Hastings & District Geological Society Journal

Founded 1992

Hastings and District Geological Society
affiliated to the Geologists' Association

President
Professor G. David Price, UCL

An outcrop of the Lee Ness Sandstone marking the crest of the Fairlight Anticline
in the cliffs east of Lee Ness Ledge - September 2007

Volume 14 December 2008

Cover picture: An outcrop of the Lee Ness Sandstone in the cliffs east of Lee Ness Ledge - photo: Peter Austen

Contributions for next year's Journal would be appreciated and should be submitted by the October meeting, **18th October 2009**.
Please contact Peter Austen on: tel: 01323 899237 or e-mail: p.austen26@btinternet.com

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2008 Officials and Committee

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John Boryer

Hastings & District Geological Society Website - http://www.hastingsgeolsoc.org.uk

Geologists' Association Website - http://www.geologistsassociation.org.uk

HASTINGS & DISTRICT GEOLOGICAL SOCIETY

Minutes of the A.G.M. - 16th December 2007

The Meeting was declared open at 2.40 p.m. by the Chairman, Ken Brooks. There were twenty-seven members present.

1) **Apologies:** Were received from:
John Boryer, Richard Crespin, Les & Vera Clarke and Rhoda Meyer.

2) **Minutes of the last A.G.M.:** These were printed in the *H.D.G.S. Journal* which had been handed out to members. Their acceptance was proposed by Trevor Devon and seconded by Tony Standen, and a show of hands indicated that they were unanimously accepted. Copies of the Minutes were available to be read.

3) **Chairman's report:**

a) 2007 Programme: Ken said that it had been a busy year and he summarised the year's activities:

Lectures by visiting speakers:
'Fairlight Sea Defences' by Terry Oakes
'A Geological Scandal: Hastings Water Supply' by Bob Allen
'Geology and Minerals of Iceland' by Peter Hay
'Fossils of the Chalk' by *Prof.* Rory Mortimore
'Minerals of the Deep Earth' by *Prof.* David Price

Members' Day talks:
'Techniques of Fossil Preparation' by John Dempsey
'Volcanoes of Tenerife' by Dave Spicer

Field Trips:
New Year's Day Walk
UCL
Beachy Head
Barbecue Party
Fairlight

Ken said that there had been very good weather this year for the field trips and that both had been very successful and well attended - fourteen on the Beachy Head trip and twenty-three on the Fairlight one. He also said that attendances for the lectures had been excellent this year, ranging from twenty to forty-three.
Ken thanked Gordon Elder, Anita and Siân for hosting this year's barbecue party.

b) Ken said that Trevor Devon was keeping the website up-to-date and that in the New Year the *H.D.G.S. Journal* would be put on to the site. He reminded everyone that the web address, www.hastingsgeolsoc.org.uk, was always on the letter to members together with the e-mail address. He said again that interesting items from members were always required for the site.

c) Ken thanked Peter and Joyce Austen for all their very professional hard work putting together the *H.D.G.S. Journal* and also thanked the contributors who made the publication possible.

d) He also thanked Gordon Elder for taking over and running the library, all the members of the Committee for their work during the year, and everyone who had helped making the tea and washing up.

4) **Treasurer's report:**

Diana had typed up Norman Farmer's *Statement of Income & Expenditure for the Year Ending 31st December 2007* which was handed out to members. Ken briefly ran through the items, mentioning that the balance was up on last year. He said that the membership numbers were up and that, although the membership fee had never been increased since the setting up of the Society, there seemed to be no reason at present to increase the subscription. He thanked Norman for his work as Treasurer.

5) **Election of the Committee:**

Ken asked whether anyone would like to stand for election on to the Committee in any capacity, but there were no volunteers. Colin Parsons then suggested that someone should propose that the Committee be re-elected *en bloc* again. This was proposed by Geoff Bennett, seconded by Tony Standen and unanimously carried. The Committee was said to be as follows:

2007	**2008**
Chairman	
Ken Brooks	Ken Brooks
Treasurer	
Norman Farmer	Norman Farmer
Secretary	
Diana Williams	Diana Williams
Journal editor	
Peter & Joyce Austen	Peter & Joyce Austen
Librarian & Education Officer	
Gordon Elder	Gordon Elder
Website Manager	
Trevor Devon	Trevor Devon
Other Officers	
1. Colin Parsons	Colin Parsons
2. John Boryer	John Boryer

6) **2008 Programme:** Copies were handed out to all members present. Those unable to attend would be receiving their copies with the next letter to members. Ken said how it was becoming more and more difficult to find new speakers. He then gave a brief résumé of next year's lectures:

'Wealden Fishes' - by *Dr.* Peter Forey
'Amber' - by John Cooper
'Geology of the Fairlight Landslip' - by *Dr.* Jackie Skipper
'Black Smokers and the Origin of Life' - by *Dr.* Richard Herrington
'Lost Chalk of Scotland' - by *Prof.* Rory Mortimore
Presidential Lecture - by *Prof.* David Price

He said that there would be two Members' Day talks this year, one of which would be:
'Planetary Geology' - by Gordon Elder

The 'outings' for 2008 would be:
New Year's Day walk at Fairlight
Field trip to Betteshanger Colliery, Kent
Barbecue Party with Trevor & Fiona Devon
Another field trip to be arranged

Ken thanked Peter and Joyce Austen for organising the Betteshanger trip and said that although the colliery was now closed, there were spoil tips there which still contained fossils.
Terry Henman asked whether there was the chance of a trip to the gypsum mines. Ken said that it was difficult as only eight people could go down the mine at any one time, so it would mean going in relays. He said that he would make further enquiries.
Terry also asked whether we could get Rory Mortimore to talk about the tunnelling under Stonehenge.
Ken said that Rory Mortimore would be organising field trips to chalk exposures in Sussex and Kent during the coming year and that he would let us know details later as he received them.
Peter Austen said that Fred Clouter had just published a book on Ammonites and Cephalopods of the Gault Clay at Folkestone. He said that the book was based on the website by the late Jim Craig and was an excellent guide to the identification of the fossils from Folkestone.

7) **Any Other Business:**

John Fowler asked whether the PowerPoint lectures we had been given were now available on CDs. Gordon said that he had seven lectures which he could download and asked if the Committee could buy CDs/DVDs to put them on.

Gordon also said that he was scanning all the past *H.D.G.S. Journals* which he would be putting on to CDs. Ken said that any contributions for the next *Journal* would be very welcome.

Ken mentioned that David Price's name appeared as the consultant on the credits of the television programme *Earth*.

Ken said that he had put out copies of the *'Deposits'* magazine for sale, and that two spare copies of *Exploring East Sussex* were also available together with a copy of the UKGE catalogue of geological equipment.

Ken thanked Anne Hancock for bringing along two geological maps for display.

Terry Henman said that he had brought sheets on the Lake District for members to look at and reminded everyone that he had a house in the area which could be rented.

Ken said that if anyone needed specimens cut he would do this for them or, alternatively, they could borrow the 10" diamond saw themselves.

Ken reminded everyone of the New Year's Day Walk which would begin with optional lunch at the Smuggler Pub, Pett, at 12 o'clock. The walk along the beach would then start at 2 o'clock. It was suggested that perhaps the walk should start a little earlier so that it did not finish in the dark. However, as letters had already gone out to members saying that it would start at 2 pm, it was decided that we should keep to that time, but perhaps change it for the next year - or even have the walk first and the meal afterwards.

Ken said that if members would like to pay their annual subscriptions, their money would be gratefully received.

Ken declared the Meeting closed at 3.10 p.m.

HASTINGS & DISTRICT GEOLOGICAL SOCIETY

Statement of Income & Expenditure for the Year Ending 31st December 2007

INCOME	£	EXPENDITURE	£
Subscriptions		G.A. Affiliation fees	33.00
Single 39 @ £12.50	487.50	Hire of rooms	90.00
Family 9 @ £15.00	135.00	Society *Journal* production	112.65
		Insurance premium	137.00
		Stationery, Copying, Postage	89.36
Donations	10.00	Field trips (inc. UCL visit)	230.00
Magazine sales	10.21	Lecture fees & Expenses	54.95
UCL visit	225.00	Conchologists' Society	5.00
Barbecue receipts	140.00	Refreshments & Lunches	25.00
Fossil Walks	30.00	Summer barbecue expenses	140.00
Sale of Books	10.00	Tributes & Donations	25.00
		Bank charges	6.42
	1,047.71		948.38
		Surplus being excess of income over expenditure	99.33
	1,047.71		1,047.71

HASTINGS & DISTRICT GEOLOGICAL SOCIETY

Bank Account and Monies in Hand

Balances as at 31st December 2006	£	Balances as at 31st December 2007	£
Nat. West Bank	325.43	Nat. West Bank	354.05
Monies in hand	14.08	Monies in hand	84.79
	339.51		438.84
Increase in Balances	99.33		
	438.84		438.84

December 2007

HASTINGS & DISTRICT GEOLOGICAL SOCIETY

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16th August 2008

Congratulations to the **Brighton & Hove Geological Society** on your 25th Anniversary from the Hastings & District Geological Society (only 16 years old!) and we wish you every success in the future.

We are fortunate to live in a county which is so rich in geological interest. In fact, between our two societies, we cover the entire Cretaceous period.

Over the past years we have always enjoyed our contacts with you, particularly in the exchange of speakers, and we now look forward to our continuing friendship.

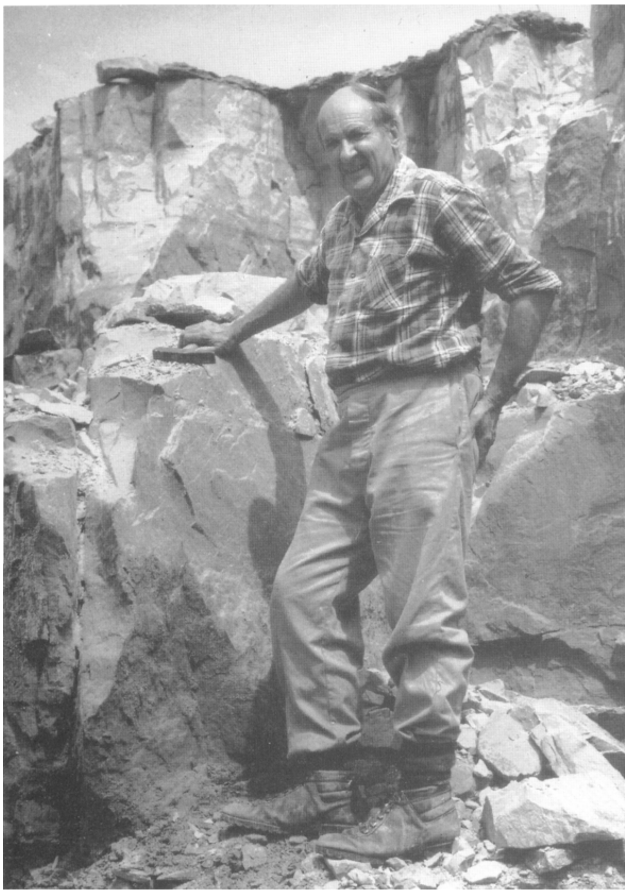
With very best wishes,

Ken Brooks (Chairman)
and all members of the H.D.G.S.

OBITUARY

PERCIVAL ALLEN

1917 - 2008



Although few of us knew Perce Allen directly, those of us who have walked the coastal sections east of Hastings, between Rock-a-Nore and Cliff End, will have been exposed to his influence. Perce Allen, who died on the 3rd April 2008 at the age of 91, was one of the giants of 20th century geology. He took a leading international role in the development of sedimentology, with much of his work revolving around the understanding and interpretation of Wealden sedimentation, including that of the classic sections along the Hastings coastline. His work on Wealden deposits and environments (the Hastings Group and the Weald Clay) dominates our thinking and understanding of the Weald to this day. Arguably his most important paper was his 1975 contribution to the Geologists'Association's Topley volume, where he turned his old ideas on the Wealden on their head, and proposed a new model for the Weald, one which still holds good more than 30 years later.

He was born at Brede, near Hastings in 1917, and attended Rye Grammar School, and although he spent much of his academic life in Reading he frequently visited his beloved Sussex in his quest to understand the Wealden rock formations of south-east England.

He took his BSc at Reading University in 1939, followed by a PhD in 1943 on the Cretaceous sediments of the Weald. In 1946 he took up a lectureship at Cambridge, and in 1952 moved back to Reading, where he was appointed Professor and Head of the Geology Department. He remained at Reading until his retirement in 1982, when he became an Emeritus Professor, and he was still contributing to research at the age of 91.

In 1959 he published a prophetic paper emphasising the importance of the North Sea as a potential source of oil, and advocating a programme of exploration there. At Reading in 1962 he founded the Sedimentology Research Laboratory, working tirelessly to raise funds for it, mainly from the oil industry. He also founded the Sedimentological Research Group, and proposed the formation of the International Association of Sedimentologists. He was also a member of the Natural Environment Research Council and founded the Association of European Geological Societies.

He received the Lyell Medal from the Geological Society in 1971, and was elected to Fellowship of the Royal Society in 1973, serving as Vice-President from 1977-79. He also served as President of the Geological Society from 1978 to 1980, and was an honorary member of the Geologists' Association and many other societies.

For all of his academic achievements, he also displayed a mischievous sense of humour. In 1959 he collaborated with Reading University's rag students in the announcement that diamonds had been found in the gravels of the Thames Valley. For this he achieved considerable notoriety and attracted the wrath of certain members of the academic establishment as well as of *The Times* newspaper, which wrote a stiff leader about the irresponsibility of a scholar indulging in such frivolity.

Perce Allen was undoubtedly one of the leading international figures in sedimentology, and it is fair to say that his lifelong passion for the Weald has given us a much deeper understanding of the rocks on our own doorstep.

Mineral collecting trip to Slovakia

by Trevor Devon

Slovakia is situated at the north-western end of the Carpathian Mountains, a region well-known for its metal ore mines and quarries. One of the Sussex Mineralogical Society's members had been a schoolteacher in Slovakia and had explored many of its mineral locations. Through his contacts there, an 11 day visit was arranged and a quite large group comprising 17 society members descended on the rural tranquillity of eastern Slovakia in August 2008. We were met by our two expert guides, one of whom was Dr Rudolf Ďud'a, Head of the Department of Natural History, Eastern Slovak Museum in Košice and author of the Slovakia chapter in the book "Minerals of the Carpathians".

Our journey took us on a round trip from Eastern Slovakia up to Prešov and the Tatra Mountains on the border with Poland, across to Banská Bystrica in central Slovakia, south to Šiatorská Bukovinka near the Hungarian border and back to Košice. Much of the driving was through heavily wooded mountains and attractive scenic valleys. The mines (now mostly inactive) and quarries were often well hidden, and generally required some walking (upwards of course!) to get to from our coach.

During our trip we visited four quarries, eight mine dumps and a wooded mountainside deposit of "flesh opals", so we were kept busy! One of the lasting impressions of the mine dumps (some very large indeed) was the richness of secondary mineralization: when in Cornwall one is usually excited by any tiny piece of "blue" or "green" on the rock – in the Slovakian mine dumps we saw seas of green/blue mineralization! Closer inspection revealed much of it as microcrystalline crusts that we were happy to discard while looking for the real crystalline specimens. I personally came home with a lot of small but fine specimens of many of the copper secondaries such as azurite, malachite, brochantite, chalcophyllite, liroconite, cornubite, tyrolite, chrysocolla and cornwallite. Others collected nice crystals of the famous euchroite from L'ubietová (the Type Location). Unfortunately while we were at L'ubietová (Libethen in German), we did not manage to get to the area famous (Type Location) for libethenite, so I bought a nice specimen from a local dealer instead!

In addition to the copper secondaries, mine dumps yielded many of the metal sulphides, notably crystals of chalcopyrite, pyrite, bornite, marcasite, metastibnite, tennantite, realgar, sphalerite and tetrahedrite. Despite visiting a former gold mine dump, no gold was found! At one location the group split into two; the fit and adventurous went up a two kilometre steep path to a mine dump while the rest (including me) stayed down below exploring the track that had been constructed from mine dump rock. Needless to say we collected much the same minerals at the bottom as they found at the top (although, truth to say, the top group did find larger crystals!). Most of us found the rare lead-antimony sulphide tintinaite, which appears in the quartz rock, as dark acicular crystals up to 10mm long.

Quarries are usually a particularly good source of mineral specimens for the collector as fresh material can often be uncovered, either by excavation of an evident mineral seam or through the quarrying if still active. We were not to be disappointed by the four different quarries we visited. The first, called Vechec Lom (lom means quarry), was a large active andesite quarry from which we extracted many good hand specimens of the high temperature quartz crystal polymorphs tridymite and cristobalite (the reason they can still be found naturally is because their breakdown to quartz takes place very slowly). One geological feature of Vechec was a spectacular outcrop of large hexagonal andesite columns (Figs 1 & 2) (now I don't need to visit the Giant's Causeway or Fingals Cave!).

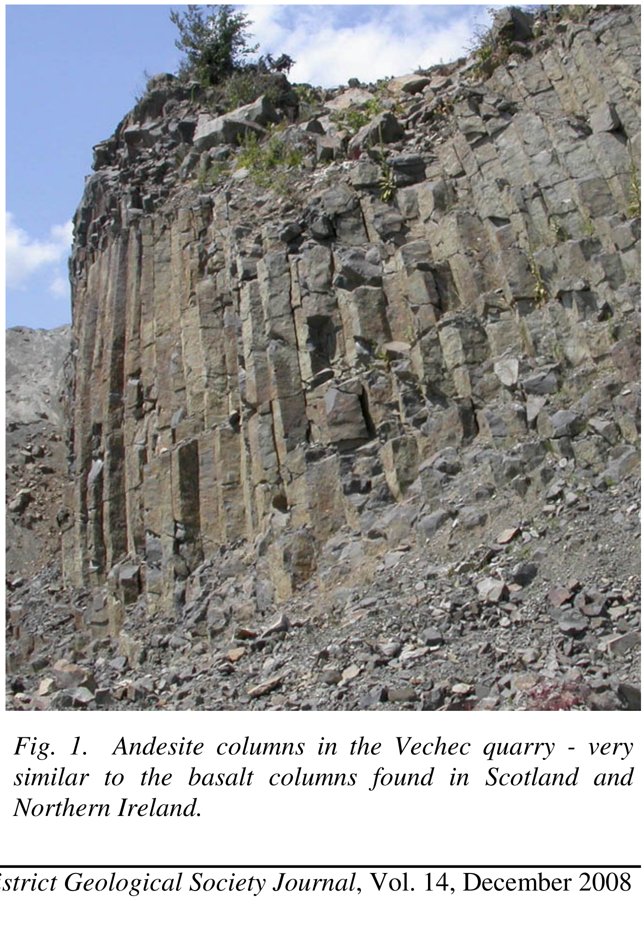


Fig. 1. Andesite columns in the Vechec quarry - very similar to the basalt columns found in Scotland and Northern Ireland.

Our second quarry, Maglovec Lom, was also an andesite quarry and is well known mineralogically for its pale green chabazite, a zeolite mineral. We did find plenty of the chabazite, but much of it was present as filler in cracks between andesite blocks. Some nice hand specimens of rhombohedral crystals were extracted however. Of some interest too were the unusual sheets of material forming thin layers on the surface of the chabazite: the fine fibrous material was in fact a magnesium silicate mineral palygorskite that is known as "mountain leather".

Fig. 2. John Pearce and me resting from our exertions having extracted a nice hand specimen of ferroan dolomite from the hard andesite rock in Vechec quarry. Note the hexagonal columns of andesite in the foreground.

The third quarry at Dobšiná was quite different, being an asbestos quarry. The matrix rock was serpentine and the asbestos could easily be found as layers of golden fibrous clinochrysotile. Yellow-green specimens of the magnesium silicates antigorite and lizardite were commonly found along with the asbestos. Also at this location several small specimens of bright grass-green crystals were uncovered by cracking open small boulders: these were a variety of andradite garnet known as demantoid (meaning "diamond-like" because of their adamantine lustre).

Our final quarry down near the Hungarian border, Šiatorská Bukovinka, was a working andesite quarry. We could not go down to the base of the quarry because of the active machinery, but we nevertheless found plenty of interest on the higher benches. First finds were zeolites: lots of white, chalky prisms of laumontite crystals (to 10mm) and white radial sprays of scolecite. These were sometimes accompanied by an unusual, platy form of apophyllite. Higher up in the quarry one of our colleagues uncovered a horde of the rare zeolite, epistilbite, in a cavity in the quarry wall: fortunately there was enough for everyone to have a good specimen of these crystals! I was also fortunate in finding, on my way down the quarry, some really nice specimens of chabazite that had been extracted earlier by persons unknown and left on a rock. It does pay to keep your eyes open at all times!

Mention should be made of the other form of mineral collecting, by cheque book. We did meet up with several collectors/dealers during our trip and several of us supplemented our finds with purchased specimens from Slovakia that we either hadn't found or were better examples of what we had found. In this way I acquired some nice representative crystalline specimens of euchroite, libethenite and langite for example.

On our last day we drove back to Košice where Dr Ďud'a arranged a tour of his Natural History Department of the Eastern Slavic Museum. This turned out to be really quite exceptional – bright, clearly laid out modern displays with a wide range of minerals, local and worldwide. We also were treated to a visit to a unique exhibit, displayed inside a double vault, of the Košice Horde – a priceless treasury of medieval gold coins that had been hidden over the centuries from various invaders and were returned to Košice in 1970. A pleasant walk around this city before lunch revealed some magnificent architecture that suggested a return trip one day. Then after lunch we repaired to the home of Dr Ďud'a to see his amazing mineral collection displays (he has amassed over 3,500 different species of mineral!). As a further treat, we were offered boxes of his duplicate minerals from which to select free specimens. It was at about this stage that we started to think about our luggage allowances!

Geology of Venus

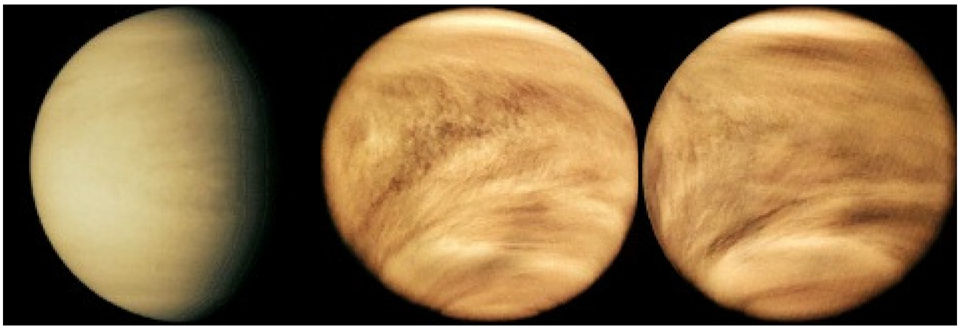
by Gordon Elder

In the last issue (*HDGS Journal*, Dec 2007, Vol. 13, p.12-16) I looked at the new definition of a planet and the subsequent downgrading of Pluto from a 'planet' to a 'dwarf planet' (Fig. 1), but the main body of the article examined the geology of Mars. In this article I have turned my attention to the geology and atmosphere of Venus.

Fig. 1. The planets as they are now classified.

It is important to realise that Venus has a thick and very dense atmosphere that is opaque to visual light, consisting mainly of carbon dioxide and a small amount of nitrogen. This opacity gives Venus a high albedo (reflectivity) which is why it is often known as the Morning/Evening star and, at times, can be seen during the day.

This atmosphere provides a pressure at the planet's surface about 90 times that of Earth (a pressure equivalent to a depth of 1 km under Earth's oceans). The carbon dioxide rich atmosphere results in a strong greenhouse effect raising the surface temperature more than 400°C (750°F) above what would be expected given its size and distance from the sun. In low elevation regions near the planet's equator, this causes temperatures at the surface to reach extremes as high as 500°C (930°F) (more than enough to melt lead). There are strong 300 km/h (185 mph) winds at the cloud tops (Figs 2b & 2c), but winds at the surface are very slow, no more than a few miles per hour. However, due to the high density of the atmosphere at Venus's surface, even such slow winds exert a significant amount of force against obstructions (rather reminiscent of gyres (swirling currents) deep in the Earth's oceans) making Venus's surface hotter than Mercury's. Due to the thermal inertia and convection of its dense atmosphere, the temperature does not vary significantly between the night and day sides of the planet despite its extremely slow rotation of less than one rotation per Venusian year (a Venusian year is 224.7 Earth days, whereas a



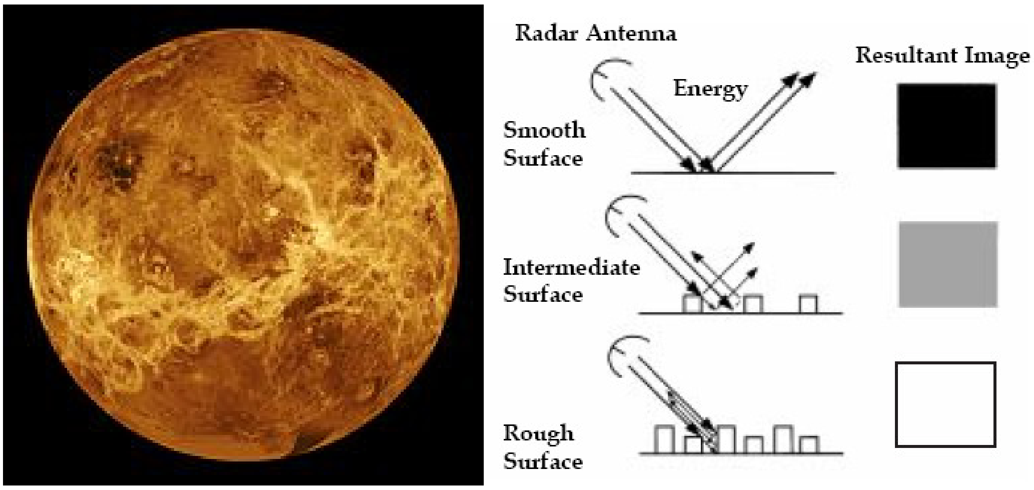
Figs 2a, b & c. (a) Image captured by the Galileo *spacecraft in visual light. (b) & (c) Images taken by the* Pioneer Venus Orbiter *spacecraft in ultra-violet light, that demonstrates the existence of super-rotation in the upper atmosphere of Venus. It takes 243 days for Venus to spin once on its axis, and yet the two images here were taken only 24 hours apart showing that the atmosphere of Venus is rotating far faster than the planet itself – in fact, sixty times faster!*

Venusian day is 243 Earth days giving a rotation speed of 6.5 km/h (4 mph) at the equator).

The clouds of Venus are mainly composed of sulphur dioxide and sulphuric acid droplets engulfing the planet completely, obscuring any surface details from the human eye and, therefore, from any visual optical instrument (telescope). The temperature at the tops of these clouds is approximately -45°C (-50°F).

Apologies for carrying on about the atmosphere and clouds here, but all will be revealed (pardon the pun) as you read on. The atmosphere also contains hydrogen sulphide and carbonyl sulphide. Hydrogen sulphide reacts with sulphur dioxide, which implies that something must be creating these components. It is unclear how the carbonyl sulphide could be formed as it is often a sign of biological activity. Some scientists have suggested that microbes exist in the clouds (which also contain droplets of water) and produce these components from water, carbon monoxide and sulphur dioxide[1].

Now, to get to the Venusian geology the atmosphere and clouds had to be penetrated via special techniques developed by the US Navy. Submarines mapped the Earth's sea floor using micro-wave radar synthesis and altimetric tomography (Fig. 3b); so why not use the same techniques for Venus?



Figs 3a & b. (a) Radar image of the surface of Venus, centred at 180 degrees east longitude. (b) Simplified diagram of how the radar antenna works, so, any rough surface is bright and smooth surface is dark.

Most current knowledge about the surface comes from radar observations (Fig. 3a), mainly images sent by the *Magellan* probe. The first images of Venus were received on the 16th August 1990. After carrying out a few final experiments, *Magellan* successfully completed its mission on the 11th October 1994, and was de-orbited to burn up in Venus's atmosphere.

Ninety-eight per cent of the planet's surface was mapped, 22% of it in three-dimensional stereoscopic images. This was at the time that I was reading for my undergraduate degree in Physical Sciences at UCL and was lucky enough to be lectured by Prof. John Guest (*Magellan* planetary science advisor) and Dr. Claudio Vita-Finzy (neo-tectonics), UCL.

Despite the fact that Venus is the planet closest to Earth (some 40 million km (25 million miles) at inferior conjunction) and is similar in size, the resemblance is superficial: **no** probe has survived more than a few hours on its surface because of the atmospheric pressure.

The surface of Venus is comparatively very flat – 93% of the topography was mapped by *Pioneer Venus*. Scientists found that the total distance from the lowest to the highest point on the entire surface was about 13 km (8 miles), while on Earth the distance from the basins to the Himalayas is about 20 km (12.4 miles). According to the *Magellan* data, 80% of the topography is within 1 km (0.6 miles) of the median radius (since Venus does not have an ocean there isn't a mean sea level datum). The most important elevations are in the mountain chains that surround Lakshmi Planum and include Maxwell Montes (11 km, 6.8 miles), Akna Montes (7 km, 4.3 miles) and Freya Montes (7 km, 4.3 miles). About 75% of the surface is composed of bare rock.

It seems that, based on the altimeter data of the *Pioneer Venus* probe, supported by the *Magellan* data, the topography of the planet is divided into three topographical provinces: lowlands, deposition plains, and highlands.

Highlands: This unit covers about 10% of the planet's surface, with altitudes greater than 2 km. The most important provinces of the highlands are Aphrodite Terra, Ishtar Terra, and Lada Terra, as well as the regions Beta Regio, Phoebe Regio and Themis Regio. The regions Alpha Regio, Bell Regio, Eistla Regio and Tholus Regio form a less important group of highlands.

Deposition plains: Deposition plains have altitudes averaging 0 to 2 km and cover more than half of the planet's surface.

Lowlands: The rest of the surface is called *lowlands* and generally lies below zero altitude. Radar reflectivity data suggests that at a centimetre scale these areas are smooth, as a result of gradation (accumulation of fine material eroded from the highlands).

Impact craters (Fig. 4)**:** Earth-based radar surveys made it possible to identify some topographic patterns related to craters, and the *Venera 15* and *Venera 16* probes identified almost 150 such features of probable impact origin. Global coverage from *Magellan* subsequently made it possible to identify nearly 900 impact craters.

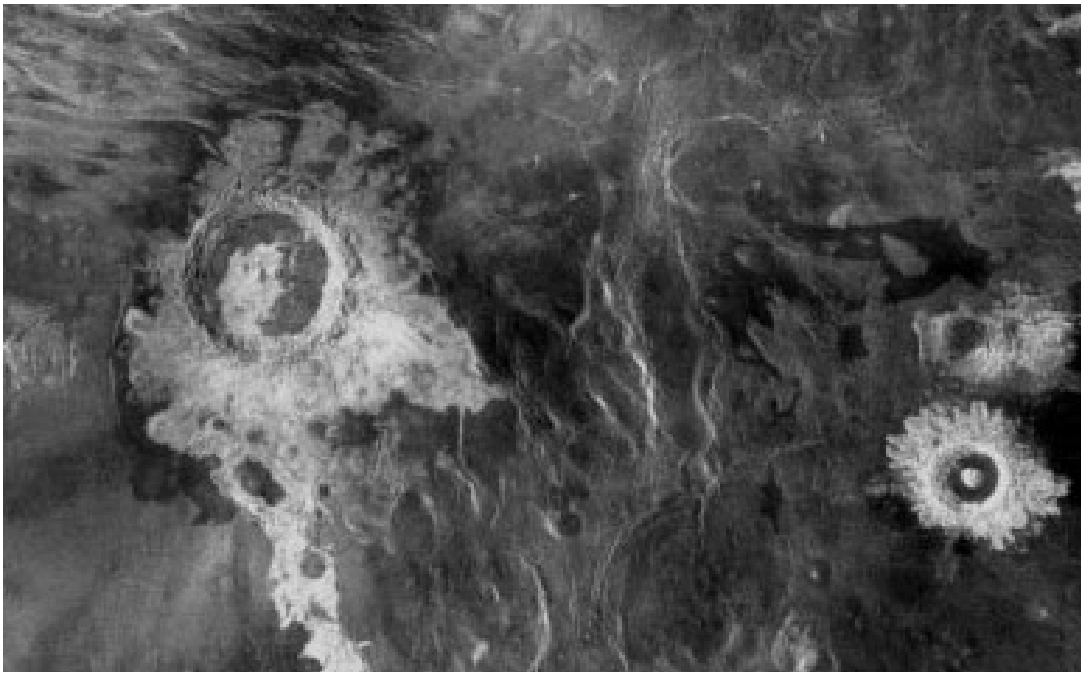


Fig. 4. Danilova and Aglaonice craters.

The *Venera* and *Magellan* data agree: there are very few impact craters with a diameter less than 30 km (19 miles), and data from *Magellan* show an absence of any craters less than 2 km (1.2 miles) in diameter. However, the few very large craters we know of appear very young – we can imply their young age from the fact that they are rarely filled with lava, showing that they occurred after volcanic activity in the area, also radar imaging shows that they are rough and have not had time to be eroded down.

Global Resurfacing Event: The nature of the impact craters and their random distribution give us an approximate age of much of the surface of Venus as 300-500 million years (a more ancient surface would have given a much more erratic distribution of impact craters). It is thought that the planet underwent some sort of global resurfacing at this time, when massive lava flows lasting thousands to millions of years occurred (overwhelmingly large Deccan Trap events). One possible explanation for this event is that it is part of a cyclic process on Venus.

On Earth plate tectonics allow for the escape of heat from the mantle. However, Venus has no evidence of plate tectonics, so the theory is that the interior of the planet heats up (due to the decay of radioactive elements) until material in the mantle is hot enough to force its way to the surface. The subsequent resurfacing event covers most or the entire planet with lava until the mantle is cool enough for the cycle to repeat itself.

There are other processes that link to this theory, however, there is not enough space to include these here. More evidence is needed to put the theory of global resurfacing of Venus on firm (again pun not intended) ground.

About 80% of Venus's surface consists of a mosaic of volcanic lava plains, dotted with more than a hundred large isolated shield volcanoes, and many hundreds of smaller volcanoes and volcanic constructs

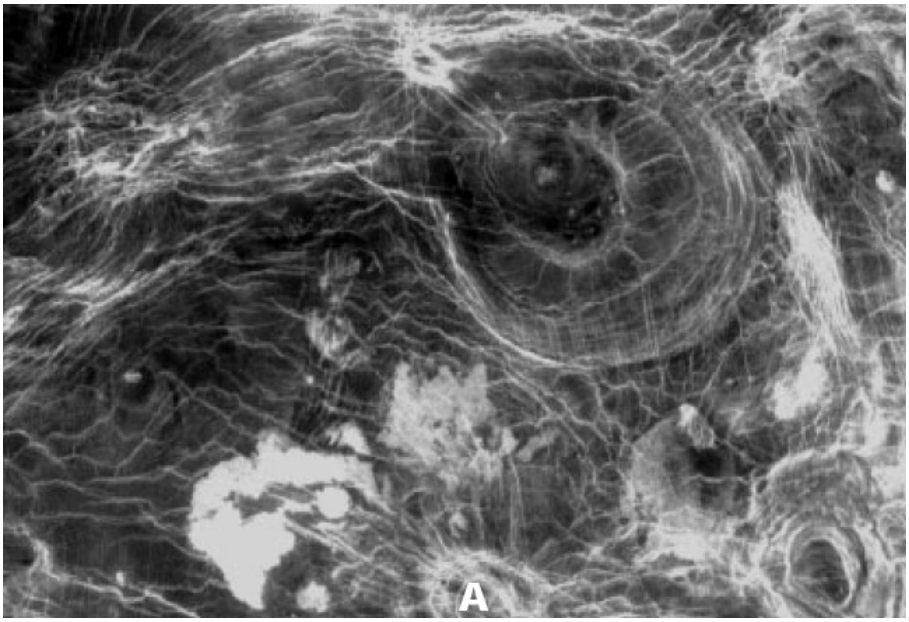


Fig. 5. Coronae – thought to have been formed by the rise and subsidence of subsurface plumes.

such as *coronae* (Fig. 5). *Coronae* are huge, ring-shaped structures 100–300 km (60–185 miles) across and rising hundreds of metres above the surface[2]. The only other place they have been discovered in the Solar System is Uranus's moon Miranda.

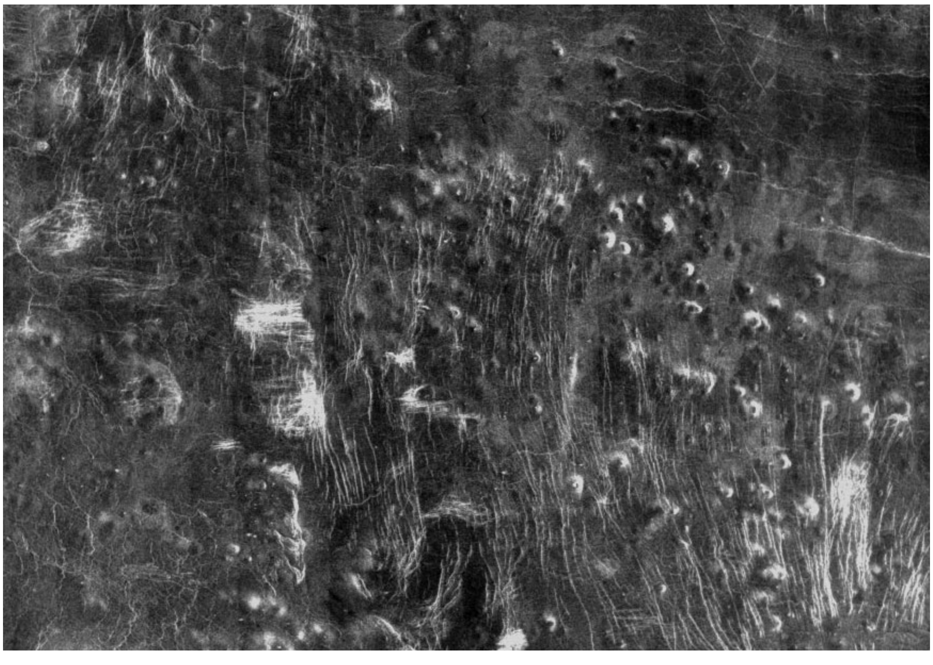


Fig. 6. Shield cluster field of shield volcanoes.

Volcanoes less than 20 km (12.4 miles) in diameter are very abundant on Venus and may number hundreds of thousands or even millions. Many appear as flattened domes or 'pancakes', thought to be formed in a similar way to shield volcanoes on Earth. These pancake dome volcanoes are up to 15 km (9.3 miles) in diameter and less than 1 km (0.6 miles) in height. It is common to find groups of hundreds of these volcanoes in areas called shield fields (Fig. 6).

The pancakes (Fig. 7) are thought to be formed by highly viscous, silica-rich lava erupting under Venus's high atmospheric pressure. Domes called scalloped margin domes (known as *ticks* because they appear as domes with numerous legs), are thought to have undergone mass wasting events such as landslides on their margins. Other unique features of Venus's surface are *novae* (radial networks of dykes or grabens) and arachnoids (named for their resemblance to spider-webs).

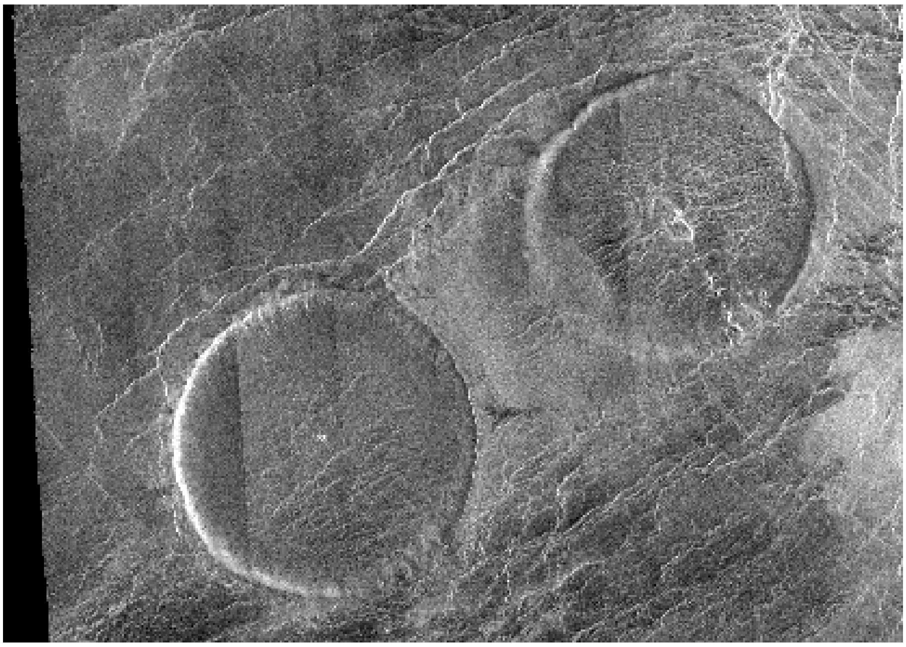


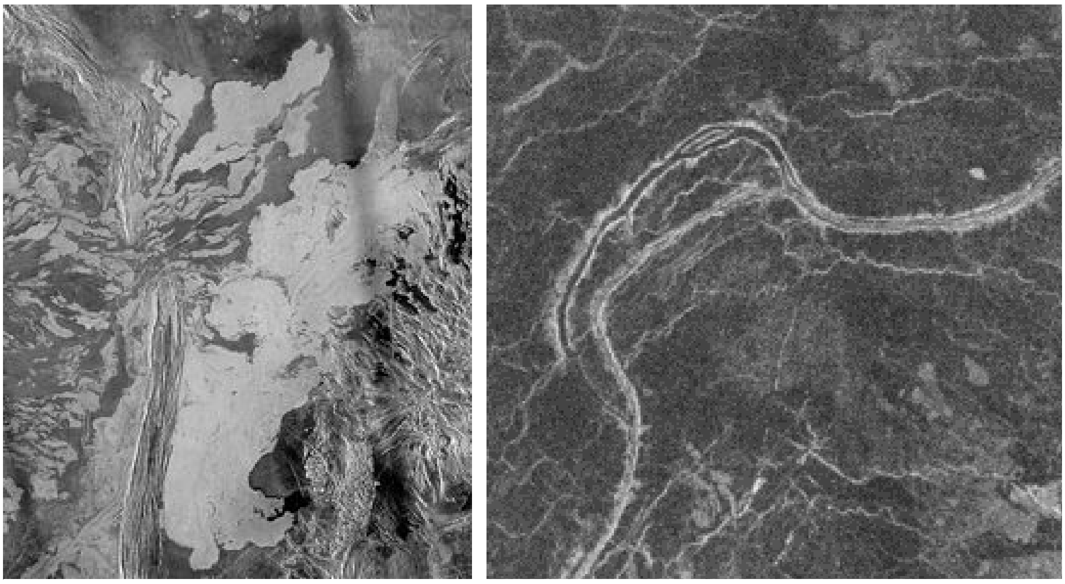
Fig. 7. Magellan radar image of volcanic 'pancake' domes in Tinatin Planitia, formed by the extrusion of high viscosity lava.

The rifts of Venus, formed by the expansion of the lithosphere, are groups of depressions tens to hundreds of metres wide and extending up to 1,000 km in length. These are mostly associated with large volcanic elevations in the form of domes, such as those at the Regios mentioned earlier. These highlands seem to be the result of enormous mantle plumes (rising currents of magma) which have caused elevation, fracturing, faulting, and volcanism. The highest mountain chain on Venus, Maxwell Montes in Ishtar Terra, seems to have been formed by a process of compression, expansion, and lateral movements.

Tesserae are found mainly in Aphrodite Terra, Alpha Regio, Tellus Regio and the eastern part of Ishtar Terra (Fortuna Tessera). These regions contain the superimposition and intersection of grabens of different geological units, indicating that these are the oldest parts of the planet. It was once thought that the tesserae were continents associated with tectonic plates like those of the Earth; in reality they are probably the result of floods of basaltic lava forming large plains, which were then subjected to intense tectonic fracturing.

Lava flows on Venus occur up to several hundred kilometres long and tens of kilometres wide. It is still unknown why these lava fields or lobate flows reach such sizes, but they may be the result of very large eruptions of basaltic, low-viscosity lava spreading out to form wide, flat plains[3]. On Earth, there are two known types of basaltic lava: aa and pāhoehoe. Aa lava presents a rough texture in the shape of broken blocks (clinkers), and pāhoehoe lava is recognized by its pillowy or ropey appearance. Rough surfaces appear brighter in radar images, which can be used to determine the differences between aa and pāhoehoe lavas. Channels and lava tubes (channels that have cooled down and over which a dome has formed) are very common on Venus.

Magellan scientists identified more than 200 channels and valley complexes[4]. The channels were classified as simple, complex, or compound. **Simple** channels are characterized by a single, long main channel (rills similar to those found on the Moon) and a new type, called *canali*, consisting of long, distinct channels which maintain their width throughout their entire course. The longest such channel identified (Baltis Vallis) has a length of more than 6,800 km (4,200 miles), about one-sixth of the circumference of the planet. **Complex** channels include anastomosed (branching and interconnecting) networks (Fig. 8b), in addition to distribution networks. This type of channel has been observed in association with several impact craters and lava floods related to lava flow fields. **Compound** channels are made of both simple and complex segments. The largest of these channels shows an anastomosed



Figs 8a & b. (a) Lava originating from Ammavaru caldera (300 km outside the image) overflowed the ridge left of centre and pooled to its right. (b) An anastomosing (branching and interconnecting) 2 km-wide lava channel in Sedna Planitia.

(branching and interconnecting) web and modified hills similar to those present on Mars.

Surface processes

Water does not exist on Venus and thus the only erosive process to be found (apart from thermal erosion by lava flows) is the interaction produced by the atmosphere with the surface – remember, the atmosphere is so dense that it acts as a fluid. This interaction can be seen in the ejecta of impact craters, which has been expelled onto the surface of Venus. The material ejected during a meteorite impact is lifted into the upper atmosphere, where winds transport the material towards the west, and as the material is deposited on the surface, it forms parabola-shaped patterns. These types of deposit can be seen on top of various geologic features or lava flows, and are believed to be the youngest structures on the planet. Images from *Magellan* reveal the existence of more than 60 of these parabola-shaped deposits that are associated with crater impacts.

The ejection material is transported by the wind at speeds of approximately one metre per second, and is responsible for the process of renovation of the surface. Given the density of Venus's lower atmosphere, the winds are more than sufficient to cause the erosion of the surface and the transportation of fine-grained material. In the regions covered by ejection deposits one may find wind lines, dunes, and yardangs. The **wind lines** are formed when the wind blows ejection material and volcanic ash, depositing it on top of topographic obstacles such as domes. As a consequence, the leeward sides of domes are exposed to the impact of small grains that remove the surface cap. Such processes expose the material beneath, which has a different roughness, and thus different characteristics under radar, compared to formed sediment. The wave-shaped **dunes** are formed by the deposition of particulates that are the size of grains of sand. **Yardangs** are formed when the wind-transported material carves the fragile deposits and produces deep furrows. The wind lines associated with impact craters follow a trajectory in the direction of the equator, suggesting the presence of a system of circulation of Hadley cells (pattern of circulation near equator) between the medium latitudes and the equator. *Magellan* radar data confirm the existence of strong winds that blow toward the east in the upper atmosphere of Venus, and meridional (north-south) winds on the surface.

Chemical and mechanical erosion of the old lava flows is caused by reactions of the surface with the atmosphere in the presence of carbon dioxide and sulphur dioxide. These two gases are the first and third most abundant gases respectively; the second most abundant gas is inert nitrogen. The reactions probably include the deterioration of silicates by carbon dioxide to produce carbonates and quartz, as well as the deterioration of silicates by sulphur dioxide to produce anhydrate calcium sulphate and carbon dioxide.

Well, there is still so much to this planet's geology, that this short essay cannot possibly capture its entirety, nor do I wish to do so. You'll just have to read more on the subject. Venus is still shrouded in mystery and will be so for some time to come.

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Letter to the Editor (& a tale of orchid evolution)

from Gordon Elder

Dear Editor & Members; 11th August 2008

When trawling the Internet, as I do when I'm bored, I sometimes come up with a seed of knowledge that to me bears fruit. As some of you know, once upon a time, I used to be a specialist in orchids.

Flowering plants (angiosperms) have recently become of interest to palaeobotanists because more scientists are finding these plants in the fossil record. But to most of us it seems that fossil plants are of the fern (sporophytes), cone (gymnosperms) and liverwort (bryophytes) genre.

It is thanks to members like Peter Austen, who unceasingly champion the plant fossil world to our membership, that I've become more aware of this interesting research. Thanks Peter!

Orchids are now probably the largest known genus and species of the Plant Kingdom (Plantae) with something over the order of 30,000 species and natural hybrids and more than 100,000 grexes (cultivars.)

In 2000 a private collector discovered a piece of Dominican amber that had entombed a now extinct stingless bee (*Proplebeia dominicana*) carrying an orchid pollinarium on its back (Fig. 1).

Angiosperms usually have pollen on stamens for dispersal via random aeolian (wind borne) or insect pollination. However, orchids are unique in that they use pollinia, where pollen is encapsulated within (usually) a pair of little sticky sacks that attach themselves to the insect as it moves into and away from the labellum and column of the now de-pollinated orchid flower. This is why, should you buy an orchid plant in flower, do not knock these caps off as the flower will turn pink within a few days and wilt or it may set a seed pod instead!

Fig 1. Extinct stingless bee Proplebeia dominicana*, and orchid pollinia* Meliorchis caribea.

This Dominican specimen displays an active pollination of the orchid by the way the pollinia is attached in the correct configuration on the back of the bee – the same as with today's orchids and associated insects – and indicates that this is not a random association. The bee is the vector for this particular plant's pollination process. This is some of the first evidence showing a specific insect-plant association in the fossil record.

Charles Darwin was one of the first scientists to theorise that certain plants have specific pollinating vectors and this was first described by him with a Madagascan orchid called *Angraecum sesquipedale* (the comet orchid[1] – I just had to get something astronomical in here!). He postulated that there should be a highly specialised tongue, just the correct length, which could reach the nectar at the end of a 12 inch (30 cm) long spur emanating from the orchid's flower. Sure enough, a hawk moth (*Xanthopan morgani praedicta*[2]) was discovered some forty years later but not until after the 1970's recorded to pollinate this orchid (Fig. 2). There are of course many other now very well known examples of directed pollination.

In 2005 the Dominican specimen, which has been dated at between 15-20 million years old, came to the attention of Dr. Santiago Ramirez of the Museum of Comparative Zoology, Department of Organismic & Evolutionary Biology, Harvard University, USA[3].

Fig 2. Painting by Sue Abonyi entitled "Etoile-de-Madagasca" of Angraecum sesquipedale *and* Xanthopan morgani praedicta *in their correct proportional sizes to each other.*

Ramirez and his colleagues used the characters of the pollen (named *Meliorchis caribea*) entombed in the amber to establish its phylogenetic position within the orchid family[4]. Using *Meliorchis caribea* and the ages of other known fossil monocots, together with a molecular clock analysis of present day orchids (a method that compares the molecular structures of related proteins of present day orchids to estimate their evolutionary relationships and how far back they originated), the researchers were then able to create a molecular phylogenetic tree for the orchid family.

Their work indicates that the origin of the orchid family dates back to between 76 and 84 million years, much older than the 45 million year Tertiary origin that scientists had previously estimated[5]. Their work also suggests that the orchids underwent a dramatic radiation shortly after the demise of the dinosaurs at the KT boundary, 65 million years ago. Some of these ancient orchids are of the Vanilla genera, and it's from the dried seed pods of the present day *Vanilla planiflora* that we get that wonderful natural flavouring for ice cream.

So, perhaps mentally doodling through the Internet is time consuming and certainly a money sponge but can, on rare occasions, be rewarding when you make connections.

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Yours,
Gordon Elder
Education Officer

A Response (& the ongoing tale of *Bevhalstia*, Sussex's own fossil angiosperm)

from Peter Austen

Thank you, Gordon, for an extremely interesting and informative article on orchids and orchid evolution. I thought that as you had mentioned the recent increase in interest in fossil angiosperms (flowering plants), my response would be a good opportunity to update both yourself and members on recent developments on Sussex's very own fossil angiosperm, *Bevhalstia pebja*, but first a bit of history to set the scene.

The angiosperms are the most important group of vascular plants on the planet, giving us almost all of our food resources, either directly through our food crops, or indirectly through the livestock that feeds on them. They include most trees (not conifers), flowers, grasses, cereal crops, rice, fruits, vegetables and even most of our weeds, but they only first appeared in the fossil record during the Cretaceous. Other groups, the pteridophytes (ferns, horsetails and clubmosses) and the gymnosperms (conifers and cycads) have been around for much longer, but once the more adaptable angiosperms began evolving they eventually came to dominate the landscape, forcing the more primitive plant groups to play a much lesser role.

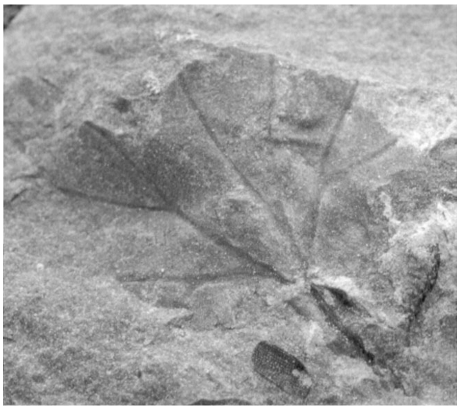

Fig. 1. Leaf of Bevhalstia pebja *displaying well defined venation (size of specimen - 14mm left to right). (Smokejacks)* *Photo: Terry Keenan*

From around 1985 to 1993, Joyce and I collected a large amount of an extremely poorly preserved, but unusual plant from the Weald Clay brickpits of Surrey (Smokejacks Brickworks – Barremian, Lower Cretaceous) and Sussex (Keymer Tileworks – Hauterivian, Lower Cretaceous). We were spurred on by Ed Jarzembowski, who had first noticed this plant in the 1970s. The remains largely consisted of stems and fragments of veined leaves, preserved as impressions in fine-grained clay ironstones and siltstones from within the Weald Clay. Whereas normally plant remains are black and carbonised, the plants that we were collecting were mostly fragmentary impressions in the rocks, with very little preservation of original organic matter. On top of that they were like no other plants that had been found either in the Weald Clay or elsewhere in the Early Cretaceous rocks of SE England. To make matters worse the manner in which the plant was preserved and the way that the rock fractured means that we have never found a complete leaf – figure 1 shows one of the best preserved leaves recovered to date. By 1990 it was felt that, together with Ed Jarzembowski's earlier collecting, we had accumulated sufficient material to allow someone to do some meaningful work on the plant, and we arranged for it all to be sent to the Natural History Museum where Chris Hill, who was then Head of Palaeobotany, had agreed to look at it.

His initial investigations led him to believe that we had an early angiosperm, but we needed more evidence, more specifically we needed flowers. A year's intensive fieldwork was organised, during which time the first 'flowers' (Figs 2 & 3) were discovered along with other significant material. Following several years of research by Chris Hill and extensive collaboration with Ed Jarzembowski, the plant was formally described in 1996 as a possible early angiosperm (Hill, 1996). The plant was named *Bevhalstia pebja* and the species was based on a specimen (the holotype – fig. 4) that Joyce had found at Keymer Tileworks in Sussex. It's worth noting that Chris regarded it as the most difficult plant he had ever worked on.

Fig. 2. Flower-like organ of Bevhalstia pebja. *(Smokejacks)* *Scale in mm*

Why name the plant *Bevhalstia pebja*? – *Bevhalstia* in honour of the late vertebrate palaeontologist Beverly Halstead, and *pebja* after the collecting team put together to look for the flowers – yours truly **P**eter Austen, **E**d Jarzembowski, **B**iddy Jarzembowski, **J**oyce Austen and **A**ndrew Ross (this name, *pebja*, had been mooted in the pub following one of our last visits, rather

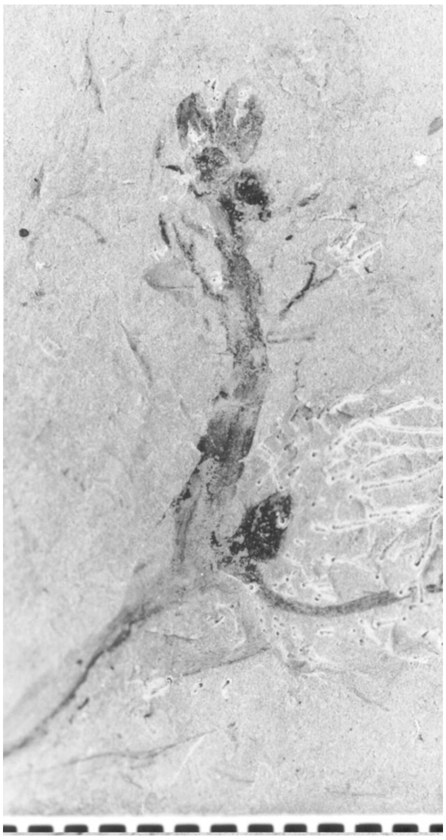

Fig. 3. Shoot of Bevhalstia pebja *with apical flower-like organ. (Smokejacks)*

Scale in mm

Fig. 4. Holotype of Bevhalstia pebja *showing stem with leaves. (Keymer)* *Scale in mm*

Fig. 5. Reconstruction of Bevhalstia pebja. *Painting by Neil Watson*

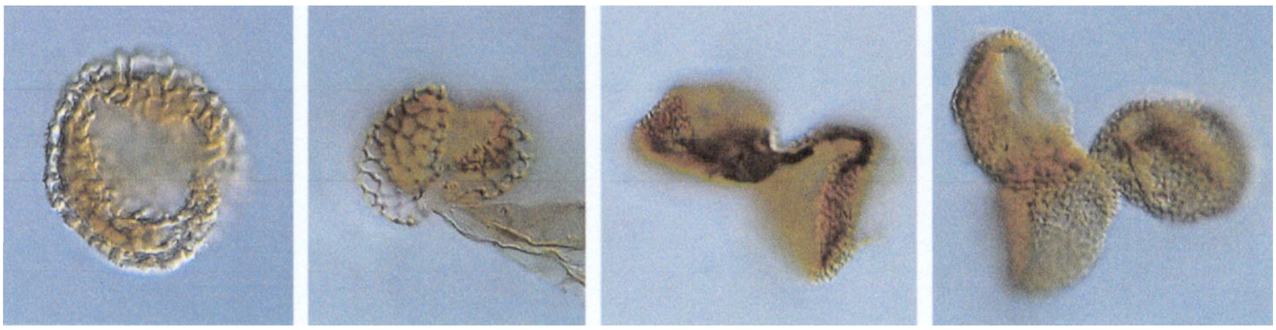

Fig. 6. Angiosperm pollen Retimonocolpites *sp., tentatively linked to* Bevhalstia pebja. *(x 900) (Smokejacks) (from Nye,* et al.*, 2008)*

more in a spirit of joviality than as a serious suggestion, but it stuck!).

When published, the new plant received a lot of publicity, with coverage in most of the newspapers and popular science magazines. It even appeared on BBC's *Gardeners' World*, and was also featured in the *National Geographic* magazine's 2002 article on the evolution of flowers (Klesius, 2002).

Bevhalstia itself was a weakly constructed herbaceous plant, which grew to a length of around 25 cm, and although the leaves and vascular system displayed primitive fern-like characteristics, it possessed more advanced flower-like reproductive structures. It grew in single species stands in boggy or shallow freshwater/brackish environments, and superficially resembled a water buttercup (Fig. 5). Evidence for the origin of angiosperms has always been somewhat elusive and up until the early 1980s it was often speculated that the lack of fossil evidence was due to an upland origin of the angiosperms (i.e. woody magnolia-like shrubs growing some distance from water). However, slightly younger plant material from the Australian Aptian (Lower Cretaceous) (Taylor & Hickey, 1990), not that dissimilar to *Bevhalstia*, has led to the hypothesis of a possible herbaceous origin for the angiosperms. The discovery of *Bevhalstia* not only supports this, but also implies a possible aquatic origin. When the paper was published in 1996 Dr Una Smith, a palaeobotanist at Yale University, said of the plant "This is potentially the most exiting fossil plant found in Southern England for nearly 200 years". In 1999 seed-like structures were discovered at Smokejacks by Paul Davis (Natural History Museum). They were found in association with *Bevhalstia*, although not directly attached. This was an important discovery because the younger Australian specimens, to which *Bevhalstia* has been compared, contained fossilized fruits that once enclosed seeds.

In July 2001 on our Geologists' Association fieldtrip to Smokejacks, the partial skeleton of a juvenile *Iguanodon* was discovered and subsequently excavated by a team from the Natural History Museum (Austen, 2001). It was one of the most complete and best preserved specimens of *Iguanodon* to come out of the Weald Clay, but as an added bonus whilst excavating the skeleton the Natural History Museum undertook a detailed analysis of the palynology and micropalaeontology of the sediments in a 10 m section surrounding the skeleton. The study, which was published earlier this year (Nye, *et al*., 2008), discovered four types of angiosperm pollen (*Retimonocolpites* sp. 1, 2, 3 & 4) (Fig. 6) all with a similar structure and size to that produced by species within the lily family. The authors also suggested that *Bevhalstia pebja* could possibly have been the parent plant of this pollen, this being the only angiosperm-like plant known from the Weald in SE England or other Barremian localities.

At the time of its discovery *Bevhalstia* was thought to be the world's earliest angiosperm, but older material has since been found in China (*Archaefructus*). Also much more work is required to establish whether *Bevhalstia* is an early angiosperm, a basal ancestor of the angiosperms, or a sister group. Whatever its affinities, more than two decades after we first started collecting this strange looking plant another piece has been added to the jigsaw, perhaps raising even more questions, but it will probably be many more years before the full story of *Bevhalstia* and its true place in relation to the angiosperm family tree is known.

Fig. 7. Cartoon by Nick Baker illustrating the hunt for the elusive 'flower'. (First appeared in Wealden News *No.3, Nov 1999)*

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Rocks are not always what they seem

A cautionary tale by Jim Priestley

I was visiting the Wupatki National Monument Park on the Colorado Plateau, near Flagstaff in Arizona. The park is contiguous with the Sunset Crater National Monument Park with its spectacular volcanic geology. The two are connected by a loop road.

At Wupatki there are the ruins of a number of buildings constructed in the local sandstone by a race of Native Americans who vacated the site in the 15th Century, for reasons that are not known. One multi-story building has more than 100 rooms and there is a ball court similar to those found with Aztec ruins in Mexico.

In the park there is also a "blowhole", a fissure in the ground surface, about 300mm x 200mm, out of which a current of air blows at times. This is caused by the effect of sun-warmed ground on air in cavities just below the surface.

Having examined the ruins and the blowhole, I turned my attention to the geology. The country rock in the park is a red sandstone of the Triassic Moencopi Formation, which is one of the rocks which make the Colorado Plateau into what a local geologist described as "a Wonderland of Rock Scenery."

In part of the park it is overlain by a flow of Tertiary black basaltic lava, only about 300 to 450mm thick. Where the interface between the two rocks is exposed, a baked margin in the sandstone is clearly visible. It is a 20mm band of classic needle-like quartz crystals, standing tightly packed together at right angles to the interface.

I was filled with a desire to take a specimen of the margin home, where it would surely take pride of place in my collection but there was a problem. In US national parks, visitors are forbidden to disturb or remove anything whatsoever and anyone doing so can be subject to penalties that stop just short of the electric chair, so I could not get out my hammer and start hacking.

In spite of their reservations about disturbing anything, the Park Authorities themselves have provided a network of well-surfaced paths throughout the park, so visitors can experience "the Great Outdoor Experience" without their feet leaving a pavement. In several places the construction of the path had cut through the lava into the sandstone and I thought that the excavators might have left behind a piece of the baked margin, so I searched in the likely places. Sure enough, I spotted a handy sized piece of rock, black on one side and red on the other.

There was still the prohibition of taking anything away to consider, so I looked carefully around, saw no one was looking, grabbed it and stuffed it into my jacket pocket without examining it.

I did not look at my prize until I was safely back in the car. Disappointment! The red was sandstone all right, but the black was some of the bit-mac surfacing of the path. To make it worse, the bitumen binder was still tacky and some had transferred itself onto my nice new jacket.

Rabbie Burns was right about the best laid schemes of mice and men!

Recent fossil finds in the Hastings area

by Ken Brooks

Lepidotes head

This specimen was found in blue-grey clay on the beach at Bulverhythe, near Bexhill, by a local fossil collector in May 2008. The name of the fish, *Lepidotes mantelli*, comes from the Greek; *lepidotos*, meaning 'scaly'.

Between 145 and 125 million years ago there would have been a variety of fish living in the lakes and rivers of this area, but by far the most frequently found remains are those of *Lepidotes*. It could grow to over one metre (3ft) in length, and was covered in thick scales coated with a hard, shiny layer of ganoin. This 'armour-plating' would have given *Lepidotes* protection from some predatory animals and also ensured that its remains survived long enough to become fossilised.

Individual teeth and scales of this fish are very common in local rocks, but specimens with articulated scales are rare. This *Lepidotes* head provides important clues to its feeding habits, as its mouth contains rounded teeth which were probably used for crushing the shells of aquatic molluscs. *Lepidotes* fossils are often found near bivalves, such as *Neomiodon,* which are abundant in sandstones of the Lower Cretaceous Ashdown and Wadhurst Formations (Hastings Group). Such observations can provide evidence of a small link in the food web of this environment.

The teeth of *Lepidotes* were continually growing to replace those which were worn or broken, as they still do in fish and reptiles today. With this information we know that finding a large number of fossil teeth does not necessarily indicate huge populations of particular species. The modern descendants of this ganoid fish include the sturgeon, garfish and bowfin.

The *Lepidotes* head was prepared by John Dempsey at his 'Fossil Farm' workshop and was purchased by Peter Marsden, curator of the Shipwreck Heritage and Coastal Centre in Hastings Old Town. It will be included in the display of local geology and fossils at the Centre.

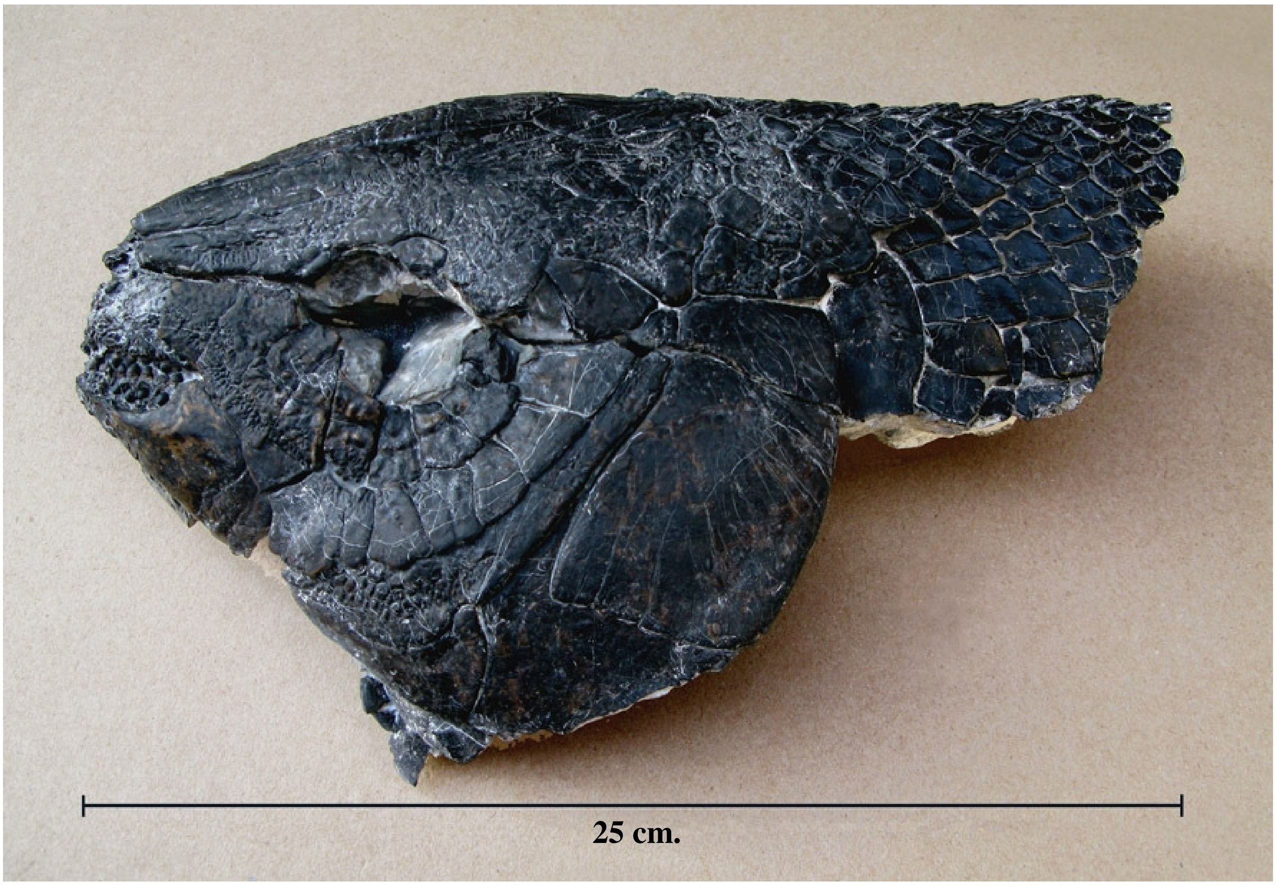

Photo: Diana Williams

Theropod footcast

This theropod dinosaur footcast was found at Fairlight, where the eastern end of the Lee Ness ledge dips down to beach level. A plaster cast of the natural footcast was made on 23rd June 2008, and from this a fibreglass impression was taken.

Footprints and footcasts of the plant-eating *Iguanodon* are often seen on the bedding planes of this silty sandstone, but those of carnivorous theropods are not so common. Dinosaur footprints may be seen in certain outcrops along the beach from Cliff End to Pevensey Bay - although some of these locations may now be covered by shingle, sand or sea defences. There are even rare examples of trackways with three or four footprints in sequence.

Dinosaur footprints, footcasts and tracks provide an extremely valuable source of information on the size and behaviour of these animals and the habitats they occupied. On rocks between Pett Level and Fairlight the overlapping *Iguanodon* footprints of varying sizes indicates that they moved in herds or family groups. Other evidence, such as associated ripple-marks, suggests that these animals may have been grazing on the shore of a lake or river estuary. Sometimes, even their possible food source, plants such as horsetails (*Equisetites*), may be seen as fossils in nearby rocks.

While the fossilised bones of a foot will give its structure, a preserved footprint or footcast will show the actual shape of a living dinosaur's foot. In fact, the shape of a footprint can also tell us something of the animal's mobility. The bulbous heel and fleshy pads of an *Iguanodon* footprint suggest a large, slow-moving animal, such as a plant-eater, whereas the narrow, bird-like foot impressions of a theropod indicate a fast-moving hunter.

Occasionally both herbivore and carnivore footprints may be seen on the same bedding plane, giving important clues as to their ratio in the area. Here we might visualise a lakeside scene 138 million years ago - with a theropod stalking a group of *Iguanodon*!

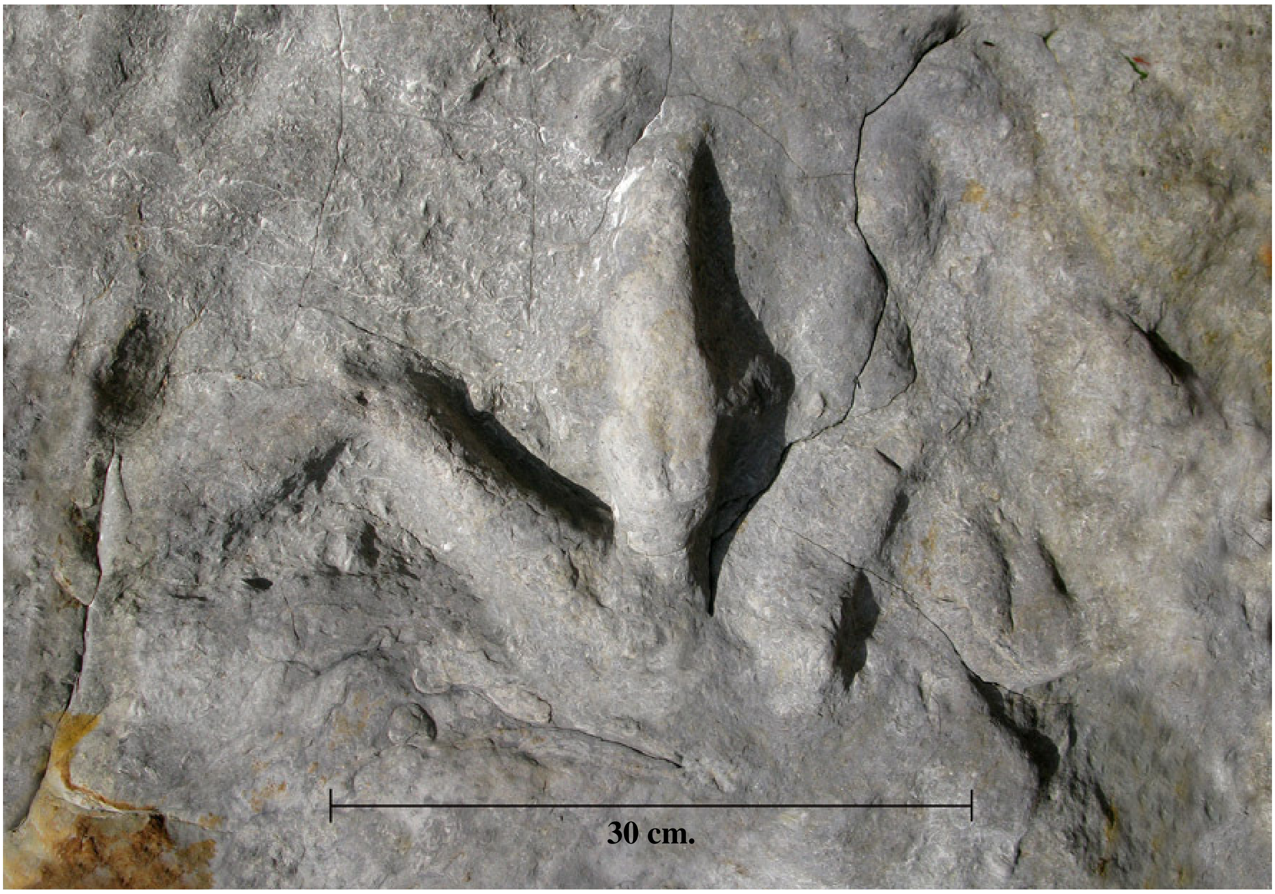

Photo: Diana Williams

Conifer cone

In April 2008 work was in progress on the Fairlight landslip sea defences when Jackie Skipper discovered this unusually large fir-cone in a block of sandstone. Jackie, a senior geologist at the Natural History Museum, was employed as the site geologist by Rother District Council. The cone was later cut from the rock and it is now awaiting formal identification by Paul Kenrick, a Natural History Museum plant specialist.

Because plants are particularly sensitive to climatic and environmental conditions, their fossils can provide very useful information. Plant remains found in Lower Cretaceous sediments have shown that the seasons ranged from warm and wet (monsoonal) to hot and dry, resulting in vegetation fires and carbonised plant material.

The low-lying flood-plains, deltas and lakesides provided ideal environments for the pteridophytes (ferns, horsetails and clubmosses), which reproduced by means of spores, but the gymnosperms ('naked seeds'), which include the conifers, would have grown on slightly higher ground.

Complete specimens are rarely found, as most plants soon decomposed in the humid conditions or were washed away and reduced to fragments in turbulent waters. The few that have been preserved intact were probably covered quite rapidly by sediment in calm water.

For many millions of years the gymnosperms, with their tough stems and leaves, dominated the land, but it was during the Lower Cretaceous that the first true flowering plants, or angiosperms ('enclosed seeds'), began to spread and diversify.

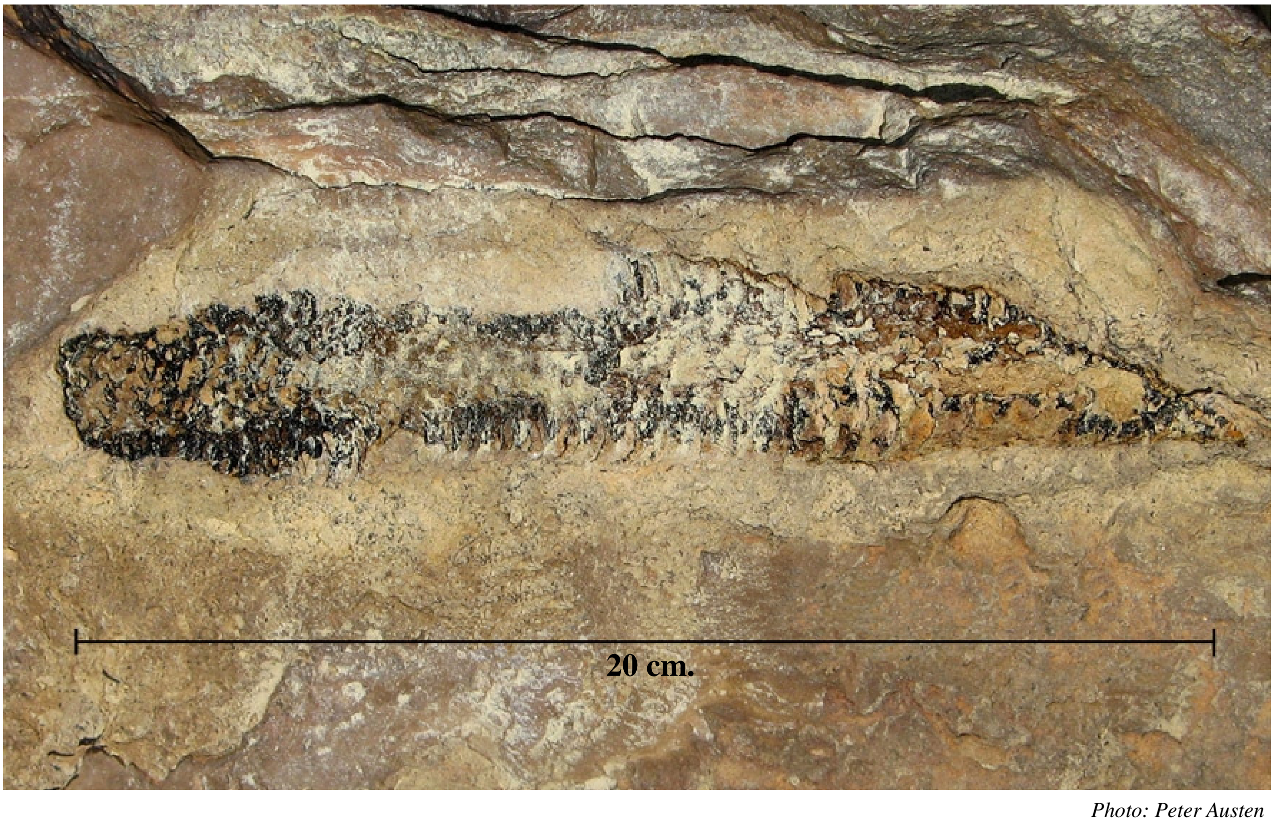

Photo: Peter Austen

First prize at Sussex Mineral and Lapidary Society Annual Show 2008

Congratulations to Trevor Devon for securing first prize for his exhibit of calcite at this year's Sussex Mineral and Lapidary Society Annual Show.

The SMLS Show at Haywards Heath successfully celebrated its Silver Jubilee (25 years!) in November this year with an attendance of well over 600 during the day. One of the features of this "best mineral show in the south of England" has become the annual mineral display competition. In its fifth year of running, the mineral subject this year was "Calcite" and six competitors were invited to provide entries, including HDGS's very own Trevor Devon. Choosing the theme "World of Calcite", Trevor illustrated the range of calcite crystal forms with 39 specimens from 16 different countries. He was rewarded for his efforts by being awarded first place by Bob Symes, an eminent mineralogist and former Keeper in the Department of Mineralogy at the Natural History Museum. Bob complimented Trevor's display for its variety of specimens and subtlety of presentation.

Trevor's winning "World of Calcite" display - *Photo: Jolyon Ralph (SMLS)*

Bob Symes presenting first prize to Trevor

Photo: Jolyon Ralph (SMLS)

Details of next year's Sussex Mineral and Lapidary Society Show are on page 42.

Geological features from South Island, New Zealand

by Marilyn Hadley

Moeraki Boulders Scenic Reserve

The Moeraki boulders on the east coast of South Island, 50 miles north of Dunedin, are spherical concretions formed from the mineral calcite around a nucleus of organic matter, such as a shell, a small piece of bone, or a scrap of wood. The ones shown are about 2 metres in diameter, and although they can be found in other localities in New Zealand, the ones shown are amongst the largest found, and they are concentrated in this one small area (Fig. 1). It is estimated that they took around 4 million years to form.

The Moeraki boulders are embedded in the mudstones in which they formed. At the sea these mudstones form cliffs, and as the cliffs are eroded by the sea, they slump and the boulders are washed out onto the beach (Figs 2 & 3). Once exposed to the weathering effect of the sea, the boulders lose their outer layers, leaving hard veins of crystallised calcite standing out in relief (Fig.4). As these calcite veins weather, the boulders break up into small polygonal pieces (Figs 5 & 6).

Jurassic Petrified Forest - Curio Bay, South Island, New Zealand

Curio Bay lies at the south-east corner of South Island. Years of pounding by the sea have worn away the softer, surrounding sandstones and mudstones of Curio Bay, to reveal the hard silica-impregnated tree stumps and logs on the rock platform, exactly as they were when they fell. This is recognised as one of the best examples of a Jurassic fossil forest in the world.

Fig. 1. Jurassic fossil forest in Curio Bay.

Fig. 2. Jurassic fossilised log in Curio Bay.

Cartoon by Jim Priestley

They are not really extinct but they only come out at Christmas,
when their favourite food, Christmas Trees, is available.

Cliff fall at Cliff End, East Sussex – 30th January 2007

by Dave Talbot (Medway Lapidary and Mineral Society)

This was already my second trip to the area in 10 days, the first had been to do some photography and this was to collect some more rock samples, but I also took my camera for any further photo opportunities.

The reason for these forays was to collect as much information as possible for a rock and photographic collection of the various sediments of the cliffs between Cliff End, at Pett Level, and Haddock's Reverse Fault, at Fairlight Cove, about 800 metres to the west. This is a project I am attempting after working on the Wealden Rock Collection CD-Rom with colleagues from the Medway Society back in 2000 (Day, *et al*., 2004). I have currently divided the cliffs into 34 separate layers, although this may change.

There was a light wind blowing, the tide was on the way out and the weather a bit overcast; I was expecting to stay about 4 hours. Sometimes when I get here I think I'll walk straight to the far end of the cliffs at Haddock's Reverse Fault and then take a slow walk back to Pett, checking the foreshore for different rocks and trace fossils on the way back. It never happens, as there is always something of interest on the way out, and that means I always take my time from the moment I step onto the shingle at Cliff End, until the moment I return (I've never tried, or had to get off the beach from the far end at Fairlight Cove – there is a route, but this is getting somewhat degraded).

Today was no exception as I sauntered along the beach looking at various rocks and forms within them, and taking more photos as well. After searching around a bit, slowly getting to Haddock's Reverse Fault, I came across a fairly recent cliff fall (Fig. 1) from the Cliff End Sandstone (CES), probably that morning. At the time I didn't think too much about it, just that I would collect some rock samples on the way back for my collection.

I took a photo of this initial fall on first seeing it. When I returned about an hour or so later, I started to look around for some samples, but soon moved away as a small section fell away from the ironstone band that separates the Ashdown from the Wadhurst Formations. I began to think I might see a larger fall if I stayed around long enough. I positioned myself away from this initial fall and waited, camera now at the ready. As I watched, more pieces were falling away and at times I was able to catch this on frame, in free-fall (Fig. 2).

Fig. 1

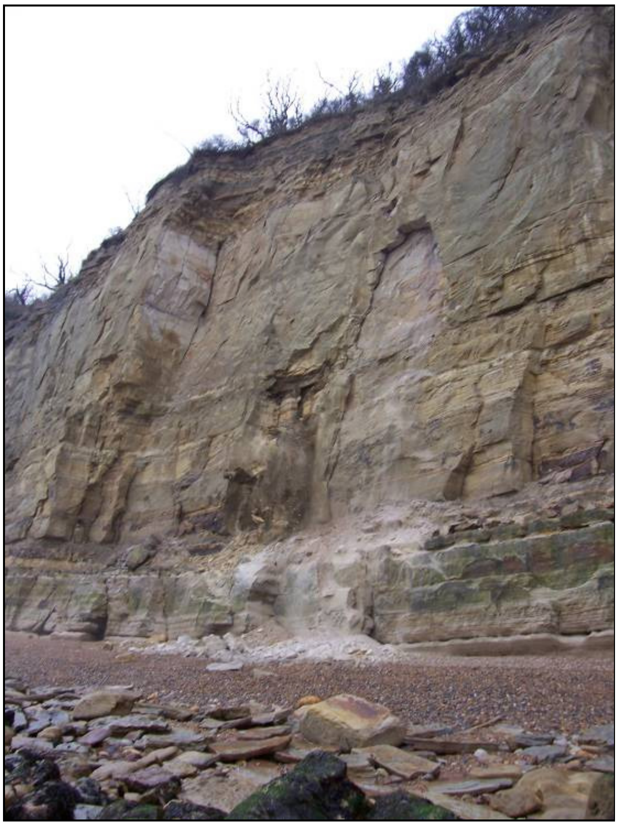

Fig. 2

The cliffs here are about 25-28 metres high – the bottom half is the Ashdown Sandstone and the top half is the Wadhurst Clay. These are nearly all sandstones or siltstones of the Lower Cretaceous Hastings Group and are separated by an ironstone band that stretches across the Weald; the CES above the ironstone is a 10 metre thick sandy unit of the Wadhurst Clay.

As I watched the cliff more and more rocks were falling, the unconsolidated sand of the CES making it appear like a waterfall (Fig. 3). All of a sudden the whole section started to drop (Fig. 4), and in no time at all it was all over, a cloud of dust rolled toward me, but gradually abated, looking misty (Fig. 5), and smelling musty, of earth. My heart was beating like a drum – where I had positioned myself I was OK, but you never know! I took some more photos of the cliff face and the pile of rubble on the beach. Where there had been clean washed shingle there was now a cluttered mess of roots, soil and rock.

There was not another soul in sight! I hadn't got a hard hat, although I don't think it would have been of much use under that lot. I had a mobile phone, but that does not work near the cliffs as there is no signal.

I have visited this area many times over the last 15 years and have seen the aftermath of many falls but **this is the first time I've ever seen this erosion in action – quite magnificent.**

Fig. 3

Fig. 4

Fig. 5

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Pierre Teilhard de Chardin 1881-1955

by Ken Brooks

This year (2008) marks the 100th anniversary of Teilhard de Chardin's arrival at Ore Place in Hastings.

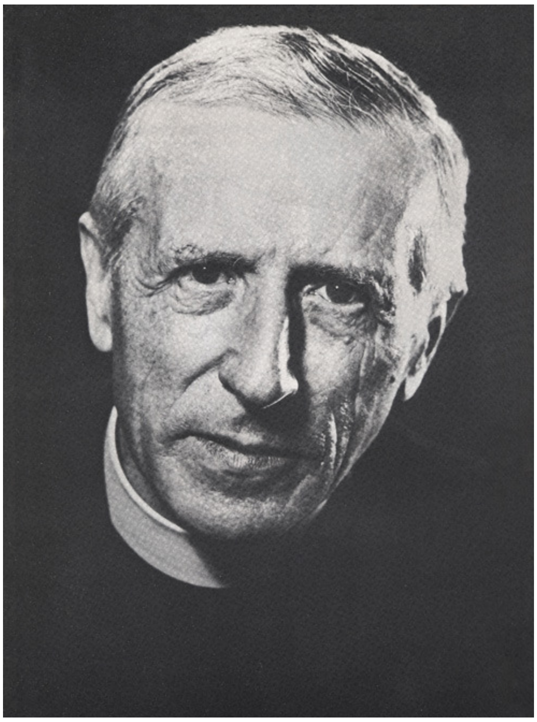

Fig. 1. Pierre Teilhard de Chardin in 1955.

Pierre Teilhard de Chardin was born in the Auvergne region of France on 1st May 1881. His enthusiasm for science developed in his childhood, partly through the influence and encouragement of his father, who was a keen naturalist. In 1899, at the age of 18, having completed secondary education, he joined the Society of Jesus as a novice. While severe intellectual discipline was a characteristic of his Jesuit Order, it also included instruction in all branches of science, particularly geology and zoology. Shortly after, as a result of legislation in France directed against the religious orders, the Jesuits moved to the Channel Islands and in 1901 transferred their juniorate to the institution Notre Dame de Bon-Secours at Maison St. Louis in Jersey. Teilhard stayed here for three years studying theology and philosophy, but he was also able to spend time developing his interest in geology. It is said that he never went for a walk without a hammer and a magnifying glass.

In 1905 Teilhard was sent to Egypt in order to gain teaching experience at the Jesuit College of St. Francis in Cairo, where he studied and taught physics. For the next three years his naturalist inclinations were developed through field trips into the countryside near Cairo studying the existing flora and fauna as well as fossils from Egypt's very ancient past. He also made time for extensive collecting of fossils and for correspondence with palaeontologists in Egypt and France. In 1907 he heard that, due to his finds of shark teeth in Fayum and in the quarries around Cairo, his French correspondent had presented a paper to the Geological Society of France naming a new species of shark *Teilhardia* after him and also recognizing three new varieties of shark.

In September 1908 Teilhard travelled to England to complete his theological studies at the Jesuit Seminary in Ore Place, Hastings (Elphinstone Road) (Fig. 2). Despite his strictly disciplined and structured life, Teilhard still found time for geological activities. He would make field trips to the cliffs at Rock-a-Nore, Fairlight and Pett Level, often accompanied by a fellow student, Felix Pelletier. Here they would search for fossils in rocks from the Ashdown and Wadhurst Formations of the Lower Cretaceous Hastings Beds (140 to 138 million years old).

Fig. 2. Ore Place, Hastings.

It was during a trip to Fairlight the following year that Teilhard met Charles Dawson, who was also an enthusiastic fossil collector. This meeting led to an introduction to Arthur Smith Woodward, Curator of Geology at the British Museum. A few months later Dawson visited Teilhard at Ore Place with some fossil remains; "an elephant's tooth, and one from a hippopotamus, and even some fragments of a human skull." In return Teilhard showed Dawson a dinosaur's footprint in the cliffs near Hastings. This was later followed by a visit to a local quarry where they were delighted to discover the fossilised bones of an *Iguanodon*.

In 1911, during a field trip with Dawson to the beach at Pett Level, Teilhard and Felix Pelletier found two very rare multituberculate (rodent-like) mammal teeth of *Loxaulax valdensis* in the Cliff End Bone Bed, one of which became the type specimen for the species. This bone bed is a hard, coarse-grained rock found in lenticular deposits, 4 - 5 inches (10 - 13 cm) thick, which occur in Wadhurst shales above the Cliff End Sandstone. It contains an abundance of small fossil bones, scales and teeth of fish and reptiles. In August 1911 Teilhard's parents and younger brothers came to Hastings for his ordination as a priest by the Bishop of Southwark at Ore Place.

On one occasion Teilhard assisted Charles Dawson and Arthur Smith Woodward in their excavations for the remains of early man in gravel pits near Uckfield. It was this field trip that resulted in his involvement in the discovery of the controversial Piltdown skull (*Eoanthropus dawsoni*). In a letter to his parents in June 1912, he described the event: " We worked for several hours and finally had success. Dawson discovered a new fragment of the famous human skull; he already had three pieces of it, . . ." Although questioning the validity of this fossil 'evidence' from the very beginning, one positive result was that Teilhard then became particularly interested in the study of fossil hominids. However, it was not until 41 years later that the Piltdown skull was exposed as a forgery. It was proved by the fluorine dating technique that the mandible and canine tooth were from a modern ape, and had been artificially fossilised by surface-staining and mechanical working - a hoax of extraordinary skill. Today most archaeologists believe that Teilhard was not involved in the scandal.

He closely studied the evidence provided by local rocks and fossils, but it was Henri Bergson's book, *Creative Evolution* (1907) that had the greatest influence on Teilhard, since it resulted in his lifelong commitment to the fact of evolution. It is worth emphasizing that it was Bergson's interpretation of evolution rather than Charles Darwin's *On the Origin of Species* (1859) that convinced Teilhard that species are mutable throughout organic history. He was also influenced by Cardinal John Henry Newman who declared "I cannot imagine why darwinism should be considered inconsistent with catholic doctrine."

When his four-year theology course at Ore Place ended in July 1912, Teilhard presented his extensive collection of local fossils to the Hastings Museum. Among over 150 specimens were bivalves (*Unio*, *Neomiodon*, *Paludina*), gastropods (*Viviparus)*, the scales, teeth and bones of fish (*Lepidotes),* sharks *(Hybodus*), crocodiles (*Goniopholis),* pterosaurs and other unidentified reptiles. There were also 74 plant fossils, including horsetails *(Equisetites),* ferns (*Cladophlebis*, *Onychiopsis*, *Ruffordia*, *Hausmannia* (Fig. 3), *Matonidium*), cones (*Pinites*) and bennettitales (*Williamsonia*). These fossil plants formed the basis of an important paper in the *Quarterly Journal of the Geological Society* (Seward, 1913). Some of his donated specimens are still in the original cigar-boxes and have his own hand-written labels on them (Fig. 4). Later that year Teilhard and Pelletier also donated "a valuable gift of Wealden fossils" to the British Museum (Natural History).

In the summer of 1912 Teilhard returned to France. He moved into the little Jesuit community in Paris and was accepted as a student in palaeontology under Marcellin Boule at the Paris Museum of Natural History. It was here that his scientific career started with the study of the Middle Tertiary mammals of Europe.

During the First World War Teilhard served as a stretcher-bearer with a French infantry division and took part in major battles, including Verdun. In 1917 he was cited for displaying "the greatest self-sacrifice and contempt for danger" and later awarded the 'Military Medal' and 'Legion of Honour' for gallantry in action.

Fig. 3. A specimen of the rare Wealden fern Hausmannia dichotoma *found by Teilhard at Hastings.* *Photo: Diana Williams*

Fig. 4. Bones from the Wealden fish Lepidotes mantelli *found by Teilhard at Hastings together with his own hand-written label. (Actual size)* Photo: Diana Williams

After demobilisation he continued his scientific work at the Museum of Natural History in Paris. Teilhard also lectured in geology at the Catholic Institute where, through observations made in his study of fossils, he tried to reconcile religion with evolution. As a result of his research he eventually qualified as a doctor of science and professor of geology.

In 1923 the Museum sent Teilhard to China to search for the remains of prehistoric man. During the next 15 years, as adviser to the National Geological Survey, he travelled the country studying and recording the geology of areas that were completely unknown to science. He also took an active part in the discovery and study of Peking Man and through these experiences he became an undisputed authority on the quaternary geology and palaeontology of South-East Asia.

On his return to France in 1938, Teilhard began giving public lectures on the process of biological evolution. He also started writing a synthesis which would bring together his geological knowledge and religious beliefs. After two years he completed his major work, *The Phenomenon of Man*, in which he argues that mankind has a special place within the spiritual universe and that we are evolving towards an end goal that he called the 'Omega Point' - ultimate unity with God. He was a leading proponent of orthogenesis - the idea that evolution occurs in a controlled direction. Unfortunately, because Teilhard's radical ideas were seen as a threat to the traditional beliefs of the Roman Catholic Church, his book was consequently denied publication. He was also banned from teaching his theological views, and was even 'exiled' from France by his own Jesuit order, the Society of Jesus. Despite this, Teilhard's faith in the Church and the Society never wavered. Twelve years later his unpublished writings were still deemed so threatening that they were implicitly attacked in *Humani Generis*, Pope Pius XII's encyclical against dangerous opinions about the evolution of mankind.

At the outbreak of the Second World War Teilhard returned to China, where he remained, cut off from Europe, until 1945. In May 1950, he was elected as a Foreign Member of the Linnéan Society of London "for his distinguished contributions to the study of the fossil mammalian faunas of China and the Far East, and for his studies in the philosophy of science."

In spite of a serious cardiac illness in 1947, Teilhard led an active life. It was in 1955, during dinner at the French Consulate in New York, that he said, "If in my life I haven't been wrong, I beg God to allow me to die on the Day of the Resurrection." His wish was granted when he died quite suddenly a few days later on 10th April, Easter Sunday, at the age of 74. He was buried in the local Jesuit cemetery in New York.

Teilhard's death deprived the scientific world of a very distinguished geologist and palaeontologist. As a Christian thinker of great originality and vision, many people have been influenced by his ideas. However, it was not until 20 years later that his philosophical works were printed - these included *The Phenomenon of Man* and *Christianity and Evolution*. Although during his lifetime he failed to persuade the Catholic Church to accommodate evolutionary theory, years later, in October 1996, Pope John Paul II issued a statement to the Pontifical Academy of Sciences in which he endorsed evolution as being "more than just a theory."

Teilhard made a deep impression on those who came into contact with him. He was described as "a tall, distinguished figure, whose keenly intelligent face and vivid eyes were lit by an inner flame of enthusiasm." It is a fascinating concept that one of the great philosophical thinkers of the 20th century was inspired by fossils found on the beach in Hastings! On 8th October 2008, a plaque (Fig. 5) was unveiled at the entrance to Ore Place to commemorate Teilhard de Chardin's stay in our town.

Fig. 5. Plaque at the entrance to Ore Place to commemorate Teilhard de Chardin's stay in Hastings.

Photo: Diana Williams

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Palaeontology in the News

A review of recent research and discoveries

Edited by Peter Austen

Introduction

The following is a summary of recent research and discoveries in or associated with palaeontology. Where possible I have included enough detail (i.e. species name, author, etc.) to allow for a search of the internet for further information. In most cases more information is available, including an abstract of the paper, press releases, and quite often if you go to the author's own website you may be able to obtain a copy of the original paper. If you do not have a computer at home, all libraries in the UK are now equipped with computers with internet access for use by the general public.

Giant Argentinian dinosaur

One of the largest ever dinosaurs has been discovered in northern Argentina by a team of Brazilian and Argentinian palaeontologists. The dinosaur named *Futalognkosaurus dukei* was almost complete and was thought to have been more than 32 metres long (*Annals of the Brazilian Academy of Sciences*).

Oldest reptile footprints

A team led by Howard Falcon-Lang of the University of Bristol has found the earliest known reptile footprints (*Journal of the Geological Society*, 2007, Vol. 164, p.1113-1118). The fossilised footprints, found in Grande Anse rock formation in New Brunswick, Canada, are between 316 and 318 million years old. Previous evidence of the earliest reptile was 315 million year old skeletons of *Hylonomus lyelli* found in Nova Scotia in 1859.

Dinosaur dam

China has built a 1.5 km dam to protect a rich fossil bed from flooding. The site, close to the Russian border in China's northern province of Heilongjiang, lies alongside a river and thousands of dinosaur fossils, including 13 partially complete skeletons, have already been unearthed there (*New Scientist*, 2007, Vol. 196, No. 2627, p.5).

Fingers formed from fins

A study undertaken by Per Ahlberg of Uppsala University in Sweden has at last proved that our fingers and toes did evolve from the fins of ancient fish. This resolves a long-running debate over when digits first appeared in the tetrapods (land vertebrates) – previously it had been thought that the digits evolved quite abruptly in the amphibians that first walked on land between 380 and 365 million years ago. All tetrapods evolved from ancient lobed-finned lungfish, of which there are four surviving species. Ahlberg studied one of these, the modern lobe-finned Australian lungfish *Neoceratodus forsteri*, and discovered that the gene that switches on to develop the radials (a set of fine bones at the edge of the fins) is the same as that which switches on to grow the digits in modern day land vertebrates. Ahlberg reported his findings to a meeting of the Society of Vertebrate Paleontology in Austin, Texas, USA in October 2007 (*New Scientist*, 2007, Vol. 196, No. 2627, p.14).

Early mammal teeth

Tribosphenic or 'grinding' molars seem to have evolved twice in mammals: once in the group that gave rise to the marsupial and placental mammals and once in the group that gave rise to the monotremes (egg-laying mammals). Zhe-Xi Luo from the Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA, and colleagues describe a new species of the latter, *Pseudotribos robustus* discovered in the Middle Jurassic Jiulongshan Formation of Ningcheng County, Inner Mongolia (*Nature*, 2007, Vol. 450, p.93-97). This early mammal had very advanced teeth compared with the primitive nature of the rest of its body, and reveals a far greater range of dental evolution in the early mammals than in their present day descendants. The beds also yielded a beaver-like swimming mammal and a gliding mammal.

Dinosaur extinction – Part 1

The eruption of the Deccan Traps volcanoes in India have often been implicated in the extinction of the dinosaurs, but many scientists have argued that could not have been the case because they occurred 300,000 years too early. Now new research presented to a meeting of the Geological Society of America in Denver, Colorado, in October 2007 shows that microfossils found above the lavas show that the eruptions coincided with the peak of the main extinctions (*New Scientist*, 2007, Vol. 196, No. 2628, p.5).

Raptors were pack hunters

A new trackway found in 100-120 million year old Cretaceous rocks in China gives the first solid evidence that raptors were pack animals. The trackway was found by Rihui Li of the Qingdao Institute of Marine Geology in China and shows non-overlapping footprints of six dromeosaurs (the formal name for raptors) beside what would have been a stream. Martin Lockley of the Dinosaur Tracks Museum at the University of Colorado, USA, in Denver, who was a member of the team that found the tracks said the nature of the rocks was such that the tracks were buried soon after they were made, indicating that the creatures that made the tracks were there as a group. They also found that the third toe, which normally bears the long slashing claw, must have been held off the ground as the tracks showed two long toes and a stub for the third toe (claw) (*Naturwissenschaften*, 2008, Vol. 95, p.185-191).

Lunch in the Carboniferous

A rare fossil found in 300 million year old Carboniferous rocks in Germany shows the oldest known example of a food chain with three links. The find, described by Jűrgen Kriwet of Berlin's Natural History Museum shows a fossil shark *Triodus sessilis* with the remains of two amphibians in its stomach, one of which had already eaten a small fish called *Acanthodes bronni* (*Proceedings of the Royal Society B: Biological Sciences*, 2008, Vol. 275, No. 1631, p.181-186). The fossil was found near Saarbrűcken in southwest Germany.

500 million year old jellyfish

Fossils of 500 million year old jellyfish have been found in shales from the Marjum Formation in northwestern Utah, USA. Prior to this discovery the earliest known jellyfish fossils were from shale quarries in Pennsylvania and were only 320 million years old. The find described by Paulyn Cartwright of the University of Kansas in Lawrence, USA, and colleagues (*PLoS ONE* 2(10): e1121 (2007)) shows that jellyfish evolved far earlier than previously thought.

Cretaceous gymnosperm seeds

A new technique has recently been developed by Else Marie Friis of the Swedish Museum of Natural History in Stockholm, and colleagues to study fossilised charcoalified gymnosperm seeds (*Nature*, 2007, Vol. 450, p.549-552). The seeds from the Early Cretaceous of Portugal and the Potomac Group of eastern North America were subjected to phase-contrast-enhanced synchrotron-radiation X-ray tomographic microscopy, which allows the internal structure to be studied in fine detail. The work has linked the seeds to both the present-day Gnetales (an obscure gymnosperm with three living genera) and the extinct Bennettitales (an extinct group of cycad-like plants), and has added support to the controversial anthophyte hypothesis, which links the angiosperms (flowering plants), Bennettitales and Gnetales.

Angiosperm origins

Mike Moore at Oberlin College in Ohio, USA together with colleagues has sequenced the entire chloroplast genomes for 45 flower species for all the major groups of flowering plants (angiosperms) (*Proceedings of the National Academy of Sciences*, 2007, Vol. 104, p.19363-19368). He found that five sister groups split off almost simultaneously 140 million years ago. The five groups consisted of the eudicots (including the roses, sunflowers and tomatoes) and the monocots (grasses and their relatives), which together account for 95% of the angiosperms. The magnolias form a third group and the remaining two groups are less well known.

Snowball Earth?

A recent study by W. Richard Peltier of the University of Toronto, Canada, and colleagues has shown how a full blown "snowball Earth" may have been avoided (*Nature*, 2007, Vol. 450, p.807-808 & p.813-818). Current theories propose that the Earth was fully covered in ice 700 million years ago during the Neoproterozoic. An alternative 'slushball Earth' has also been proposed which allows for open water to exist in the equatorial regions alongside snowball conditions elsewhere, but the matter remained controversial. Peltier's work presents a new climate model of the coupled development of the carbon cycle and climate system during this period. The climate model shows that as the surface temperature falls, atmospheric oxygen becomes more soluble in the cooling ocean, allowing a massive pool of dissolved organic carbon to be converted into carbon dioxide more efficiently. This leads to an increase in atmospheric CO2, more greenhouse warming and the prevention of a full blown 'snowball Earth'. Peltier also speculates that as biochemical reactions run faster in warmer environments this may have been the trigger that led to the explosion of life at the start of the Cambrian.

Whale evolution

A study of fossil whales by J.G.M. Thewissen of Northeastern Ohio Universities College of Medicine, Ohio, USA, and colleagues has found that the terrestrial ancestors of the whales may have been the raoellids, a group of small, primitive even-toed ungulates (artiodactyls) from India (*Nature*, 2007, Vol. 450, p.1190-1194). The raccoon-sized raoellid *Indohyus* is similar to whales, and it was thought to be an aquatic wader, which initially took to the water for food before eventually evolving into the whales.

Ordovician worm

Machaeridians are small shell-like fossils found in marine environments in rocks from the Ordovician to the Carboniferous. Since their first discovery 150 years ago, they have been variously assigned to the arthropods, echinoids, annelids and molluscs. The discovery of a fossil in the Lower Ordovician Lower Fezouata Formation in southeastern Morocco with soft tissue preservation has finally solved the problem. In a paper by Jakob Vinther of Yale University, Conneticut, USA, and colleagues the animal is described as a previously unknown segmented annelid worm named *Plumulites bengtsoni* (*Nature*, 2007, Vol. 451, p.133-134, p.185-188). The 'shells' are in fact calcareous plates carried as armour on the back of the worm.

Giant mouse

A giant skull found in the 4 million year old Pliocene San José Formation in Uruguay is that of a 1-tonne rodent. The fossil rodent described by Andrés Rinderknecht of Museo Nacional de Historia Natural y Antropología, Montevideo, Uruguay, and colleagues, lived in a woodland associated with an estuarine or deltaic environment, and should help reconstruct the appearance of the ancestors of today's much smaller rodents (*Proceedings of the Royal Society B: Biological Sciences*, 2008, Vol. 275, No. 1637, p.923-928).

Bats – flight before echolocation

There has been an ongoing debate about what came first in the bats, flight or echolocation. Newly discovered fossils from the Eocene Green River Formation in Wyoming, USA has settled the controversy. The 52.5 million year old bats, described by Nancy Simmons of the American Museum of Natural History, New York, USA, and colleagues as *Onychonycteris finneyi* are the most primitive found to date and include two near complete skeletons (*Nature*, 2007, Vol. 451, p.774-775, p.818-821). They show that the bats had fully developed wings and were clearly capable of powered flight, but the morphology of the ear regions on their well-preserved skulls suggests that they could not echolocate. They also had tiny claws on all of their elongate fingers, implying that the bats may have been good climbers. They are thought to be a link between bats and their mammalian ancestors.

2.9 billion year old microbial mats

Evidence of 2.9 billion year old microbial mats has been found in sandstones in the Sinqueni Formation, part of the Pongola Supergroup of eastern South Africa. The rocks were formed from sandy sediments, deposited in a tidal environment and add considerably to our knowledge of microbial mats during the Archaean. The work by N. Noffke of Old Dominion University, Virginia, USA, and colleagues (*Geobiology*, 2008, Vol. 6, p.5-20) concludes that the mats are consistent with, but not necessarily indicative of, construction by photosynthesising cyanobacteria. If this is correct it would push back evidence of oxygenic photosynthesis by cyanobacteria from 2.7 to 2.9 billion years, the previous oldest having been found in Western Australia.

Cretaceous weather in Siberia

The study of fossilised fern leaves from 65 million year old rocks in central Siberia has shown that the weather there was similar to modern-day Florida, with lush vegetation and lots of rain. The work by Bob Spicer of the Open University in Milton Keynes contradicts previous climate models which had estimated the temperature at that time as 0 °C. A possible reason for this discrepancy is that present day models for extreme warm climates are wrong, implying that present day climate change models are underestimating the magnitude of future temperature change. (*New Scientist*, 2008, Vol. 197, No. 2646, p.15).

First monkey in America

Chris Beard of the Carnegie Museum of Natural History in Pittsburgh, USA, has reported the first primate to move into America (*Proceedings of the National Academy of Sciences*, 2008, Vol. 105, p.3815-3818). The fossilised teeth of the mouse-sized monkey *Teilhardina magnoliana* were discovered in the 55 million year old Tuscahoma Formation on the Gulf Coastal Plain of Mississippi. It is thought that the monkey must have entered America via Alaska, crossing from Asia via the Bering land bridge.

Dinosaur extinction – Part 2

Stephen Blake and his colleagues at the Open University in Milton Keynes have found rare glass inclusions in volcanic rocks in the Deccan Traps in India, the deposits that have been implicated in the extinction event which killed off the dinosaurs. Previously geologists have been unsure whether enough gas was released by the Deccan Traps eruptions to cause a mass extinction. However, these glass inclusions hold a record of the gases in the magma before eruption, and studies by Blake and his colleagues have estimated that 10^{12} tonnes of sulphur and chlorine were released into the atmosphere – more than enough to cause drastic climate change (*New Scientist*, 2008, Vol. 197, No. 2649, p.16).

Looking into amber

A new X-ray technique has been used by French palaeontologists at the University of Rennes in France to look inside amber. The researchers in collaboration with the European Synchroton Radiation Facility in Grenoble used a synchroton X-ray imaging technique called propagation-phase contrast microradiography to peer into opaque mid-Cretaceous amber from sites in southwestern France. Two of the images are shown (right) and further examples of the spectacular three dimensional images may be seen on the website www.esrf.eu/news/general/amber. (*Nature*, 2008, Vol. 452, p.677).

Arachnid

Hymenopteran

Feeding in the Cambrian

Scientists from the University of Cambridge have reported on the sophisticated feeding apparatus of an Early Cambrian arthropod (*Nature*, 2008, Vol. 452, p.868-871). It was previously thought that the feeding capabilities of Cambrian arthropods were much more basic, and that more advanced feeding apparatus did not appear for another 100 million years. However, a study by Thomas Harvey and Nicholas Butterfield of an arthropod from the late Early Cambrian (510-515 mya) Mount Cap Formation, Northwest Territories, Canada, has revealed sophisticated feeding apparatus that would have allowed it to handle fine food particles. The study implies that these early Cambrian arthropods had a far wider range of ecological niches open to them for feeding than previously thought.

Swimming elephants

Recent research by Alexander Liu of the University of Oxford and colleagues has provided evidence that early elephants may have been aquatic (*Proceedings of the National Academy of Sciences*, 2008, Vol. 105, p.5786-5791). Fossil skeletons of the hog-sized *Moeritherium*, a relative of the elephants, were found in 37 million year old deposits in Egypt and it is thought that they had lived in freshwater swamps or rivers. This was supported by a study of the stable isotopes in their teeth, where they found uniformly low levels of the isotope oxygen-18, a distinctive signature of life in freshwater. Levels of the isotope carbon-13 in their teeth also indicated that they ate freshwater plants.

Dinosaur extinction – Part 3

Soot found in world-wide deposits marking the K-T boundary had been thought to come from global forest fires following the impact of an asteroid in the Yucatan Peninsula in Mexico. Now, Mark Harvey and Simon Brassell of Indiana University, Bloomington, USA, have studied soot at three of the best-preserved sites in New Zealand, Canada and Denmark and found that the soot did not come from burnt plants. Instead, the high temperatures and pressures generated by the impact created the soot by vaporising oil or coal at the impact site (*Geology*, 2008, Vol. 36, p.355-358). This casts doubt on the global fires scenario and perhaps explains why some species that should have been killed off by global fires survived.

Diamond studded foraminifera (Dinosaur extinction – Part 4)

Fossils of amoeba-like single-celled organisms called agglutinated foraminifera have been found coated in minerals and diamonds from the asteroid impact that supposedly killed off the dinosaurs (*Proceedings of the Seventh International Workshop on Agglutinated Foraminifera*, 2008, Vol. 13, p.57-61). Michael Kaminski of University College, London, and colleagues, discovered the forams in the Umbria-Marche basin of eastern Italy. These forams build protective 'tests' around themselves by sticking together sediment grains, usually quartz, from the deep-ocean floor. Kaminski's team studied the rocks above and below the layer created by the asteroid impact 65 million years ago, and found that the forams above the impact layer had microscopic granules of carbon (later identified as diamonds) included in their 'tests'. The diamonds actually came from two sources, one from terrestrial graphite rock, altered by the extreme pressure and temperature of the asteroid impact, and a small proportion from carbon in the asteroid itself. They think that the organisms preferred heavier grains (a preference shared with present day forams), presumably to help them sink to the ocean floor.

Frog ancestors

The discovery of an archaic amphibian known as a temnospondyl (an archaic amphibian related to frogs, toads and salamanders) from the Early Permian of Baylor County, Texas, USA, will help fill the gap in the fossil record between frogs, toads and salamanders and their early ancestors (*Nature*, 2008, Vol. 453, p.515-518). The fossil of *Gerobatrachus hottoni* described by Jason Anderson of the University of Calgary, Alberta, Canada, and colleagues has the overall appearance of the temnospondyls but also has many features seen in frogs, toads and salamanders.

Live birth in the Devonian

A remarkable fossil fish discovered in the 380 million year old Late Devonian Gogo Formation of Western Australia is evidence of the earliest known live birth. The armoured fish, a placoderm (the most primitive known vertebrates with jaws), was preserved in the process of giving birth: it had a single large embryo connected to the adult by a permineralised umbilical cord. The discovery was made by John Long of Museum Victoria, Melbourne, Australia, and colleagues, and has been named *Materpiscis attenboroughi* (*Nature*, 2008, Vol. 453, p.575, p.650-652). It also pushes back evidence of the earliest known live birth by 200 million years, and reveals reproductive biology in the 'primitive' placoderms comparable to some modern day sharks and rays.

Scanning dinosaur eggs

Amy Balanoff of the American Museum of Natural History in New York has used a high-resolution CT scanner on a Mongolian dinosaur egg to reveal a three-dimensional image of the bones within. These toothpick-sized bones are normally difficult to extract without damaging them, but Balanoff's use of this technique on the egg revealed a small, primitive cousin of Triceratops, and the specimen remains undamaged (*Naturwissenschaften*, 2008, Vol. 95, p.493-500).

Cambrian explosion

There was a rapid increase in the abundance of multicellular organisms at the Precambrian-Cambrian boundary around 542 million years ago known as the Cambrian explosion. This has been put down to changes in environmental conditions, but the nature of the changes has been open to debate. Now, research by Martin Wille of the University of Bern, Switzerland, and colleagues, on the molybdenum isotope signatures of black shales from two localities at the boundary has revealed a change in the molybdenum signature immediately after the boundary (*Nature*, 2008, Vol. 453, p.767-769). They have suggested that the early Cambrian animal radiation may have been caused by major changes in ocean circulation, brought on by a massive upwelling of hydrogen sulphide-rich deep ocean water. Prior to this there had been a long period during which the oceans were stratified, with sulphidic deep water, not conducive to an explosion of life.

Fish to tetrapod transition

In the 2006 issue (*HDGS Journal*, Dec 2006, Vol. 12, p.22) we reported on the discovery of *Tiktaalik roseae* from Devonian rocks of the Canadian Arctic. The find represented a transitional form between fish and tetrapods (limbed vertebrates). Per Ahlberg of Uppsala University, Sweden, and colleagues now report on newly discovered material of *Ventastega curonica*, an intermediate link between *Tiktaalik* and the more advanced Devonian tetrapods *Acanthostega* and *Ichthyostega* (*Nature*, 2008, Vol. 453, p.1199-1204). This new find from the Late Devonian of Latvia has the skull of an early tetrapod, but body proportions that more closely resemble a fish, and adds to our understanding of the fish to tetrapod transition.

Migrating eyes in flatfish

One of the arguments used against Charles Darwin's theory of evolution has been dealt a blow. Flatfish (which include plaice, sole, turbot and halibut) have highly asymmetrical skulls, with both eyes on only one side of the head, allowing them to lie flat on the sea-floor. During the larval stage of the flatfish, when the embryo is developing, the eye is seen to migrate from one side of the head, over the top of the skull, to the other side, but no transitional form has been found in the fossil record, giving ammunition to the anti-evolutionists. The discovery of the flatfish *Heteronectes chaneti* from the 47 million year old Lower Eocene rocks of Monte Bolca in northern Italy has at last given us a transitional form (*Nature*, 2008, Vol. 454, p.169-170, p.209-212). The fish, described by Matt Friedman of the University of Chicago, Illinois, USA, has a highly asymmetrical skull, but the migrating eye never gets further than the dorsal midline (top of the skull) even in the adults, confirming that the development of the flatfish bodyplan (i.e. both eyes on the same side of the head) was a gradual process.

Lucky dinosaurs

A new study by Steve Brusatte at the American Museum of Natural History in New York, USA, and Mike Benton at Bristol University, UK, has found that the dominance of the dinosaurs in the Jurassic and Cretaceous was more down to luck than better adaptations (*Science*, 2008, Vol. 321, No. 5895, p.1485-1488). Near the start of the Triassic, 250 million years ago, the reptilian archosaurs split into two groups, the dinosaurs and the crurotarsans (which include the crocodiles). It had been previously thought that the dinosaurs dominated the last 30 million years of the Triassic, but the new study finds that the two groups coexisted, evolving at essentially the same rate, in fact the crurotarsans had a much wider range of bodyplans than the dinosaurs, implying that they would be the dominant group. However, rapid climate change 200 million years ago wiped out all of the crurotarsans apart fron the crocodiles, while the dinosaurs seemed relatively unaffected.

Geological Websites

Useful websites with a geological interest

Edited by Peter Austen

The internet is home to tens of thousands of websites with a geological interest, and it is often difficult to sort the wheat from the chaff. For every quality website there are many which leave a lot to be desired. As a general rule university and museum websites are fairly good, and given below are details of a few other sites worth a visit. If you do not have a computer at home, all libraries in the UK are now equipped with computers with internet access for use by the general public.

All sites were valid as at 25th November 2008.

If you know of any particularly good websites then please let me know and I will include them in the next issue of our Society Journal.

Geological Conservation Review sites

http://www.theGCR.org

Over the past 17 years Natural England (formerly English Nature) has undertaken to document and publish accounts of the most important areas of Great Britain's geological heritage. This Geological Conservation Review (GCR) was initiated in 1977, and since 1991 a series of GCR volumes has been published, each covering a network of key sites representing either a portion of the geological column, or a geological, palaeontological or mineralogical topic. A total of 34 volumes have been produced to date, with a further nine still to be published, most of which are nearing completion. Natural England are now making this information freely available on the World Wide Web. Data from 16 of the 34 published GCR volumes has so far been put on-line. The volumes are:

Caledonian Structures in Britain South of the Midland Valley
Coastal Geomorphology of Great Britain
Fluvial Geomorphology of Great Britain
Mass Movements in Great Britain
The Old Red Sandstone of Great Britain
British Silurian Stratigraphy
Marine Permian of England
Permian and Triassic Red Beds and the Penarth Group of Great Britain
British Upper Jurassic Stratigraphy: Oxfordian to Kimmeridgian
British Upper Cretaceous Stratigraphy
Quarternary of Scotland
Palaeozoic Palaeobotany of Great Britain
Fossil Fishes of Great Britain
Caledonian Igneous Rocks of Great Britain
Carboniferous and Permian Igneous Rocks of Great Britain north of the Variscan Front
British Tertiary Volcanic Province

To access the site go to http://www.theGCR.org and click on 'Site reports', this will then allow you to choose your required site by volume (i.e. Fossil Fishes of Great Britain) or by block (i.e. Wealden). Not all of the sites from the above volumes have been loaded yet, but the number of sites available will gradually increase over time.

I would highly recommend the GCR volumes – they are an excellent resource and give up-to-date information and detailed species lists for all of the sites.

Palaeobiology: A Synthesis – edited by D.E.G. Briggs & P.R. Crowther (1990)

http://www.earth-pages.com/paleobiology.asp

Palaeobiology: A Synthesis was published in 1990 as a joint venture between the Palaeontological Associaton and Blackwell Scientific Publications. It brought together 111 leading international workers from a wide range of fields to write about their specialist areas. The content is arranged as a series of concise articles (124 in total), but rather than looking at various groups of fossils, the book is divided into sections each looking at a particular theme (see list below). When published it was highly acclaimed, both for its content and its quality. The book is now out of print, but the Palaeontological Association and

Blackwell Scientific Publications have undertaken to make the content freely available on the World Wide Web. The areas covered are:

Major Events in the History of Life	(18 articles)
The Evolutionary Process and the Fossil Record	(22 articles)
Taphonomy	(25 articles)
Palaeoecology	(24 articles)
Taxonomy, Phylogeny and Biostratigraphy	(21 articles)
Infrastructure of Palaeobiology	(14 articles)

Although *Palaeobiology II* was published in 2001 it does not cover exactly the same ground, and most of the articles in *Palaeobiology: A Synthesis* are still very relevant, and still used as a teaching resource. It's an excellent read – you cannot fail to find something of interest.

As mentioned in the 2006 Journal (*HDGS Journal*, Dec 2006, Vol. 12, p.28) the Palaeontological Association have also made all their volumes of *Palaeontology* from 1957 to 1998 (Vols 1-41) freely available on the World Wide Web. This valuable resource can be accessed by going to http://www.palass.org and following the relevant links (Publications -> Palaeontology Online). Copies of the Palaeontology Newsletter from 1995 to 2008 (Issue 27 to 68) are also freely available online, and can be accessed on the same site (follow the links: PalAss Newsletter -> PalAss Newsletter Home -> PalAss Newsletter Archive).

Stratigraphic Charts

http://www.stratigraphy.org

The International Commission on Stratigraphy is responsible for setting the boundaries and dates of geological Eons, Eras, Periods, Series and Stages. They base this on the latest available data and the charts are periodically updated (i.e. the 2004 International Stratigraphic Chart has been updated this year (2008)). Once you are into the site click on 'Geological Time Scale 2004' and then click on 'Download stratigraphic charts'. This will allow you to download a selection of stratigraphic charts. The charts can be freely used for non-profit educational purposes, and the latest chart can be found inside the back cover of this Journal.

Update on '*Wealden News*'

by Peter Austen

Unfortunately no *Wealden News* has been produced since Issue No.7 which appeared in the last HDGS Journal, however all back copies of *Wealden News* are now available online. They can be found by going to http://www.kentrigs.org.uk/wealden.html.

Issues and file sizes are listed below.

Wealden News No.1 – Jul 1998 (2 pp.)	(File size: 0.7 MB)
Wealden News No.2 – Mar 1999 (4 pp.)	(File size: 1.5 MB)
Wealden News No.3 – Nov 1999 (4 pp.)	(File size: 1.2 MB)
Wealden News No.4 – Apr 2000 (6 pp.)	(File size: 0.9 MB)
Wealden News No.5 – May 2001 (6 pp.)	(File size: 0.8 MB)
Wealden News No.6 – May 2005 (10 pp.)	(File size: 3.8 MB)
Wealden News No.7 – Sep 2007 (18 pp.)	(File size: 8.9 MB)

It is hoped that the next issue of *Wealden News* will be produced in Spring/Summer 2009.

GEOLOGISTS' ASSOCIATION FIELD MEETINGS – 2009

The Hastings and District Geological Society is affiliated to the Geologists' Association, and as such members are entitled to attend GA lectures, normally held at Burlington House, London, W1, or attend any of the GA field trips. Below is the 2009 GA field programme, although some of these dates may still change. Details of these trips and also GA lectures appear in the *GA Circular*, which is available at HDGS meetings. Details can also be found on the Geologists' Association website www.geologistsassociation.org.uk. All bookings must be made through the Geologists' Association – details in the *GA Circular*.

FIELD MEETINGS IN 2009

Sat 7th Feb. and Sun 8th Feb.	Microfossil workshops	Dr Adrian Rundle
Sat 7th March	The Chalk of Hope Gap	Geoff Toye
Sat 4th April to Sun 5th April	The geology of the Forest of Dean	Bernard Cooper
Sat 25th April	Puddingstone Foray in Herts and Bucks	Mike Howgate
Sat 9th May to Sun 10th May	Gower - Joint meeting with Linnean Soc.	Brian Rosen
Sat 23rd May	Somerset quarries	Simon Carpenter
Sat 30th May	Northants churches	John Potter
Sat 13th June	Fossil Fest V	Neville Hollingworth
Fri 26th June to Wed 1st July	Darwin 200 week	Peter Worsley
Sat 18th July	Wealden excursion	Peter Austen
Sat 19th Sep. to Sun 20th Sep.	Leamington Spa by rail	Martyn Bradley
Sep / Oct (to be confirmed)	Potluck	Mick Oates
Sat 7th November	Sedgwick Museum of Earth Sciences	Liz Harper

SUSSEX MINERAL SHOW

Saturday 14th November 2009

10.00 am - 4.30 pm

Clair Hall, Perrymount Road, Haywards Heath

(Close to Haywards Heath Station)

Minerals, gems, fossils, meteorites, flints, books and accessories on display and for sale

Illustrated Talks

Organised by the **Sussex Mineral & Lapidary Society**

Details and map available at HDGS meetings closer to the date of the Show

Facing page
International Stratigraphic Chart produced by the International Commission on Stratigraphy. The charts are periodically updated and further copies can be downloaded from http://www.stratigraphy.org/cheu.pdf.

INTERNATIONAL STRATIGRAPHIC CHART

International Commission on Stratigraphy

ICS

IUGS

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary *	Holocene		0.0117	
			Pleistocene	Upper	0.126	
				"Ionian"	0.781	
				Calabrian	1.806	
				Gelasian	2.588	
		Neogene	Pliocene	Piacenzian	3.600	
				Zanclean	5.332	
			Miocene	Messinian	7.246	
				Tortonian	11.608	
				Serravallian	13.82	
				Langhian	15.97	
				Burdigalian	20.43	
				Aquitanian	23.03	
		Paleogene	Oligocene	Chattian	28.4 ±0.1	
				Rupelian	33.9 ±0.1	
			Eocene	Priabonian	37.2 ±0.1	
				Bartonian	40.4 ±0.2	
				Lutetian	48.6 ±0.2	
				Ypresian	55.8 ±0.2	
			Paleocene	Thanetian	58.7 ±0.2	
				Selandian	~ 61.1	
				Danian	65.5 ±0.3	
	Mesozoic	Cretaceous	Upper	Maastrichtian	70.6 ±0.6	
				Campanian	83.5 ±0.7	
				Santonian	85.8 ±0.7	
				Coniacian	~ 88.6	
				Turonian	93.6 ±0.8	
				Cenomanian	99.6 ±0.9	
			Lower	Albian	112.0 ±1.0	
				Aptian	125.0 ±1.0	
				Barremian	130.0 ±1.5	
				Hauterivian	~ 133.9	
				Valanginian	140.2 ±3.0	
				Berriasian	145.5 ±4.0	

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
					145.5 ±4.0	
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	150.8 ±4.0	
				Kimmeridgian	~ 155.6	
				Oxfordian	161.2 ±4.0	
			Middle	Callovian	164.7 ±4.0	
				Bathonian	167.7 ±3.5	
				Bajocian	171.6 ±3.0	
				Aalenian	175.6 ±2.0	
			Lower	Toarcian	183.0 ±1.5	
				Pliensbachian	189.6 ±1.5	
				Sinemurian	196.5 ±1.0	
				Hettangian	199.6 ±0.6	
		Triassic	Upper	Rhaetian	203.6 ±1.5	
				Norian	216.5 ±2.0	
				Carnian	~ 228.7	
			Middle	Ladinian	237.0 ±2.0	
				Anisian	~ 245.9	
			Lower	Olenekian	~ 249.5	
				Induan	251.0 ±0.4	
	Paleozoic	Permian	Lopingian	Changhsingian	253.8 ±0.7	
				Wuchiapingian	260.4 ±0.7	
			Guadalupian	Capitanian	265.8 ±0.7	
				Wordian	268.0 ±0.7	
				Roadian	270.6 ±0.7	
			Cisuralian	Kungurian	275.6 ±0.7	
				Artinskian	284.4 ±0.7	
				Sakmarian	294.6 ±0.8	
				Asselian	299.0 ±0.8	
		Carboniferous	Pennsylvanian Upper	Gzhelian	303.4 ±0.9	
				Kasimovian	307.2 ±1.0	
			Pennsylvanian Middle	Moscovian	311.7 ±1.1	
			Pennsylvanian Lower	Bashkirian	318.1 ±1.3	
			Mississippian Upper	Serpukhovian	328.3 ±1.6	
			Mississippian Middle	Visean	345.3 ±2.1	
			Mississippian Lower	Tournaisian	359.2 ±2.5	

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
					359.2 ±2.5	
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	374.5 ±2.6	
				Frasnian	385.3 ±2.6	
			Middle	Givetian	391.8 ±2.7	
				Eifelian	397.5 ±2.7	
			Lower	Emsian	407.0 ±2.8	
				Pragian	411.2 ±2.8	
				Lochkovian	416.0 ±2.8	
		Silurian	Pridoli		418.7 ±2.7	
			Ludlow	Ludfordian	421.3 ±2.6	
				Gorstian	422.9 ±2.5	
			Wenlock	Homerian	426.2 ±2.4	
				Sheinwoodian	428.2 ±2.3	
			Llandovery	Telychian	436.0 ±1.9	
				Aeronian	439.0 ±1.8	
				Rhuddanian	443.7 ±1.5	
		Ordovician	Upper	Hirnantian	445.6 ±1.5	
				Katian	455.8 ±1.6	
				Sandbian	460.9 ±1.6	
			Middle	Darriwilian	468.1 ±1.6	
				Dapingian	471.8 ±1.6	
			Lower	Floian	478.6 ±1.7	
				Tremadocian	488.3 ±1.7	
		Cambrian	Furongian	*Stage 10*	~ 492 *	
				Stage 9	~ 496 *	
				Paibian	~ 499	
			Series 3	Guzhangian	~ 503	
				Drumian	~ 506.5	
				Stage 5	~ 510 *	
			Series 2	*Stage 4*	~ 515 *	
				Stage 3	~ 521 *	
			Terreneuvian	*Stage 2*	~ 528 *	
				Fortunian	542.0 ±1.0	

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

Eonothem Eon	Erathem Era	System Period	Age Ma	GSSP GSSA
			542	
Precambrian Proterozoic	Neoproterozoic	Ediacaran	~635	
		Cryogenian	850	
		Tonian	1000	
	Mesoproterozoic	Stenian	1200	
		Ectasian	1400	
		Calymmian	1600	
	Paleoproterozoic	Statherian	1800	
		Orosirian	2050	
		Rhyacian	2300	
		Siderian	2500	
Precambrian Archean	Neoarchean		2800	
	Mesoarchean		3200	
	Paleoarchean		3600	
	Eoarchean		4000	
Hadean (informal)			~4600	

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Standard Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (*www.stratigraphy.org*).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (*www.cgmw.org*).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

* Definition of the Quaternary and revision of the Pleistocene are under discussion. Base of the Pleistocene is at 1.81 Ma (base of Calabrian), but may be extended to 2.59 Ma (base of Gelasian). The historic "Tertiary" comprises the Paleogene and Neogene, and has no official rank.