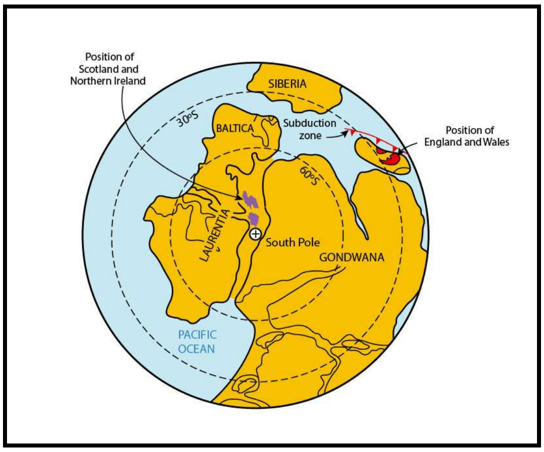


Fig. 1. The world in late Precambrian times ca 600Ma.

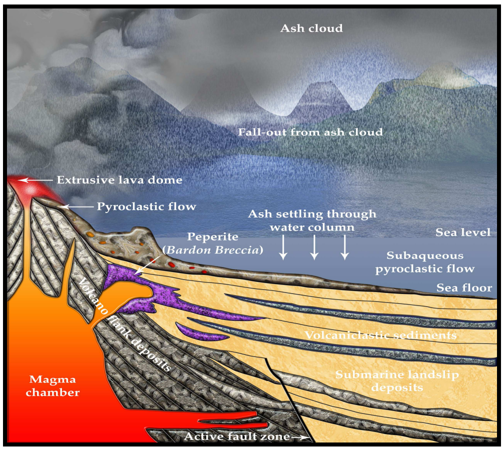


Fig. 2. Schematic of the Charnian Volcanic Province.

The northern margin of Avalonia (where Charnwood sat) was an active subduction zone. Magma rising from the melting of the subducted plate rose to form a series of explosively island arc volcanoes, similar to Soufrière Hills, Montserrat, in the Caribbean today (Figures 3, 4).

Fig. 3. Debris arising from a pyroclastic flow forms a fan running into the sea.

Fig. 4. Pyroclastic flow running out over the sea.

The volcanoes probably sat on the edge of a deep sea, into which, considerable layers of debris from the eruptions were deposited (as run off from the coast, aerial deposition and re-deposition as submarine landslides). Many vents ejecting material probably existed on the volcanic slopes and the numerous earthquakes associated with the underground movements of magma (especially when associated with collapsing caldera) made the slopes very unstable, consequently slumped sequences are relatively common. It is these volcanic rocks and marine deposits that form the Charnian Supergroup, a series of rocks in excess of 3,500m thick.

At Beacon Hill the outcrop comprised 560Ma rocks that showed the characteristic pattern of material deposited as turbidites. The beds varied between lighter, coarser grained material, 'sandstones' (Figures 5, 6), to darker, fine-grained mudstone deposits. Although of sandstone grain size, the 'sandstone' clasts were in fact of volcanic origin. Cleavage was clearly visible.

Fig. 5. A typical sand grade turbidite

Fig. 6. Sequence of coarse grained turbiditic rocks

At Bradgate Park, rocks of the Precambrian-aged Maxwell Group occurred. These were formed at a time of continuous volcanic activity and associated earthquakes. Blocks of volcanic rock as well as large amounts of ash and debris were blasted from volcanoes and settled in the surrounding seas. Earthquakes caused violent slumping of the sediments down steep submarine slopes, as demonstrated in the photograph below of the Sliding Slump Breccia (Figure 7). Visible are large pieces of broken rock, some contorted and bent in this violent episode.

Fig. 7. Slump Breccia (pieces over 35 cm long)

Fig. 8. A Sag Structure (see text for discussion)

The feature shown in Figure 8, also in the Sliding Stone Formation, caused some discussion. Further investigation suggested that there was tension along the bottom of it, as though the underlying beds had been stretched. John Carney's interpretation (private correspondence) is that 'the whole thing seems to propagate upwards from a thin sandstone bed. Perhaps this was fluidised and began to move slightly, causing the tensional structures and sagging in the beds above, which was then passively filled by later sediment towards the end of the event.' Since 575Ma, primitive soft-bodied animals had existed and their remains have been preserved in the volcaniclastic sediments of the area. One such was *Charnia Masoni*, see Figure 9 below.

Close to the ruins of Lady Jane Grey's house we examined thick rather homogeneous Cambrian-aged sandstones and an intrusion into the Charnian rocks. It is a diorite, a very colourful coarse grained igneous rock, with pink feldspar and green hornblende. We observed a highly polished surface which had been slickensided during fault movements. Subduction eventually ceased and with it volcanism in the area. Erosion gradually reduced the islands so that by Cambrian times (543Ma), the area was covered by a sea in which mud was deposited which would later form the Swithland Slates.

At Swithland Woods, the formation we saw was originally thought to be of Precambrian age, but the discovery of the trace fossil *Teichichnus*, which is confined to Cambrian-aged rocks elsewhere, has put this formation into the late Cambrian. *(Teichichnus is a simple feeding burrow that shows vertically to obliquely oriented spreite and probably made by a bivalve.)* We walked around the perimeter of a disused quarry in the Swithland Greywacke Formation. These rocks are extensively cleaved and have, in the past, been quarried. The Romans used this slate for roofing and in later times it was used for both roofing and headstones. Some local graveyards have these headstones, some with sections of *Teichichnus* visible. Figures 10, 11 show this trace fossil.

Fig. 9. *Charnia Masoni*

Fig. 10. The trace fossil found at Swithland Woods

Fig. 11. Internet image of the trace fossil *Teichichnus*

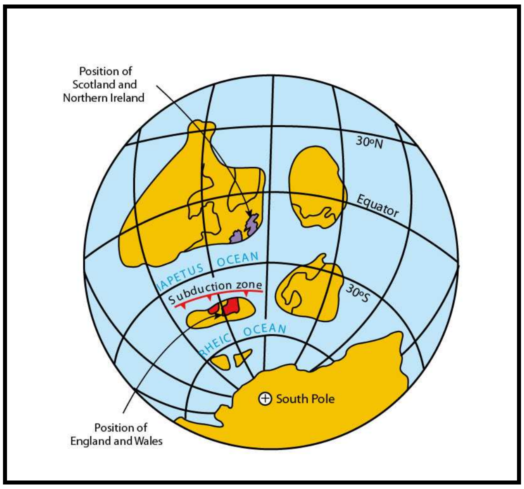


Fig. 12. The world, late Ordovician, ca 450Ma.

Towards the end of the Ordovician, ca. 450Ma, the microcontinent of Avalonia lay more or less equidistant between the remains of Gondwana in the south (separated by the Rheic Ocean) and Laurentia in the north (separated by the Iapetus Ocean), See Figure 12. Whilst Avalonia with what was to become England, Wales and southern Ireland had drifted south to lie about 50°S of the Equator, Laurentia had moved N to straddle the Equator, although the area where the north of the modern British Isles lay was about 20°S.

During this period, two important events were taking place. Subduction had started again to the N of Avalonia as had various types of igneous activity. Relevant to this area was the emplacement of slow cooling magmas at depth, which solidified to form the Mountsorrel granodiorite. The quarry at Mountsorrel, South of Loughborough, is the largest granite quarry in Europe.

Towards the end of the Silurian (ca. 420Ma) the area was caught up in a period of compression and mountain building, with fold structures (the SE-dipping Charnian Anticline) and low-grade metamorphism showing a strong WNW cleavage. This cleavage is found throughout the rocks of the area but most clearly visible in units such as the Swithland Slates. The Acadian Orogeny, part of the Caledonian Orogeny, saw the closure of the Iapetus Ocean and the collision of Avalonia with Laurentia along the Iapetus Suture. The suture runs approximately NE to SW and passes through the area of the Solway Firth. This event finally saw the joining together of the landmasses that form the modern British Isles. A major fault, the Thringstone Fault, was formed about this time. This fault forms the W boundary to the area and has had a major impact on the local geology and economy of the area.

During the Carboniferous Period the area straddled the Equator. Warm, shallow seas dominated with the deposition of limestone. However, most of the Charnwood area lay to the E of the Thringstone fault and formed an exposed mountain range. One of the few examples of Carboniferous Limestone occurs around Grace Dieu. The shallow seas gave way to swamps and forests, which form the basis of the N W Leicestershire Coalfields.

Early Permian times (ca. 290Ma) saw the closure of the Rheic Ocean in the south and the formation of the super continent, Pangaea, was almost complete. During the Permian Period (299-251Ma) the Charnwood area lay about 10°N in the midst of Pangaea. It was a stable area, on the London Platform, surrounded by areas of rift basin formation. Climatic conditions have been compared to those of Death Valley and erosion characterises this period with much of the Carboniferous sequence being removed.

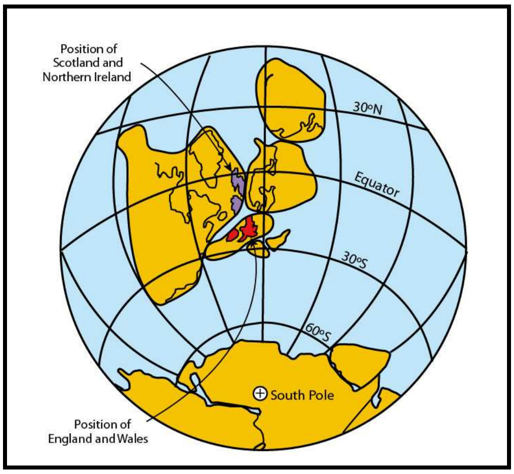


Fig. 13. The world, end of the Silurian Period, ca 416Ma.

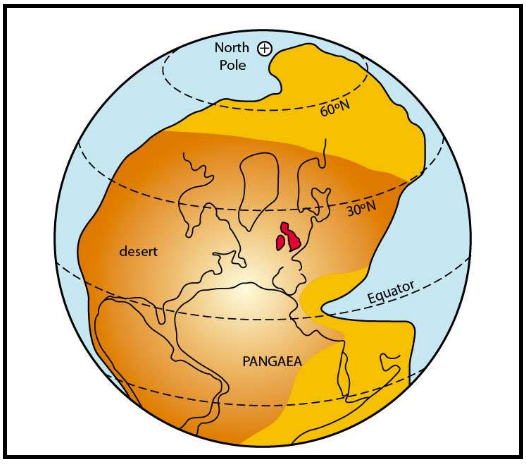
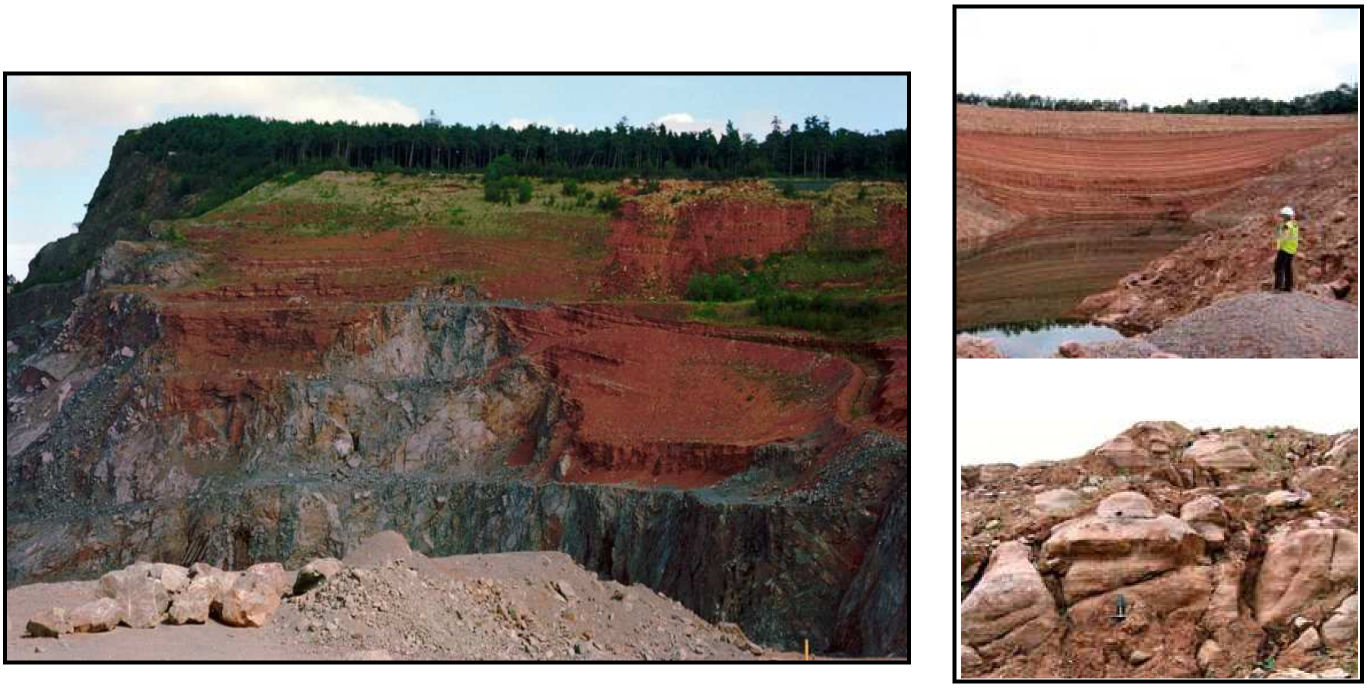


Fig. 14. The world, Lower Triassic, ca 250Ma.



Above: New Cliffe Hill Quarry, Stanton under Bardon, Leicestershire. Palaeovalley incised into Neoproterozoic rocks and filled by Mercia Mudstone. Top Right: Valley fill sediments; Btm Right: wind-eroded Charnian granodiorite tors underlying the Triassic.

The Triassic Period (251-200Ma) started with a period of fluvial deposition from large rivers that carried material from the Variscan Mountains to the S. The Charnwood area contributed material to these rivers. Examples of these deposits can be seen in the Shepshed Sandstone. The latter part of the Triassic Period was characterised by conditions akin to those in the present day Arabian Peninsula with a combination of flash floods forming deeply cut wadis, seasonal lakes, and for the most part, wind-blown, fine-grained silts and muds.

The result of this continental environment was the formation of a major unconformity which is illustrated dramatically below where the grey Precambrian-aged Charnian Volcanic Complex are overlain by the blanket of red Triassic fluvial and wind-blown sedimentary strata.

In the intervening period, up to the Quaternary (2Ma), the record of the Cretaceous, Jurassic and much of the Triassic strata has been eroded away. The Quaternary Ice Ages have left their mark as glacial tills and striations.

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Maps
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Andrew Ashley and Margaret Richards

Influence of geology on the development of narrow gauge railways in NW Wales

Summary of July lecture given by Dr Alan Witts, Member FGS

Geology has always had a strong influence of the development of railways, both in defining suitable ground formations through which to build the infrastructure and in creating demand for transport of economically important materials such as coal and building stone. The focus for this talk is the link between the rise and fall of the slate industry and the development of a supporting network of narrow gauge tramways and railways in NW Wales with particular reference to the Corris area. There are three main slate producing areas in the region of interest:

- A belt running roughly NE from Penygroes, through the Llanberis area to Bethesda containing the large quarries in the Nantlle valley, at Dinorwig and Penrhyn, generally considered to be of Cambrian age (Howells, 2007).
- A belt also running roughly NE from Porthmadog to Blaenau Ffestiniog containing quarries in the Croesor valley and at Blaenau Ffestiniog, considered to be early Ordovician in age (Howells, 2007).
- A belt with a similar orientation from the coast South of Tywyn, through Corris to Dinas Mawddwy with mines at Bryneglwys, Corris, Aberllefenni, Hendre-Ddu and Dinas Mawddwy, considered to be of late Ordovician age (Howells, 2007).

The slate in the above regions is considered to have originated as fine grained mudstone, which was subject to low grade regional metamorphism (high pressure low temperature). The pressure, generally from the NW, was exerted during the Caledonian Orogeny in late Silurian to early Devonian times (Howells, 2007). Cleavage in the slate, which is at right angles to the direction of the pressure, can be independent of the original bedding plane and is caused by alignment of mica-type minerals. Slate is composed of mainly very fine grained quartz and muscovite or illite, with biotite, chlorite, hematite and pyrite (Wikipedia). It can vary considerably in colour and consistency, thereby affecting its commercial value. Incorporation of small quantities of iron in ferrous and ferric oxidation states tends to produce greenish and purple tinges respectively, while the predominant colour is grey to black. The presence of iron pyrites compromises the longevity of slate due to oxidation.

There is evidence for small scale use of slate back to Roman times (Richards, 2006), but the great expansion of the industry occurred in the late eighteenth to nineteenth century as the Industrial Revolution led to demand for building materials. Although available in large quantity, slate deposits were usually located inland and at elevation and were initially difficult to exploit due to poor communications. Early transport by pack animals or horse and cart to suitable ports led initially to improvements in roads, but, in what became a highly competitive industry, innovation soon led to the development of dedicated ports and horse drawn tramways which greatly improved the efficiency of transport and hence reduced the cost of the delivered material. The pioneer tramway, which opened in 1801 and linked the Penrhyn quarry with Port Penrhyn (near Bangor), apparently allowed around 16 horses and 12 men to do the work previously done by up to 400 horses and some 140 drivers (Richards, 2006).

Others soon followed, serving quarries, for example, at Dinorwig (1824), Nantlle (1828) and Blaenau Ffestiniog (1836).

The Corris area entered the tramway age relatively late with the Corris railway opening as a horse drawn tramway in 1859. The Corris railway became part steam operated in 1879 and carried passengers as well as slate products from the 1880s. Business declined in the 20th century in line with the welsh slate industry and the Corris Railway was finally closed in 1948.

A society was formed in 1966 with the initial aim of restoring a short demonstration track at Corris. Over the succeeding 44 years the initial ambition has been achieved and greatly enhanced. A museum has been established in the old stable building at Corris. The original engine shed was purchased in 1981. Some ¾ mile of track was re-laid, and a diesel operated passenger train service commenced in 2002. A 10-year project to build a new steam engine culminated in steam-operated trains from 2005. Development has continued at increasing pace with 2009 seeing the completion of a new carriage shed built mostly by the railway's volunteers and commencement of a programme to design and build a second steam locomotive. In 2009, the volunteers ran demonstrations of horse-drawn and gravity-worked trains to commemorate the 150th anniversary of the opening of the original tramway. Progress since 1966 can be seen in Figures 1 and 2.

Fig. 1. Corris Railway's Main Engineering base following closure and lifting of rails in 1948.

Fig. 2. Similar viewpoint to Fig. 1, Main Engineering Base in April 2009, showing engine shed (in distance Left) and new carriage shed (Right).

Slate extraction in the Corris area has not fared so well. At its peak, the area possessed around 12 substantial mines and many small concerns, most of which were exploiting a ‘narrow vein’ of slate around 30m thick which dipped steeply into the ground at 60°-90°. This meant that the normal method of extraction was by mining rather than surface quarrying. The ‘narrow vein’ produced excellent quality slab slate, which was machined into rectangular slab in mills attached to the mines. Slate slab found a great many applications - from memorials, sills, lintels and manhole covers to snooker tables and mountings for electrical switch-gear. Off-cuts were used as a local building stone. A number of the mines survived WWII while some continued working into the 1970s. The final working mine, the large complex at Aberllefenni (Figure 3), finally ceased slate extraction as recently as 2003, although the associated slate working mill is still operating.

Fig. 3. Aberllefenni Slate Mine showing end-on exposure of the ‘narrow vein’ dipping at near 90°.

The story of slate mining and its associated railway at Corris nicely illustrates the ups and downs of a once great industry that exploited local geology. Slate is still produced in North Wales, notably at the Penrhyn quarry near Bethesda, while a number of rebuilt narrow gauge railways now bring tourists to the area. It is still possible to appreciate this heritage in the Corris area by taking a ride on the Corris Railway (www.corris.co.uk) and visiting the King Arthur's Labyrinth at the Corris Craft Centre which uses partially flooded levels of the Braich Goch slate mine for a magical mystery tour. Pre-booked visits into upper levels of the same mine can also be arranged by the Corris Mine Explorers (www.corrismineexplorers.co.uk). Here, the mine can be visited in the state it was left in by the miners on their last working day around 40 years ago and worked exposures of the 'narrow vein' can be observed.

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Alan Witts

FGS field trip to Madeira, April-May 2010

The Anniversary year was celebrated also by an array of field trips, the highlight of which was the trip to Madeira, April 25th to May 2nd, 2010.

Madeira is a volcanic island 600km west of Morocco. Its volcanic nature produces dramatic scenery with steep gorges radiating from rugged central mountains that rise to 1861m. The coastal scenery is spectacular with cliffs up to 600m high. Climate and vegetation varies from the desert of the eastern peninsula, through coastal vineyards and banana plantations, to lush deciduous vegetation on mountain slopes and to eucalyptus/pine forests in cooler mountain regions.

British visitors, particularly Lyell (1854), were the first to give geological accounts. Madeira rises 5000m from the 140Ma oceanic crust of the Madeira Abyssal Plain, part of the African Plate. Madeira is the product of a Mantle Plume above a 'hot spot' deep in the mantle. The African plate has drifted northwards over this 'hot spot' for over 70Ma, forming a string of volcanic piles of which Madeira is the most southerly and most recent. Today, the hot spot is just SW of Madeira.

Mantle Plumes And The Earth's Structure - The earth is ~12,740km in diameter and is stratified into layers:

- Lithosphere - the outer rigid shell, extending from the surface to ~100km. It consists of the crust and the very upper part of the mantle (oceanic crust is 4-20km thick, Continental crust is 30-70km thick, upper mantle ~50km thick). The Mohorovicic discontinuity separates the rigid crust from the plastic mantle.
- Asthenosphere - the layer below the lithosphere, ~200km thick, composed of ultramafic rocks such as peridotite and dunite that are hot, weak and plastic, and flow slowly under stress.
- Mantle - this layer between the lithospheric crust and the core is ~2800km thick; it is divided into many sub-layers, including the asthenosphere and lower mantle. It is composed of ultramafic rocks such as peridotite and dunite and their metamorphic equivalents (e.g. eclogite).
- Core - the central portion of the earth ~7000km in diameter is composed of an iron-nickel alloy. The outer core is molten, while the inner core, even though just as hot, is solid because of the increased pressure.

The planet loses its heat via convection in the mantle (which helps drive plate tectonics) and via mantle plumes that arise from near the mantle/core boundary. The mantle plume of the nearby Cape Verde Islands is modelled as a plume neck ~150km in diameter which feeds a mushroom-like head ~1500km in diameter; the plume neck is ~300°C and the head ~100°C above ambient temperature. Dynamic uplift over the convecting plume head has elevated the Cape Verde swell ~1900m relative to normal oceanic depth.

Plumes contribute to plate tectonics' processes - the Icelandic plume is believed to have contributed to the splitting of N Europe from Greenland to form the N Atlantic basin. Plumes form many of the great igneous provinces of the world - the Hawaiian chain, Iceland, Cape Verde Islands, Canaries, Reunion; on the continents, massive basaltic outpourings such as the Deccan Traps (India), Parana (S Brazil), Snake River (NW USA) and the Karoo (S Africa) all contributed to continental break-up.

The Geological History Of Madeira – this begins in the Miocene with the main island building stage:

- Miocene - the Madeiran 'shield' built up from the abyssal plain as a series of scoria and composite cones to form an island *(Basal Complex, Volcanic Complex B1*). Erosion and subsidence allowed local formation of reef limestone (~mid Miocene).
- Pliocene - this 'main shield building' stage produced huge volumes of lava and pyroclastic deposits (*Main Shield Building Stage Volcanic Complex B2* and *B3*). Between eruptions, soils formed in which terrestrial flora and fauna

were preserved. Subsequent volcanic activity continued on a reduced scale.

- Pleistocene - the 'mature' stage; fissure eruptions of lava extended the pile in an E-W direction and formed high level plateaux (*Mature Stage Fissure Eruptive Complex B4*). Intense erosion resulted in extensive alluvial fan, fluvial and coastal deposits composed of volcanic detritus, and aeolian calc-arenites.
- Late Pleistocene and Holocene - local volcanic eruptions filled valleys with lava (*Late Stage B5*) in the north of the island, formed ash cones around Funchal, and cones and flows in the extreme east (*Late Stage B6*).

The various eruptive phases were accompanied by the intrusion of numerous dykes and sills. Recent earthquakes suggest that volcanic activity is not yet extinct!

The Igneous Rocks are predominantly alkali-basalt lavas, pyroclastic deposits and dykes, with rare gabbro (coarse-grained) probably sourced from the base of the upper mantle, and formed by partial melting of mantle material ('alkali' refers to the sodium and potassium content in the feldspars).

The rocks vary from basalt to trachyte and even rhyolite (i.e. from 'basic' to 'acid' and mafic to felsic) and include rare ultramafic xenoliths of dunite and lherzolite derived from depleted ocean lithosphere. The composition of the original basalt melt is altered on its way to the surface. As it rises and cools, iron rich minerals crystallise, e.g. augite, and sink through the melt (they are heavier than the melt); this leaves a melt which is reduced in calcium, iron and magnesium and richer in silica and alkali metals; this process is know as fractionation. Thus, it is possible for three lavas to be extruded to surface: lava from the original basaltic melt, lava enriched with augite phenocrysts, and alkali enriched lava. In addition, there are reactions between the rising magma and the material through which it makes its way to the surface; further, the hot magma may melt and mix with the basal crustal rocks. These additional processes cause wide variations in lava composition.

- Basal Complex B1 is the product of explosive volcanism; there are pahoehoe lava flows and dyke swarms; the pyroclastic material includes large bombs and scoriae erupted from fissures and cones, and volcanic breccias.
- Main Shield-Building Complex B2 and B3 - a fissure zone produced volcanic complexes with dyke swarms. The alternations of lavas and pyroclastic rocks have a much greater proportion of lava than before. These alkali basalts include mantle xenoliths. The pyroclastic rocks include agglomerates, scoriae and tuffs, the rocks being coarser-grained close to the volcanoes and hence the centre of the island. Weathering between volcanic episodes produced thick red clays and soils (laterites).
- Mature Fissure Eruptive Complex B4 - lavas are inter-layered with abundant coarse, unconsolidated cindery ash often enclosing charred cedar wood fragments.
- Late Stage Complex B5 and B6 - minor lava flows and pyroclastic deposits. The lavas include 'A'a flows and there are lava tunnels and small cinder cones. Some of this activity took place as recently as ~5000 years ago.

The Sedimentary Rocks are predominantly alluvial fan, fluvial, coastal and aeolian sediments composed of volcanic rock fragments and particles, a testament to the extremely rapid erosion of the island. There is a Miocene reef limestone, situated over 400m above sea level, an indication of the uplift caused by the mantle plume.

The Reef Limestones are highly fossiliferous packstone and grainstone sediments deposited in a shallow sea, with colonial corals (e.g. *Porites*), larger Foraminifera (*Myogypsina, Heterostegina*), stromatolites, echinoderms, Bryozoa, bivalves, gastropods and Ostracoda. The diagenetic cements show a complex burial history. Early cementation took place soon after formation (whilst immediately below sea level); then, a second cement was added and stylolites formed (whilst buried several hundred metres below sea level, i.e. there was subsidence); then the limestone was affected by meteoric waters (rain, fresh water, so elevation above sea level), before being submerged again in marine water prior to elevation to the present height over 400m above sea level.

Siliciclastic Sedimentary Rocks are intercalated between the volcanics (red Lateritic soils), they developed in a tropical climate between volcanic episodes, which were often sufficiently long to allow a rich fauna and flora to be established, even producing lignite. Fossils plants include laurel, tree heather, fern and cedar, whilst land snails and insect remains are found.

At various periods, rapid elevation of the island allowed massive and rapid weathering and erosion. The steep slopes allow rapid transport of huge volumes of debris by rivers and by mass flow (landslides), to form steep alluvial fans which consist of unsorted material with boulders up to 5m across (e.g. in February 2010!!). Some fans show fluvial dissection (incised rivers) and these, together with raised beaches, indicate periodic uplift. Coastal beaches are few and far between, but there are some aeolian sand dunes. This sedimentary record provides clear evidence of the 'pulsing' of the underlying mantle plume, with periodic expansion and contraction (partly due to volcanic outpouring) causing uplift and subsidence.

Graham Williams

Day 1 – The Sao Lourenco Peninsula: Graham Williams

Ironically, our visit to the most easterly part of the volcanic island of Madeira began with mid Pleistocene aeolian sand dunes (Figure 1). However, as a preview of what was to come, the sand consisted entirely of volcanic debris eroded from nearby basalt and ash. We found numerous fossils including gastropods (which appeared identical to those now living in the grass), plant stems, and roots preserved as rhizoliths in calcareous tufa.

Most of the peninsula consists of Miocene Basal Volcanic Complex B1. There were fabulous views of enormous cliffs where thick layers of bright red ash and black basalt flows and dykes contrasted spectacularly with the bright blue of the sky and sea (Miradouro).

Ankaramite lava flows (basalt with large augite crystals) with well developed columnar jointing, lava spatter, laterites, tuffs and agglomerate were all well exposed (Figure 2).

Occasionally, the basalts showed excellent examples of spheroidal weathering (Figure 3).

Fig. 1. Mid Pleistocene Aeolian sand dunes

Fig. 2. B1 ash, tuffs, agglomerates ‘inter-bedded’ with basalt lava flows and cut by basalt dykes

Fig. 3. Spheroidal weathering

Fig. 4. Typical steep sided river valley & side gorge

Fig. 5. House and road inundated by debris

Fig. 6. Coral in Miocene limestone, Lameiros

Day 2 – San Vicente Valley and NW Coast; Colin Brash & Mike Rubra

Our first locality was the Miocene Reef Limestone at Lameiros, which we reached via the Ribeira Brava river valley going north across the island, into the Rio de Sao Vicente valley, which enters the sea at Sao Vicente.

These steep sided river valleys (Figure 4) were among those which had been devastated by the flash floods which swept Madeira in February this year (witnessed by Lyn Linse and reported in the June newsletter) and many JCBs and other heavy earth moving machines were to be seen working in the Brava river bed and within the tiny little side-gorges. The main road traffic in places diverted onto the river bed where the road, houses and vehicles, had been damaged or swept away (Figure 5 - erosion and tragedy on a frightening scale.

Arriving at Lameiros, we walked some 500m up a very steep road to find a disused quarry. After a slight diversion we found the new visitor centre close to the quarry. However, the entrance was blocked and the faces obscured by landslips. Some folk continued up steps to a nature reserve that overlooked the main quarry, while others investigated a much smaller quarry where samples of reef limestone containing corals (Figure 6) and fractured ooliths were found. Examples of fossil specimens from here are displayed at the Botanic gardens museum at Funchal. These quarries are about 475m above current sea level, clear evidence of the uplift of the reef as the mantle plume underlying Madeira had periodically inflated and deflated .

The next stop was at Sao Vicente 'caves' where we were led through the 5m high lava tunnels (Figure 7) that had formed during a Quaternary eruption, dated ca. 190ka, now at a constant 10°C, many with running water and small clear pools. Tunnels are formed when the outer surfaces of a lava flow chill and 'freeze' but beneath the chilled surface liquid lava continues to flow; here some tunnels were part filled with ropey lava that had cooled within the tubes as the flow ceased and ended. We then visited a display of samples of the island's volcanic rocks, and went on to experience 'a Journey to the Centre of the Earth' and a clever 3D film.

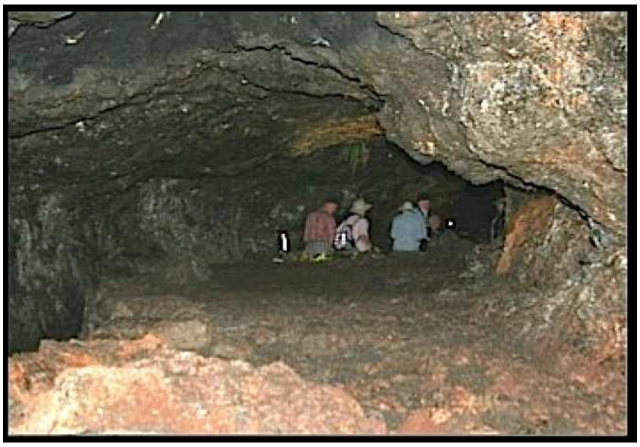

Fig. 7. Quaternary lava tunnel, Sao Vicente

Fig. 8. Seixal Quaternary lava flow (B5)

Next, we looked at the Miocene Basement lavas (B1) overlain unconformably by (B3) Pliocene lavas in a cliff on the east side of the river valley; while on the west side a Quaternary (B5) lava flow terminated in a sea cliff formed during higher sea levels. We also had a distant view of the Seixal lava delta to be visited later.

After lunching under an artistic 'basalt rocks on poles' exhibit we travelled along the north coast via a recently opened tiny cliff road, with natural car washing facilities (waterfalls) to Seixal. At the harbour we were able to walk on the lava breccia delta (Figure 8), which formed the harbour, to try and interpret whether it had been lain down under the sea or not. After much discussion we thought that some of it probably had been deposited in water, one large flow covered by later flows perhaps on land.

We moved on to our final stop of the day at Ribeira da Janela where in the cliffs opposite a small hydro-electric power station we saw multiple lava flows cut by vertical dykes and a basalt plug (Figure 9) that had radiating small columnar joints. The (B2) lavas appeared to have scoriated surfaces and not the pahoehoe ropey lava described in the geological guide (Burton & MacDonald). We returned to our hotel through a road tunnel cut in the Quaternary lava flow; one of the most impressive features of Madeira is the large number of road tunnels and sweeping bridges, built fairly recently to by-pass the hazardous old coast roads and speed up island travel.

Day 3 – Porto Da Cruz; Ian Hacker

We left Funchal by bus but returned to the bus stop to retrieve Judith's bag and passport where she had left it for safe-keeping. We arrived at Portela, with its panoramic view of the coastal lava and ash, and, allegedly, an intrusion. We finally found the exposure with B2 lava and ash cut by a steep-sided coarse grained gabbro intrusion (Figure 10), slightly over 1m wide, showing contact metamorphism at the sides and some onion skin weathering.

We then went to Porto da Cruz where there were high cliffs of lake margin sediments and alluvial fans with cross bedding. There were well-sorted thin horizontal sandy/ash deposits. Some beds had larger rounded gravels and boulders, possibly mass flow deposits. At the lower levels we found fossil wood and black vegetative deposits. The sediments were topped by a mugearite lava flow.

After lunch we walked around the Cais peninsula. The cliffs showed air-fall ash deposits, cross-bedded so possibly formed in a lake. There were no sag features under small boulders, so they may have been secondary water flow deposits. Dramatically, a layer of mugearite capped the large vertical section of sediments (Figure 11) and below them was a basalt layer with 'poor man's' pahoehoe (Figure 12) over columnar joint structures. You don't see that very often!

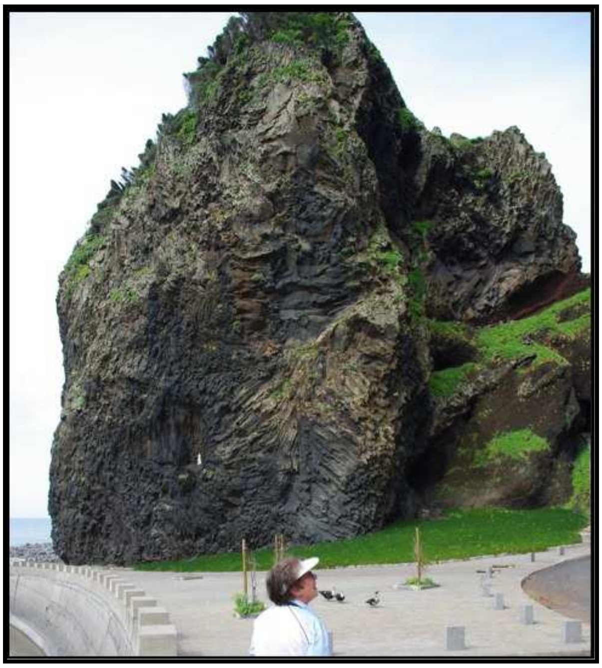

Fig. 9. Spectacular basalt lava plug, Ribeira da Janela

Fig. 10. Gabbro intrusion, Portela

Fig. 11. Mugearite lava on sediments, Cais

Fig. 12. 'Poor man's' Pahoehoe lava, Cais

We saw the contact between the lava and sediment further round the peninsula. The tall vertical cliff face had a talus-angled outcrop into the ocean from recent cliff collapses. Further along, three basalt dykes were seen at an angle of about 30° to the vertical. At a lower level, one dyke reduced the angle to about 15°, but the dykes seemed to be passing through unconsolidated sediment (Figure 13) which was strange, as the straight clear interface would not have occurred, it should have been more diffuse – answers on a postcard please. We ended another grand day out at Faial visitor's centre with a cup of tea and views of spectacular columnar jointing in a fine-grained basaltic lava before returning to the hotel.

Fig. 13. Dykes passing through unconsolidated sediment!

Fig. 14. Red lateritic soil contrasts with black basalts, P. do Sol

Day 4 – Ribeira Brava To Porto Moniz; Beryl Jarvis

At Ponta do Sol, B2 Pliocene lavas erupted sub-aerially after the initial Miocene eruptions had produced enough thickness of lava for the island of Madeira to emerge above sea level.

On the SW facing coast, we stopped on the seafront at Ponto do Sol and made for the headland at the southern end of the beach. At first sight this seemed to be a massive, (35m?) thick lava flow. The fine-grained grey basalt columns in the cliff face showed that the lava had been very viscous and had cooled quickly. Walking round the headland we could see that the 'lava flow' was more complicated than we first thought. The cliffs behind the 'lava flow' on the landward side consisted of a series of thinner horizontal lava flows within which there were brick red laterite horizons (Figure 14).

Laterite is a soil produced by the sub-aerial weathering of basalt in the tropics. All the silica and alkali minerals have disappeared in solution (rainwater) leaving the mafic minerals, e.g. augite and pyroxenes, to oxidise to a brick red colour. It forms at the top surface of a lava flow and the thickness of the deposit indicates how long the area had lain undisturbed to allow such deep weathering.

We used a particularly thick laterite horizon as a marker and saw that it disappeared behind the massive lava and emerged on the Ponto do Sol side. The massive 'lava flow' now seemed to be a separate entity, emplaced in front of cliffs. The lavas at the top of the thinner horizontal flows did not correspond to the massive lavas of the headland. We therefore decided that the headland could have been a discreet plug or lava dome and not a flow.

We saw how the lava had cooled as it came up through existing cold rocks (Figure 15). The existing basalt was pink and although the contact at the base was hidden under the footpath round the headland, it was visible in places. Examples were:

- Marginal Breccia (Figure 16) - small pieces of the former surface that were broken off and carried along by the movement of the hot magma making a filling in the sandwich between that and the cold basalt;
- Fault Planes - appearing as a series of long fine sinuous fractures near the edges in the hot lava parallel to the junction between that and the cold basalt;
- Cooling Joints (large scale fractures radiating into the cooling basalt at right angles to the cooling surface.

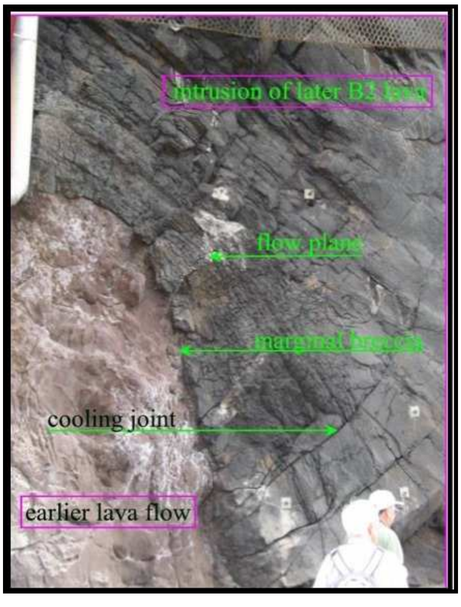

Fig. 15 (left). Later B2 lava plug intrudes earlier lava flow. The flow planes, marginal breccia (enlarged as Fig. 16 above) and cooling joints are annotated.

Fig. 17. The Faja from the terrifying 'Teleferique' cable car!!

About 25km NE of Ponto da Pargo a portion of the cliff face had slipped vertically down and spread out to form a faja deposit just above sea level (Figure 17). The plan was to travel down the cliff face in a cable car, studying the Pliocene lavas including pahoehoe lavas, laterites and dyke swarms in the cliff face as we descended. However, a strong smell of hot electrics, brakes and clutches assailed our nostrils as we peered over the edge of the cliff into the depths, and a communal sigh of relief could be heard in Funchal as we were told that the 'Teleferique' was out of action due to maintenance. We could have spent the next few hours taking the zigzag footpath down the cliff face but time and stamina were not on our side. Madeirans are a much tougher race than we are! We saw more lava flows with laterite horizons as we travelled further up the coast; in many places they were cut by dykes (Figure 18).

Day 5 – The Central Mountains; Derek Jerram

Lesley's birthday! This field day was to the Paúl da Serra, where stands Pico Ruivo do Paúl, at 1640m almost the highest pico in Madeira. The journey from sea level to almost 5,500ft made the bus and its passengers gasp. No main road journey in Madeira can be accomplished without passing through tunnels - the longest being over 3km, all built with eurodosh. There must be more tunnels per square mile on Madeira than anywhere else on earth. Their construction would have been a geologist's delight. The Serra was composed of late Pleistocene and Holocene lava flows with ash cones, dykes and vent agglomerates.

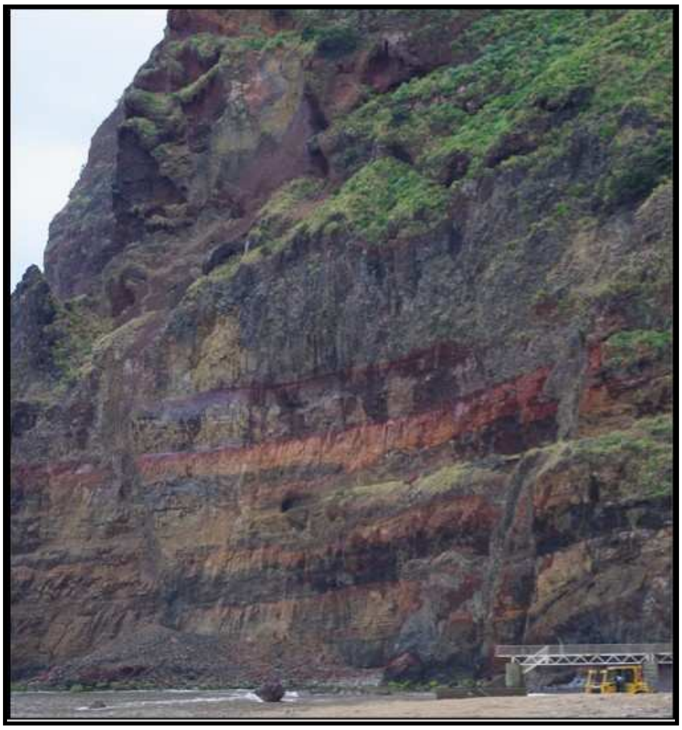

Fig. 18. Numerous lava flows with laterites, cut by vertical dyke (on right hand side).

Fig. 19. Ash Cone

First stop was at a place called Encumeada, on the north side of the Serra, which, when the cloud blanketing the north of the island parted momentarily, gave a view down a valley to the coast. Cold, damp and enveloped in many layers of clothes we had no great desire to spend the rest of the day there. Having examined (through the mist) some lateritic weathering of the Pleistocene lavas, refuge was sought in the bus, which took us through 3 more tunnels to the south side of the Serra, to warmth, sunshine and the opportunity to actually see the geology. There was an ash cone (Figure 19) through which the road had been excavated; it had been plastered on the lava flows. Dykes had cut through the lava and the ash, standing proud after erosion of the surrounding earlier deposits (Figure 20). The lava flows were spectacular.


Fig. 20. Dykes cut the lava and ash layers


Fig. 21. Extraordinary erosion in such young rocks


Fig. 22. A lava tunnel with a collapsed crest


Fig. 23. Splendid example of a Spindle Bomb

The view from a high picnic site (Figure 21) is included to show the drama of the scenery created by the Quaternary deposits and their erosion. Further sites included witnessing the effects of magnetite on a compass needle, and a lava flow in an eroded river gulley (Figure 22). This turned out to be a collapsed lava tube, the top of the tube had collapsed, but at the sides of the valley there was evidence of the arched top of the tube.

Our last locality was a short climb to the top of a conical hawaiite volcanic plug. Boulders of this lava were scattered about, but so were large pieces of exploded material and on top of one was found a splendid example of a spindle bomb (Figure 23), inconsistent with the lava flow of the hawaiite. Speculation as to what took place was not easy, as admitted. If the speculation was wrong then so what? To paraphrase Richard Nixon, it is better to be wrong than dull. Dull our leaders weren't.

If Janet Catchpole organizes something it must be geology. This time we were taken to a mandolin concert by the local orchestra (thirty musicians with instruments ranging from the size of a table-tennis bat to twice that of a double bass). We looked at the geology of the columns in the church, which appeared to be limestone with bluish streaks, but that must be another story.

Day 6 – Funchal; Graham Williams

Planned as an investigation of the various lavas exposed around Funchal, to-day turned into a tourist day; folk visited the exotic botanic gardens and explored the town. A small geological museum in the gardens exhibited fossils from the Miocene limestone and various other sediments scattered around the islands of the Madeira archipelago; there were examples the different igneous rocks that we had seen, but without the erudite explanations of Alan Bromley.

This trip was billed as an 'Exploration' led by myself and a great friend, Alan Bromley; I would have found it impossible without Alan's vast experience of igneous rocks, and his great teaching skills; and, importantly, this was one trip where every single participant made an important contribution towards the exploration of the spectacular basalts of Madeira – thanks go to all.