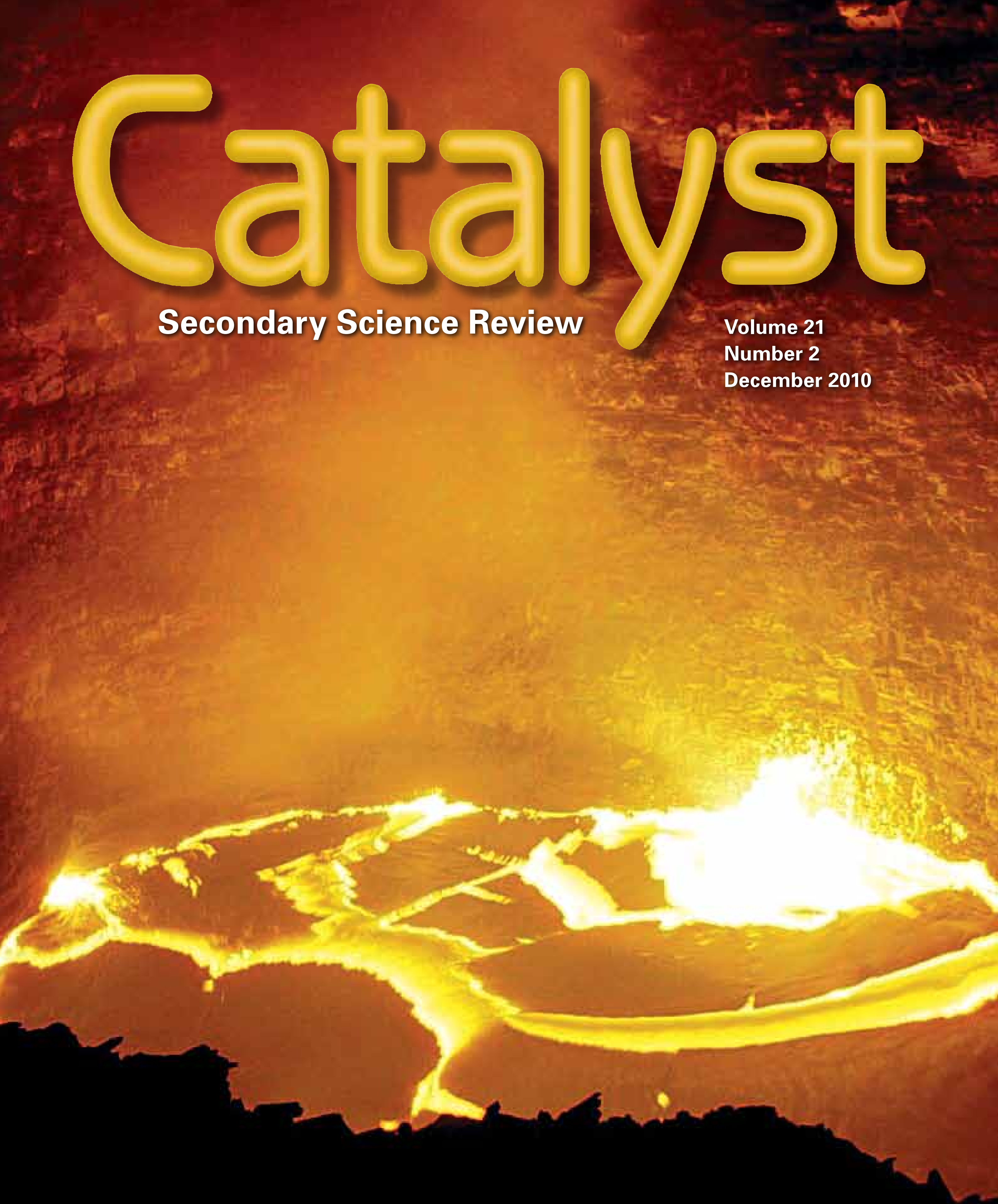

Catalyst

Secondary Science Review

Volume 21
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December 2010

Africa cracks open

When tectonic plates move apart

SEP
Science Enhancement Programme

Catalyst

Volume 21 Number 2 December 2010

The front cover shows the Erta Ale volcano in Ethiopia (see the article on pages 9-13). This is one of only three volcanoes in the world with a permanent lava lake. It lies in a region where two tectonic plates – the African and Arabian plates – are separating.

Contents

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Science looks at the past

Science can help us to understand and interpret the past. In this issue of CATALYST, we look at two projects which tell us about pre-history.

- On pages 17-19, Mélanie Salque of Bristol University describes how we can find out about the farming practices of Neolithic peoples. She extracts tiny quantities of residues from fragments of old pottery; analysis of the carbon isotopes in these residues then helps her to find out what animals they were keeping and whether they were kept for meat or milk.
- And on pages 20-22, Mark Witton of Portsmouth University goes much further into the past to bring us up to date on research into pterosaurs (flying reptiles) of the Mesozoic Era.

We look to the future, too, with news of a new ocean opening up as Africa and Arabia pull apart – see David Ferguson's article on pages 9-13.

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John Packer
Larissa Paver

Money, mistakes and the birth of a science

Key words
oceanography
mid-ocean ridge
telecommunications
electromagnetism

Over two thirds of the Earth's surface is covered in sea which can reach depths of 11 000 metres. Oceanography, the modern science of the oceans, is a huge challenge and one that requires a great deal of money, time and effort. ***John Packer*** *and* ***Larissa Paver*** *explain how it has its roots in big business, a disproved theory and national pride.*

Big business: the coming of the electric telegraph

During the 17th and 18th centuries, scientific interest in the sea was largely focussed on solving the practical problems of navigation, safety and tide prediction. However, it was not until the 19th century that detailed scientific exploration of the deep oceans began, partly as a result of governments stepping in to support a new system of fast international communication – the electric telegraph (see Box 1).

From the time of the laying of the first submarine telegraph cables, the possibility of connecting continents was a powerful reason for governments and industry to gain a better knowledge of the deep sea. The electric telegraph had the potential to change politics, diplomacy, trade, news-gathering and even war for ever. But it was a massively expensive and sometimes dangerous business. The problem was that in the absence of any maps of the ocean floor, the general assumption was that it was smooth. The first undersea telegraph cables were therefore laid with little or no slack, so that they strung out between peaks in the ocean floor and soon broke. Engineers needed to know much more about seafloor conditions, including bottom topography (the 'landscape' of the sea-bed), currents and organisms that might dislodge or destroy the cables.

Box 1: The Electric Telegraph

The electric telegraph was based on the chance discovery by Hans Christian Oersted in 1820 that electricity flowing through a wire creates a magnetic field around the wire, making a compass needle move.

This principle was used in a simple circuit with batteries, a switch and very long wires, to make a needle some distance away move. Combine this with some sort of code, like Morse code, or use a machine that spells out letters of the alphabet and you have an effective and fast way of communicating over a distance. That's exactly what telegraph means – *tele* means far and *graph* means writing.

An ABC telegraph of the sort used on overland telegraph systems. Messages were spelled out using the buttons next to the letters.

The first electric telegraph in Britain was used along a railway line in 1837 and such was its impact that a telegraph network quickly spread throughout Britain. By the 1860s, anyone could go to a Telegraph Office almost anywhere in Britain, write a telegram and send a message in far less time than ever before – fast communication had arrived.

The next logical step was to connect Britain to other countries by submarine cables, or cables under the sea. The challenge of electrical insulation was solved using a type of rubber from Malaysia and steel armouring largely overcame the problems of wave action, fishing nets and sharks. In November 1851, the first functioning submarine telegraph cable was laid across the Straits of Dover.

A submarine telegraph cable lying on the sea-bed off Bermuda.

Submarine telegraph cable sections with the copper conducting wires at the centre, surrounded by insulation, waterproofing and one or two layers of protective 'armour'.

A theory disproved: life in the deep oceans

At the same time as the electric telegraph was being developed in Britain, Edward Forbes (1815-54), professor of natural history at Edinburgh University, had collected animals in the Aegean Sea. He noticed that fewer plant and animal species were caught as his nets went deeper. So, he concluded that deep-ocean waters below 600 metres must be azoic or have no life in them. For some time, this mistaken idea was widely accepted.

Forbes' azoic theory was first questioned publicly in 1861, when a telegraph cable in the Mediterranean Sea, raised for repairs from 2000 metres deep, was found to have living animals on it. Interestingly, these findings have now themselves been questioned, as depths of 2000 metres are difficult to find along the supposed route of the cable, the animals may have been misidentified (the specimens have disappeared) and the sections of deep sea and shallower water cable mixed up. Whatever the truth of the matter, the findings had tremendous impact at the time - they raised doubts about Forbes' azoic theory, helping to prompt events that led to the birth of oceanography.

To try to answer the question of whether or not life existed in the deep oceans once and for all, Charles Wyville Thomson (1830-82), also a professor of natural history at Edinburgh University, led two expeditions between 1868 and 1870. HMS Lightning and HMS Porcupine, dredging at depths of as much as 4300 metres, both found many animal life forms. However, the results of these two expeditions were limited to specific areas of the sea, so left room for doubt about whether life would be found at all depths.

Box 2: The electric telegraph and the Mid-Atlantic Ridge

Lieutenant Matthew Maury, head of the US National Observatory, was the first to attempt to map the floor of the Atlantic, based on information from a voyage of 1853. Maury found that there was a large 'plateau' with no strong currents or disturbances between much of Newfoundland and Ireland. In a letter dated 1854, Maury named it 'Telegraph Plateau'. He described it as placed there especially 'for the purpose of holding a submarine telegraph, and of keeping it out of the way'.

Using this data and data from a 1925-27 voyage of the German research vessel Meteor, scientists proposed that the 'Telegraph Plateau' was actually a continuous ridge extending the length of the Atlantic Ocean basin. Investigations which followed revealed that this was correct, and we now call this feature the Mid-Atlantic Ridge.

National pride and the *Challenger* expedition

At the time, the British Admiralty Hydrographic Office prided itself in producing the world's finest maritime charts (or maps of the sea), but now the Office was being asked questions by the submarine telegraph companies that it was unable to answer because it had not mapped the sea-bed in any detail. This was not a comfortable situation.

So it was that with business, scientific and public interest running high, the Royal Society of London was able to persuade the Admiralty to organise and pay for the most comprehensive single oceanographic expedition ever undertaken.

The Society obtained the use of the naval ship Challenger, a sailing vessel with steam power as back-up. The ship was refitted with laboratories, winches and equipment. Wyville Thomson led the expedition and the Challenger sailed from Portsmouth in December 1872. The voyage was to last nearly three-and-a half years and cover around 70 000 miles.

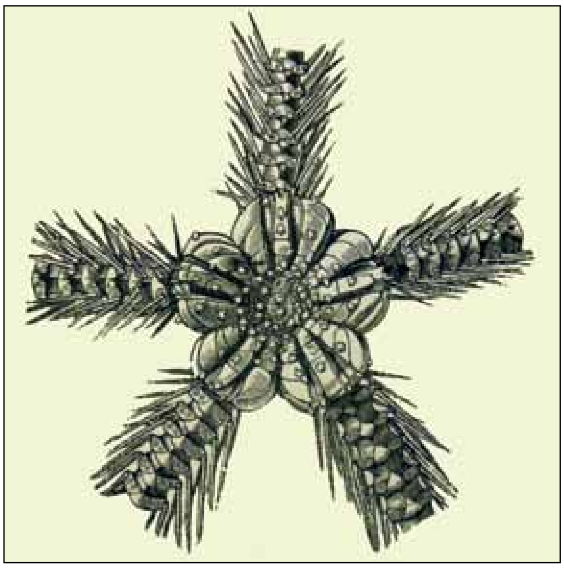
HMS Challenger, 1874, taken from the Challenger reports held at Porthcurno Telegraph Museum

The zoological laboratory aboard HMS Challenger.

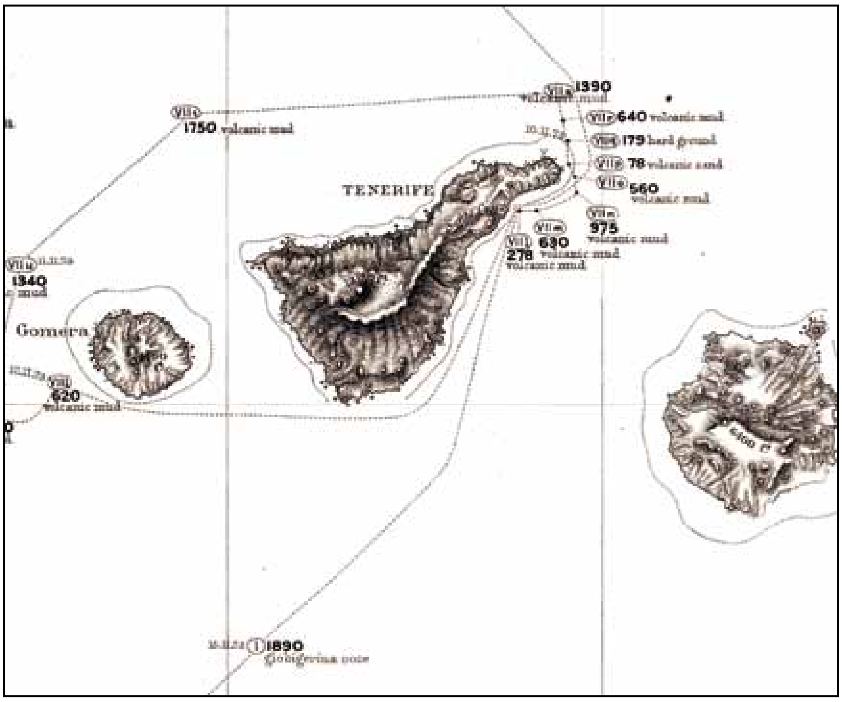
Researchers were jubilant with the scientific success of the Challenger Expedition. The crew completed more than 360 deep-sea soundings, collecting samples of sea-bed sediment at the same time. They obtained no fewer than 7000 sea-life specimens, some from as great a depth as 9000 metres. Almost 5000 new species of marine organism were. Each specimen was described, catalogued carefully, and preserved for later analysis. The findings of the Challenger crew left no doubt that organisms lived at all depths in the ocean, finally disproving Forbes' theory.

For the first time, charts that showed sea-bottom topography and the distribution of deep-sea sediments were sketched out. Needless to say, telegraph companies of the time were very interested in the findings of the Challenger Expedition and made extensive use of the expedition reports.

More than 23 years were required to analyse all of the data and specimens collected by the Challenger Expedition. These findings were published in fifty large volumes that marine researchers still consult today.



Ophiomitra chelys, *a newly discovered type of brittle star, dredged 'from a depth of over 1500 fathoms' (2700 metres) by HMS Challenger.*



A chart from the Challenger expedition. It shows the Canary Islands and gives information about depth in fathoms (a fathom is six feet, a bit less than two metres) and the nature of the seabed.

Box 3: The electric telegraph and tsunamis

On November 18th 1929, an earthquake of magnitude 7.2 occurred off the coast of Newfoundland. This 'Grand Banks Earthquake' triggered a large undersea landslide, snapped 12 telegraph cables and led to a tsunami that struck the coast of Newfoundland about 3 hours later, leaving 28 people dead and more than 10 000 homeless.

The telegraph cables were in use when the earthquake and landslide struck. Therefore the precise location and time of each of the cable breaks and sequence of breakages is known. Subsequent study of this unique set of observations has led to a greater understanding of the conditions that can lead to a tsunami.

National pride and the making of a science

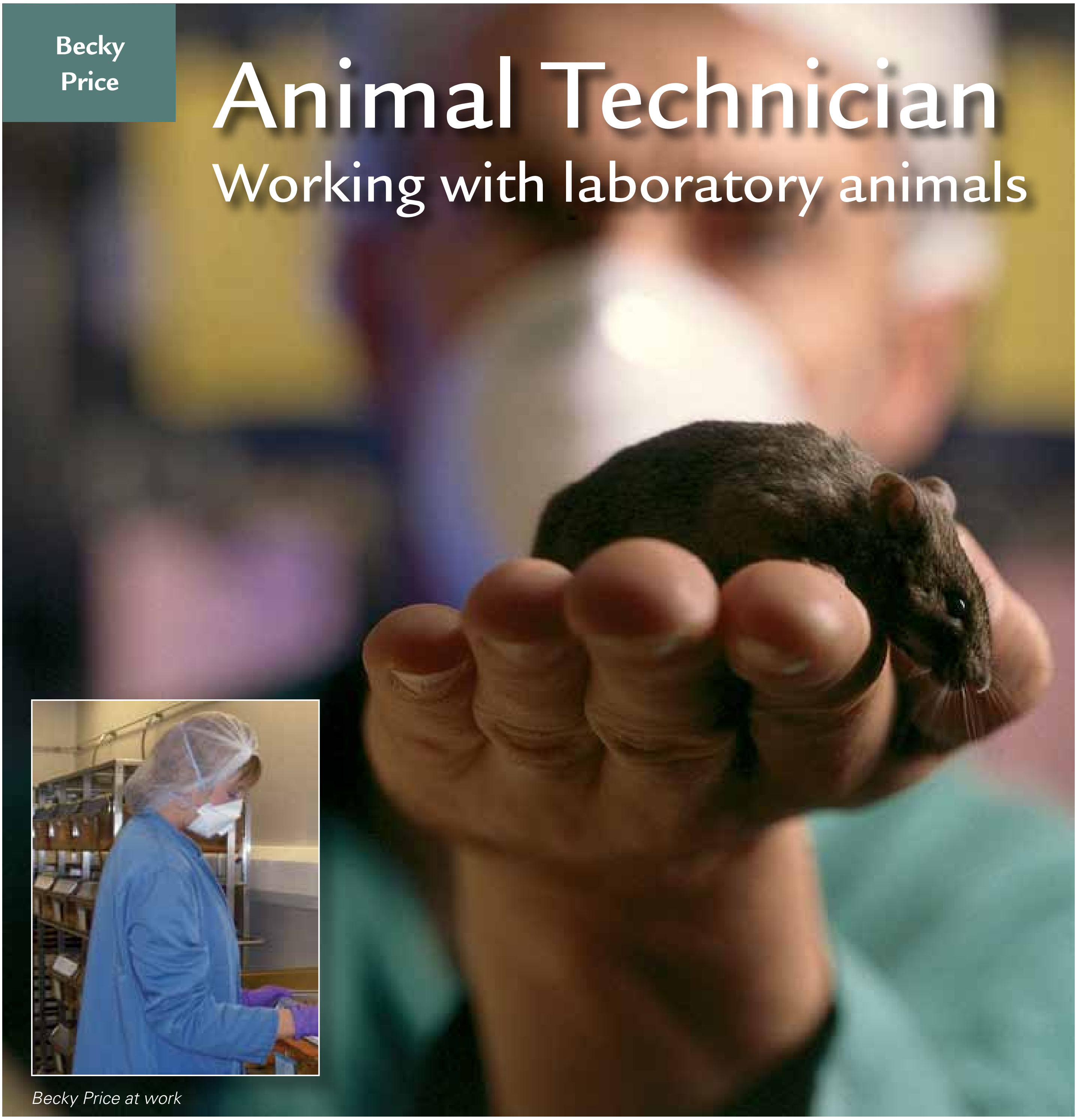
Scientists in other countries used the example of the Challenger Expedition to gain government support for their work. Although their stated purpose was the scientific exploration of the sea, national prestige was also at stake. None-the-less, the Challenger Expedition and reports laid the foundation of the science of oceanography, and modern oceanography is usually dated from this time.

John Packer is a volunteer and trustee at Porthcurno Telegraph Museum and a former telecommunications engineer & lecturer. Larissa Paver is the Museum's Learning Manager.

Becky Price

Animal Technician

Working with laboratory animals



Becky Price at work

Your future

If you thought that in order to have a career in science it would be essential to have a degree then think again. There are many positions available each year for lab technicians of various kinds in many companies in the UK. Often there is extensive training offered with the possibility of getting qualifications such as an HNC or HND, qualifications specific to the field in which you are working, or even a degree. Here ***Becky Price****, an animal technician aged 30, describes her career so far.*

Education

I left school at 18 with A-levels in Biology, English Literature and History. Now I have a degree in Animal Science and a job which I love and find really rewarding.

When I finished my A-levels, I did not want to continue on to university; I wanted independence and a break from education. At the same time I knew that I wanted a rewarding career not just a job and that I wanted to work with animals. I saw the position of animal technician advertised in the local paper and applied.

The usual minimum qualifications are 5 GCSEs at A*-C including English, Maths and Science but people with a wide range of skills are taken on. Some have been to university and have a degree; others do not even have the minimum qualifications but have relevant experience to offer and the right skills and attitude; being passionate about working with animals, having an interest in animal welfare and an understanding of the animal technology environment.

Responsibilities

An animal technician is responsible for all aspects of care and welfare of laboratory animals used in medical research. It is a highly regulated environment and the highest standards of animal welfare must be maintained at all times. The main responsibilities of an animal technician range from day to day husbandry duties such as cleaning out, providing food and water, and carrying out detailed animal observations, through to working alongside the scientists to administer new compounds and support the research process to develop new medicines for both animals and humans. Animal technicians are experts in animal care. We know each of our animals and if they are feeling unwell or show even the slightest change in behaviour we can advise the scientists accordingly.

There is scope to further your work in your own interest areas. One of the areas that I am passionate about is environmental enrichment – ensuring that the animals have an interesting environment to live in by providing items that encourage and promote natural behaviour. This would mean that mice have access to nesting materials, rabbits and guinea pigs receiving hay for example. I head up the enrichment group which identify new items for trial and then run simple studies to assess if the product is beneficial or not. We aim to provide a varied enrichment programme for all animals.

Further training

I have received continual training throughout my career, gaining qualifications from the Institute of Animal Technology and a degree in Animal Science. I am a registered animal technician which required an oral examination in all aspects of animal care and relevant legislation. I have been lucky enough to progress in my career and I am now a manager of an animal facility, managing a team of technicians who carry out the animal care duties. I am very proud of my own achievements

White mice with enrichment materials

A technician removes a white rat from its cage.

and contribution, and now also that of my team in maintaining the highest standards of animal care but also supporting the research effort which delivers new medicines to patients. We have the opportunity to make a difference every day through the care and commitment we show to ensure the welfare of laboratory animals.

This article is based on an interview with Vicky Wong,

Further information

It can be difficult to find information about a career in animal technology so if you are interested you will need to persevere. A good place to start is the Institute of Animal Technology who have a great website and careers brochure. Jobs are usually advertised locally and in job centres and companies will often contact local schools and universities directly. Completion of an animal care course can also be a good start in helping to secure a career as an animal technician.

Look here!

For more information on a career in animal technology, see the Institute of Animal Technology careers page.
www.iat.org.uk/careers/careers.htm

The Association of the British Pharmaceutical Industry has a section on apprenticeships.
abpi-careers.org.uk/

It is also worth looking at the websites of companies in your local area to find out if they offer any apprenticeship schemes or technician roles.

Steve Scott

Key words
genome
DNA
sequencing
sharing data

Ten years on
The Human Genome Project today

On Monday 26th June 2000, the US President, Bill Clinton, and UK Prime Minister, Tony Blair, announced a significant scientific landmark. Scientists had completed a first draft of the human genome, the DNA instructions for making a human being. The project had taken 10 years and promised a new age of genetic discovery and a revolution in medicine. But what has happened since the release of this draft sequence? Have there been any surprises? And has it really had much of an impact? ***Steve Scott*** *of the Wellcome Sanger Institute brings the story up-to-date.*

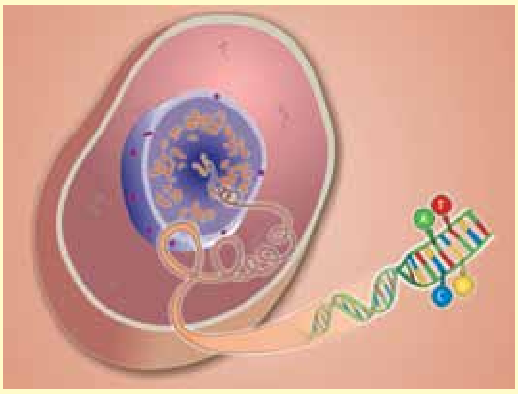
Big biology

The Human Genome Project (HGP) was the first 'Big Science' project in biology, a phrase usually used to describe large-scale government-funded science projects focusing on physics and astronomy. The HGP involved scientists from 20 centres in the USA, UK, Japan, France, Germany and China, working together to map the human genome (see Box 1). It introduced scientists to a new style of collaborative research involving the sharing of information, expertise and resources for a common goal.

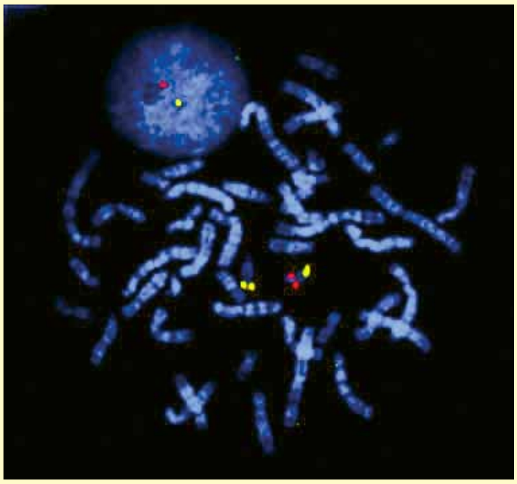
Since the HGP, many consortia have been established to study specific areas of biology. For example, the 1000 Genomes Project was launched

A small part of the Human Genome

Box 1: What is a genome?



A schematic picture showing the relationship between the structure of a typical cell, the nucleus, and the DNA stored in it. All the DNA in a nucleus is the genome.



A fluorescence in-situ hybridisation (FISH) image of chromosomes from a patient with Digeorge syndrome

All organisms, from bacteria to complex organisms like humans, have a genome. The genome is the genetic information needed to make the organism, written in a four-letter code of bases or nucleotides. It is made from a chemical called DNA, which looks like a twisted ladder with each rung of the ladder being made of a pair of bases. The Human Genome Project (HGP) succeeded in sequencing all 3 billion DNA bases of the human genome to create a list of all the genes in the genome. Sequencing the human genome has helped researchers to identify important genes and genetic sequences to better understand human evolution, development and disease.

in 2008 to sequence the genomes of 1000 people from Europe, East Asia, West Africa, South Asia and the Americas. It involves sequencing centres in the UK, China and the USA and will create a catalogue of human variation that will be used to identify genetic regions associated with human diseases. Sequencing technologies have improved and costs have fallen such that the study will now sequence the genomes of over 2000 individuals.

The International Cancer Genome Consortium (ICGC) involves researchers from 11 countries working together to sequence the genomes of more than 50 types of tumour. In 2009, the sequences of small-cell lung cancer, malignant melanoma (a form of skin cancer) and 24 breast cancer genomes were published. This knowledge will improve our understanding of the genetic mechanisms that control cancer development and identify potential targets for early diagnosis and treatments.

We knew from the outset that the human genome sequence was going to be an important resource to the scientific community. But how do you ensure all researchers have access to the information? A meeting in Bermuda in 1996 (Box 2) resulted in the drawing up of key principles to ensure that access to the human genome data was free and without restriction.

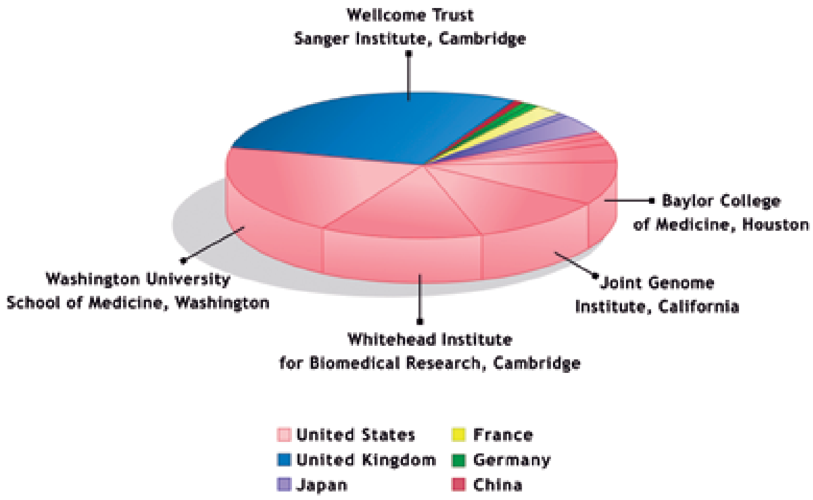
A member of the Sequencing Team at the Wellcome Trust Sanger Institute with Illumina sequencing machines

DNA sequence methods

In 1977, the first organism to have its whole DNA genome sequenced was that of a virus, bacteriophage phi X 174. This virus has just 5386 bases and only short pieces of DNA up to 50 letters long were sequenced at a time using radioactive molecules to label the DNA.

During the Human Genome Project pieces of DNA up to 1000 letters long were able to be sequenced using a faster, safer automated system that used fluorescent labels. However, even with these advances in technology it took several years to sequence and piece together the 3 billion letters of the human genome.

In the last six years, DNA sequencing technologies have taken further leaps forward. A human genome can now be sequenced within a day at a cost of less than $30 000 making it possible to compare and find differences between human genomes. Genome-wide association studies scan the genomes



The Human Genome Project was a collaboration between 20 centres in six countries

Box 2: The Bermuda Principles

On the 25th-28th February 1996 the key members of the Human Genome Project met in Bermuda. They discussed a strategy for sequencing the human genome and what should happen to the data generated. Free data release was high on the agenda of the meeting and discussions led to key principles being agreed. The Bermuda Principles have become the moral foundation for publicly-funded genome sequencing:

- All human genomic sequence information should be freely available in order to encourage research and development and to maximise its benefit to society.
- Sequence assemblies should be released as soon as possible.
- High quality or 'finished' annotated sequences should be submitted immediately to the public databases.

These principles have become fundamental in a drive for open access to data, information and published scientific articles. Today, genomic data are freely available on genome browsers such as Ensembl (www.ensembl.org) and UCSC (genome.ucsc.edu). Ensembl contains the genomes of over 50 vertebrate species from alpaca to zebrafish. You can access and download the entire human genome sequence from Ensembl. We wouldn't recommend you print it though, as you would need 150 000 sheets of A4 paper and a lot of ink cartridges for your printer!!

of many people for specific markers to find genetic variations associated with disease. The areas of the genome common in people with disease are investigated more closely to find out the role they play in disease. These studies have identified genes involved in diseases in cancer, diabetes, heart disease and obesity amongst others.

As the cost of sequencing continues to fall, the likelihood of you being able to afford to have your genome sequenced comes ever closer. This raises many questions. Would you want to get your genome sequenced? Who would you allow to have access to that information?

The issue of the scientific journal *Nature* in which the first sequencing of the complete human genome was reported

Fewer genes than expected

So how many genes do we have in our genomes? Surprisingly, it was revealed that the human genome contains only 23 000 protein-coding genes; a similar number to the worm and fly. So if only 2% of the human genome contains instructions for producing proteins, what does the rest do?

Approximately half of the genome is made up of repetitive DNA; regions containing a short sequence of DNA that is repeated many times and has no known function. Some of the remainder may have be regulatory, coding for RNA that switches genes on or off or coordinate the development. However, we are only just beginning to understand what some of this DNA does and more research is needed to uncover the mysteries of what all non-coding DNA in the genome is for.

Our DNA differs in many ways

The Human Genome sequence was derived from DNA samples from several anonymous donors. However, approximately 70% of the human genome sequence came from a single donor. As the project progressed it became clear that genomes from different individuals vary in many ways. Not only are there single letter differences throughout the DNA but sections and even big chunks are different.

Several projects have tried to compare genomes from different people. The International HapMap Project identified and catalogued differences using data from 270 different populations from African Asian and Europe. This information was then used to find genetic variants linked to human disease. DNA samples from individuals from the HapMap Project were also used to study variation in the human genome due to gains or losses of sections of DNA; so called copy number variation. This type of variation accounts for about 12% of the variation in the human genome, a similar amount to that due to single letter changes. But how important is this variation? How can we have such vast differences without any harmful effects?

The hunt for genetic variation in the human genome continues. The 1 000 Genomes Project was launched in 2008 and this year the UK10K project is beginning to sequence the whole or protein-coding parts of the genomes of 10 000 people from across the UK. UK10K will completely sequence the genomes of 4 000 people, including some twins, who have been studied for many years with their health and development extensively described. The remainder of the people being studied have a condition thought to have a genetic component such as severe obesity, autism, schizophrenia and congenital heart disease. With all this information we will gain a better understanding of the genetic variation between us. The challenge is to translate the knowledge we gain into improved healthcare.

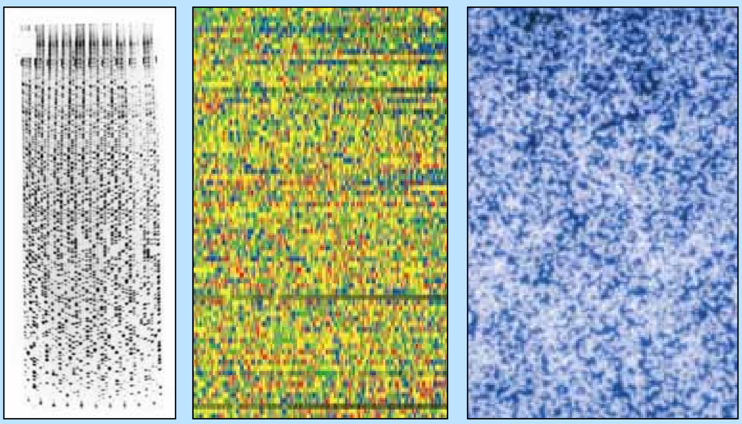
The HGP legacy

The release of the draft human genome in June 2000 marked the dawn of a new era of biological discovery. However, there are still many unanswered questions about the human genome. How is the coordination of the development of the body controlled? What changes occur in cancer genomes and how can these be targeted to improve treatment? How do small and large changes to the sequence of DNA influence susceptibility to disease? There is still much to uncover and explore. Through these discoveries we will be able to advance our understanding of the human body, how it is affected in disease and how we can utilise genomics to improve healthcare.

Steve Scott works in the Communication and Public Engagement Programme, Wellcome Trust Sanger Institute, Cambridge, UK

The changing shape of DNA sequencing

The methods of sequencing of DNA have advanced during the last 30 years which has resulted in the visual outputs of sequence changing: (left) an autoradiograph of a radioactive sequencing gel (Image: Bart Barrell, Genome Research Limited); (centre) an automated sequencing output from the Human Genome Project with the four DNA bases represented by four colours (Image: Genome Research Limited); (right) DNA clusters on a next generation sequencing machine. Millions of DNA clusters are sequenced on a small flowcell (Image: Genome Research Limited).



Birth of an ocean Africa splits apart

David Ferguson

Key words

tectonic plates

earthquakes

volcanoes

magma

The Earth's surface is not quite as stable or permanent as you may think. The tectonic plates that form our planet's outer crust are constantly moving around, bumping past each other along fault zones, crashing to create mountain belts and being pulled apart to create ocean basins. Normally these movements are pretty slow, a few millimetres per year, but in 2005 in the remote Afar desert in Ethiopia a 60 km long section of a plate boundary cracked open by 8 metres in only a few days. ***David Ferguson*** *of Oxford University has been there.*

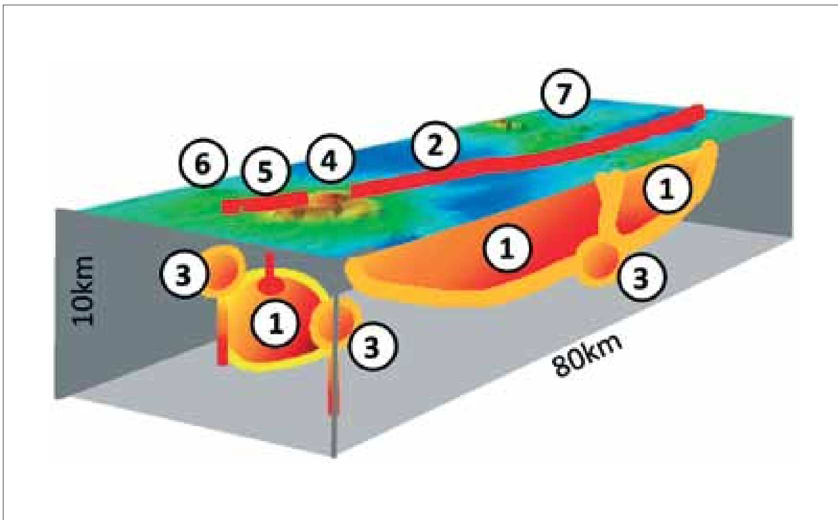
Iam one of an international team of scientists who are using the latest technologies available to geoscientists to probe deep into the Earth in Afar to discover what happens when the crust is rifted apart and a new ocean is born. In this article, I will describe some of the techniques currently being used to study Afar and what they are telling us about the formation of Africa's new ocean.

The importance of magma

When the Earth's crust is stretched it becomes thinner and thinner until eventually it fractures and breaks up. As the crust becomes stretched hotter material from below moves upwards to fill the space. When this hot rock rises it starts to melt, generating magma.

There is currently a lot of magma under Afar and it is this that is ultimately responsible for the amazing geological activity going on today. However, this magma is not spread evenly beneath the surface. Rather, it is concentrated along the fracture zones where the tectonic plate is being broken apart (i.e. where the new plate boundary is forming). Periodically a batch of magma will surge upwards, wrenching apart the crust as it tries to reach the surface. These episodes are called intrusions and they are accompanied by lots of earthquakes as the magma cracks open an upward path.

Sometimes the magma makes it all the way to the surface, erupting new lava flows on to the desert floor from long volcanic fissures. These lava flows will one day form the part of the floor of the new African ocean. Since 2005 there have been 14 separate intrusions of magma and 4 volcanic eruptions in Afar.



Below the ground – the 'plumbing' of the Afar region.

1. September 2005 dykes
2. Trace of dyke on surface
3. Magma chambers
4. Dabbahu volcano
5. Da'Ure vent
6. Gab'ho volcano
7. Ado'Ale volcanic complex

Afar

The Afar region covers the northeastern part of Ethiopia. It is a desert scrubland with saline lakes and long chains of volcanoes. It is one of the hottest and also least populated places on the Earth. In summer the tempertaure regualy gets above 50°C. As the crust in Ethiopia has been streched the ground surface has sunk lower and lower, so much so that many parts of Afar are now below sea level, though not yet under water. The geological processes we wtiness there are similar to those that occur beneath the oceans where two tectonic plates that form the sea floor are moving apart. The amazing thing about Afar is that we can observe this happening on (very) dry land! Afar is also where the earliest hominid fossils have been discovered, the most famous of which is 'Lucy', an *Australopithecus afarensis* who lived in Afar about 3.2 million years ago.

A volcanic fissure, several metres wide, formed as underground magma pushed upwards. Photographed in the Afar region of Ethiopia by Julie Rowland, University of Auckland.

Watching the Earth move

How do we know the Earth surface in Afar is being pulled apart? We know that the earthquakes and eruptions are probably being caused by the magma moving underground, but we need to be able to actually measure the movement of the surface. Geodesists use satellite radar measurements to detect very small changes in the height of the Earth's surface. Comparing measurements made at different times shows if the surface has changed during this time.

In Afar the intrusion of magma forces the ground apart and causes faults to move. This radar technique can be used to measure changes of just a few millimetres. However over the past five years the surface in Afar has been opened up by almost 10 metres!

Feeling the ground shake

When magma moves underground it needs a pathway, this means it has to break apart a lot of rock, thereby generating earthquakes. Like the ripples from a stone thrown into a pond, these waves travel outwards from the fractured rock and can be recorded with a seismometer at the surface.

The Afar team of seismologists (scientists who study earthquakes) have set up a network of stations to record the earthquakes caused by the magma. By comparing the different times that the seismic waves arrive at each station we can calculate the underground location of the earthquake and therefore the magma. During the current active phase in Afar there have been thousands of earthquakes, some very large. In 2005 when the first intrusion happened there were over 163 large earthquakes in a few weeks. Seismologists working in Afar have to travel to Ethiopia every few months to download the data from the seismic instruments.

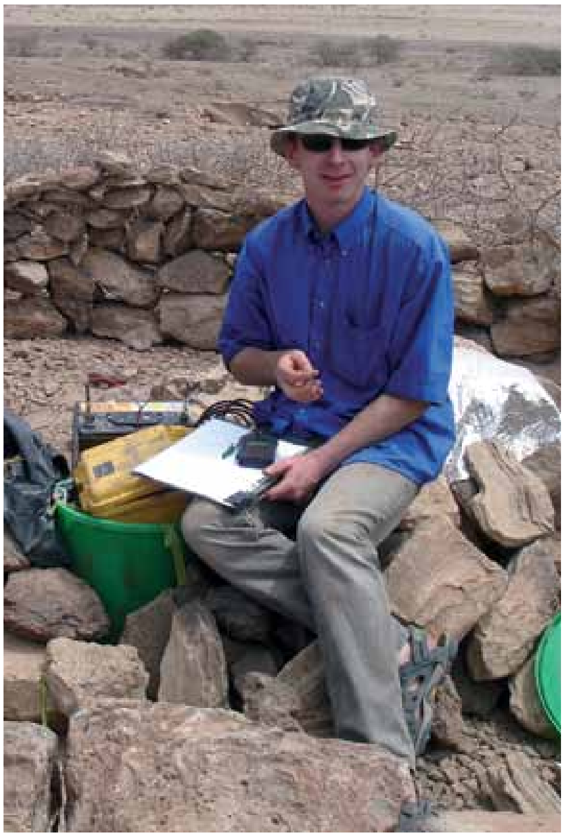
A new volcanic fissure in Afar which opened up in only a few days in 2005. It was formed as magma forced its way upwards pushing the ground apart. The light grey coloured material around the fissure is fresh volcanic ash. On the right are circular goat pens, used by nomadic herders.

Probing the Earth for magma

The satellite measurements show the ground surface is opening up along the new plate boundary; the seismic data suggests is caused by magma moving underground. But where is this magma stored? Magnetotellurics is a geophysical technique that can be used to look for an underground magma chamber. Just like a metal, liquid rock is highly conductive. Geophysicists using magnetotellurics make measurements of the electrical conductivity of the subsurface and try to find highly conductive bodies of molten rock. In Afar mangnetoelluric data has identified a large 'conductor' about 10 km below the new plate boundary. This is the magma chamber that is feeding the intrusions and eruptions.

Chasing volcanic eruptions

You might think a volcanic eruption is a pretty hard thing to miss, but how do you know when a remote volcano erupts and no one is around to see it? Satellite measurements can record the heat and gases emitted by a new eruption. Once we know an eruption is in progress the volcanologists (scientists who study volcanoes) in our group quickly travel out to Ethiopia to try and collect lava samples and to observe the eruption. Measuring the chemistry of the lava can give further clues to where the magma is stored underground, and also what the conditions were like when the magma was originally formed. Once the lava has cooled on the surface it looks very similar to other lava flows, however using infrared cameras allows us to 'see' the heat of the new eruption.



The author collecting lava samples

What have we discovered so far?

By piecing together all the different data from the various techniques we have begun to create a model of how the crust in Africa is being split apart.

- The new plate boundary in Afar is currently very active. Large volumes of magma are moving upwards, splitting apart the Earth.
- Satellite data shows us where the axis of the new plate boundary is and that over the last 5 years the plates have moved apart by up to 10 metres.
- Seismic data from earthquakes records the underground movement of magma as it travels along this new plate boundary.
- Magnetotelluric measurements allow us to 'see' the sub-surface magma chamber which is feeding the intrusions and eruptions.
- Volcanic eruptions confirm that is it indeed molten rock that is driving the activity in Afar and let us collect samples so we can analyse the chemistry of the magma.
- This activity is creating new oceanic crust that will one day form part of an ocean basin.

The Erta Ale lava lake

Africa's new ocean: the next 20 million years

The map shows what east Africa will look like in around 20 million years. A new ocean has appeared all along the eastern coast. This is where the crust is being pulled, stretched and fractured today. The floor of the ocean will be made of cooled lava flows erupted from the magmatic intrusions. The activity we are witnessing today along the plate boundary will still be happening, but will be hidden from view under the waters of the new ocean.

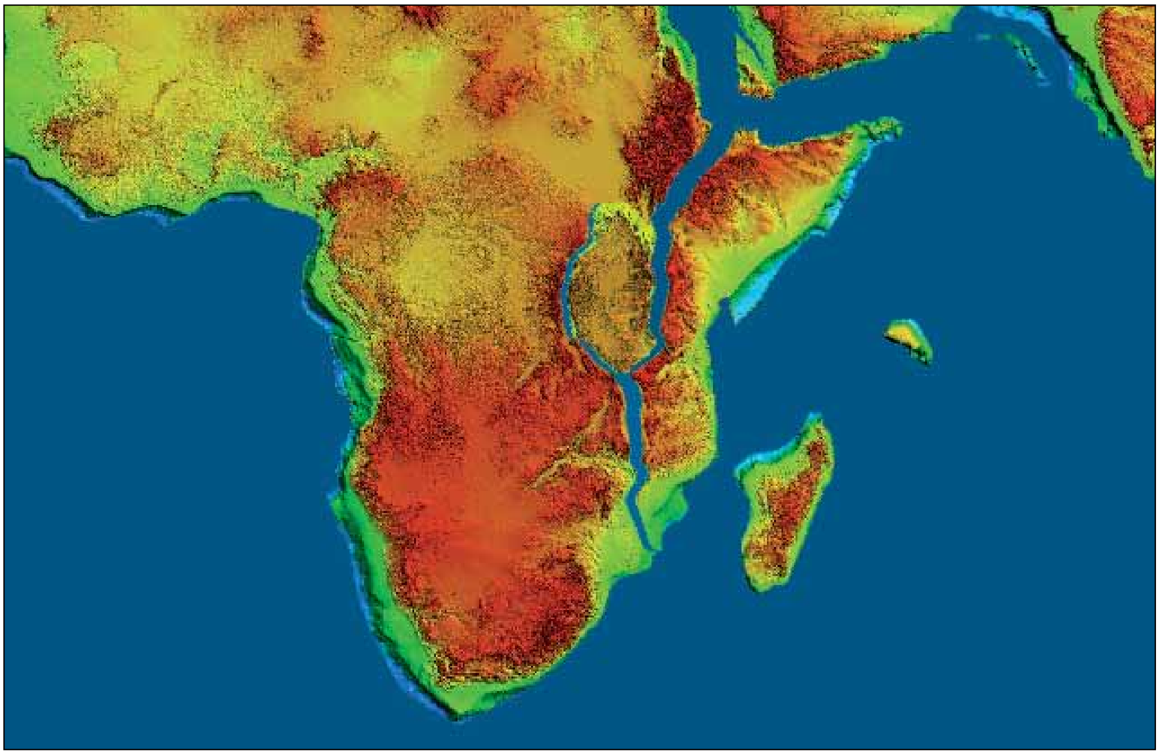
David Ferguson is a PhD student in volcanology at the University of Oxford. He is a member of an international research group who are studying plate tectonics in East Africa.

Look here!

This website has more details about the research in Afar:

www.see.leeds.ac.uk/afar

Check out the 'Day in the life of...' films to learn more about the work of geologists.



Africa 20 million years from now.

Alastair Fitter

Soil – the final frontier

Key words
soil
mycorrhiza
microbes
symbiosis

An adventurous biologist could once bank on finding new species by simply travelling to some part of the world little known to science. Darwin's famous voyage round the world produced many species new to science, many of which bear the scientific name Somethingorother darwinii. In this article, **Richard Fitter** *of York University explains that there is still much to be discovered and understood beneath our feet.*

Calceolaria darwinii *found by Darwin in Tierra del Fuego on the Beagle voyage*

Darwin's fungus Cyttaria darwinii*, found growing on Southern Beech*

New species of plants and animals are still being found all the time: we have probably described fewer than 1 in 8 of all the insects on Earth, for example, and even new birds and mammals turn up occasionally. However, the biologist who really wants to find new species in droves should become a microbiologist and delve into soil, for that is the current frontier of taxonomy, the science that deals with describing, naming and classifying the millions of species on Earth.

How many microbes?

We don't know how many species of microbes there are on Earth; we cannot even make an educated guess, because no-one has yet found a useful way of defining what a microbial species is, but however we eventually define it, the answer is likely to be millions. Bacteria and many important fungi do not reproduce sexually in the complex fashion of most plants and animals. They are largely clonal organisms although they have many curious ways of exchanging genes. They also potentially have huge populations and short generation times, so that new types can appear quickly and persist easily.

Unlike plants and animals, microbes have very few visible characteristics that allow easy classification into species, but analysis of variation in their DNA has revealed their extraordinary diversity. Bacterial diversity can be enormous: using standard assumptions about how different DNA sequences need to be for them to have come from different species, there can be 10 000 different bacterial species in a single gram of soil. There is also great diversity in fungi and many of the smaller animals which abound in soil, such as nematodes, worms and springtails.

Two small animals found in the soil – earthworms and springtails.

In some cases, the number of species found in a single place is not far off the total number of species that have been described in the whole world. Some scientists believe that is because microbes and other very small creatures are universally distributed and what you find in one place depends on what can survive there, not what can get there – a famous aphorism in microbiology is 'everything is everywhere; the environment selects'. Molecular techniques, though, suggest that is not usually true: there really is huge, undescribed diversity in these organisms.

A question of conservation

Does it matter that we know so little about these small creatures? Is there an equal moral argument for conserving microbes and soil animals as there is for conserving conspicuous and charismatic species? We put great effort into sparing tigers from extinction, but we have no idea how many species in soil are at risk of extinction. Whatever your answer to that question, the real reason why we should worry about the possible extinction of unknown species in soil is because we as a species – and the rest of the living world on land at least – depend totally on healthy soils.

Soils provide us with food, because so much of our food comes from agricultural crops. They also act as huge stores of carbon, helping to protect us from our folly in pumping greenhouse gases into the atmosphere. They store, purify and regulate supplies of water: when soils are lost, floods follow quickly. All of these essential benefits that we get from soil are now known as ecosystem services and all of them depend on the organisms within soil, cycling nutrients, creating organic matter and building soil structure.

Soil under stress, then and now – buried machinery in the 'dust bowl' of South Dakota, USA, May 1936, and salination of agricultural land, San Joaquin Valley, California, 2010

Given our dependence on soil for our survival as a species, you might expect that we would both care for it and seek to understand how the 'soil machine' works. Sadly, our record here is not encouraging. Soil is being lost at an alarming rate, globally. Only about 10% of the Earth's land surface is suited for crop cultivation and the useful depth of soil on most of that land is less than 1 metre. It seems likely that we have already lost 10 cm of soil from agricultural land, due to poor cultivation methods, and the current rate of loss is probably around 4 cm per century, though it is certainly much higher than that in some parts of the world, such as south-east Asia.

Soil does get re-created naturally, but at about a hundredth of the rate we are losing it. Add to that, the fact that we have totally lost about 7% of cultivatable land to cities and to salinity (again, thanks to poor agricultural techniques), and that human demand for food will probably double in the next 50 years, and our careless treatment of soil begins to look suicidal.

BOX Symbiosis

Symbiosis at work: root tips of a tree, covered in the white mycelium of a mycorrhizal fungus.

Symbiosis is the term used to describe close physical associations between organisms. This includes:

- **Parasitism**, where one benefits and the other suffers
- **Commensalism**, where one benefits and the other is unaffected
- **Mutualism**, where the association is beneficial to both

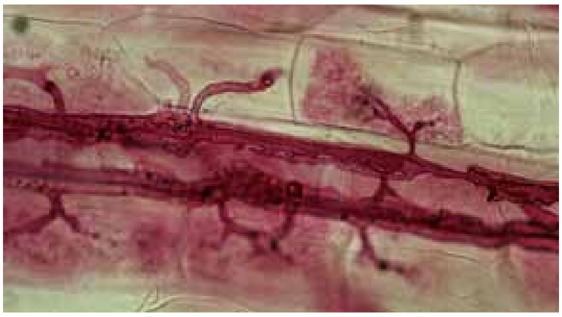
Mycorrhizal symbioses are therefore mutualistic; the fungus gets photosynthetic products from the green plant (mainly sugars), and the plant gets the increased ability to take up water and minerals from the fungus.

Fungal fertiliser

Conserving soil should be one of the most important priorities for every society, but we will also have to learn how to make use of soil in more clever ways. One example comes from the realisation that we are using up the world's stocks of phosphate rocks from which phosphate fertiliser is made. The phrase 'peak oil', describing the moment when world oil production reaches a maximum and then starts to decline, is well known; the new concern is 'peak phosphate'. All over the world there are crops being grown on soils that have insufficient phosphate, especially in Africa.

Once phosphate fertiliser becomes too rare or too expensive, what other way do we have of improving crop yields on those soils? Probably the only answer is to exploit the behaviour of mycorrhizal fungi, which are symbiotic fungi that live in plant roots and in the soil (see Box lower left). These fungi can extract phosphate from soil more efficiently than plants can, and they pass some of it to the plant in exchange for sugars. The sustainable agriculture of the future will need to make use of mycorrhizal fungi, yet we know very little about their biology, ecology or biogeography.

A root in close-up, with mycorrhizal fungus (stained blue) – the fungus is both inside and outside the root.



A close-up of an arbuscule (stained red), the site of nutrient exchange in a root cortical cell, together with the inter-cellular hyphae.

Mycorrhizal fungi are just one example of a group of soil organisms that we cannot ignore; there are many others, some of which we know to be important (nitrogen-fixing bacteria) and others that we are just beginning to learn about, such as bacteria that live in the soil around roots and can promote plant growth. Knowing more about them will not help us much, though, if we continue to destroy and damage soil at the current reckless rate.

Alastair Fitter is professor of biology at York University.

Down on the farm, 10 000 years ago

An archaeologist investigates dairying

Mélanie Salque

Key words
farming
fatty acids
lipids
isotopes

To find out about how people lived in the past, archaeologists look at the items (called artefacts) these cultures left behind. Using chemical analysis of residues in the artefacts an enormous amount of additional information can be gleaned. In this article, ***Mélanie Salque*** *of Bristol University describes how she investigates early dairy farming.*

The domestication of sheep, goats and cattle took place around 10 000 years ago in the Fertile Crescent in the Near East (see map). Neolithic culture, technology and economy (pottery, domestic plants and animals) came to Britain nearly 6000 years ago. When farming began, only meat was exploited, and it was later that people realised the benefits of exploiting the so-called 'secondary products', such as milk, wool, manure or muscle power, which can be obtained without slaughtering the animal.

Milk can be obtained from cattle, sheep and goats (ruminant animals). For each unit of their food, their milk yields 4 to 5 times the amount of energy and protein compared to meat. Therefore, the regular consumption of milk would have been highly beneficial to prehistoric people and a very important step in human prehistory.

The fertile crescent - the region of the Middle East where many agricultural crops and animals were first domesticated.

Archaeologists systematically excavating pottery and bones from a neolithic site

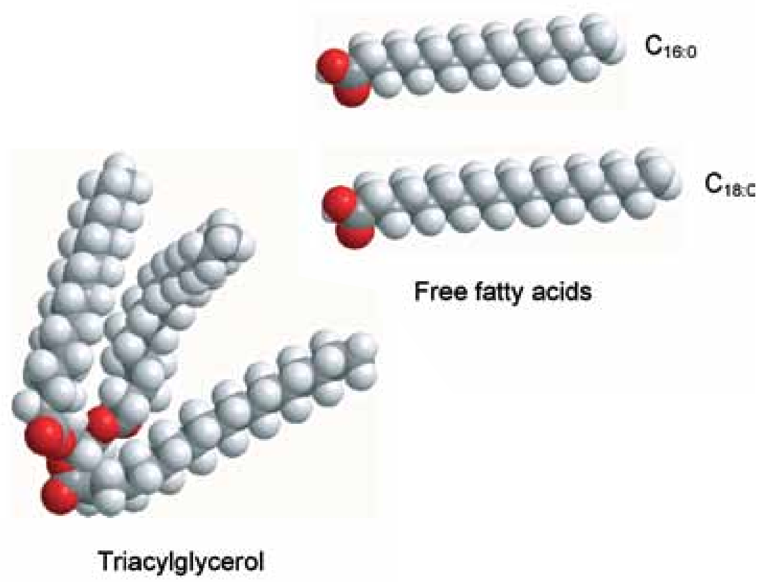
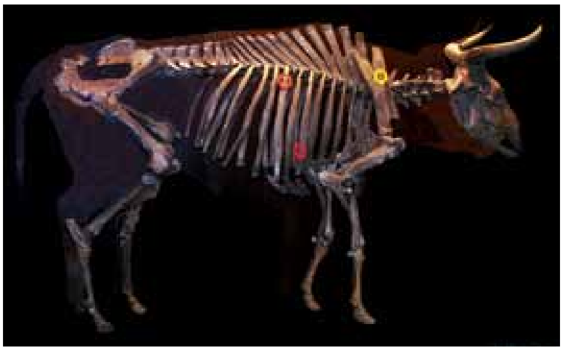


Figure 1 *Triacylglycerol (a lipid) can be split up to produce free fatty acids. $C_{16:0}$ is palmitic acid, $C_{18:0}$ is stearic acid.*

Ancient clues

Milk production and processing in the past have left clues that archaeologists, archaeozoologists (specialists in ancient animals) and chemists are now recovering. Just imagine yourself as a Neolithic herder, 6000 years ago. To get the maximum amount of goats' milk, most of the kids are slaughtered so that you can keep all the milk produced for yourself. To store and process the milk you use very porous pottery, as glaze has not been invented yet. You usually make cheese and yoghurt, so that you can transport the milk and its calcium, vitamin D and fat very easily and keep it for a long time (when you do not have a fridge, it's the only way to preserve milk!). It is also easier for you to digest than raw milk as after childhood drinking fresh milk makes you ill because you have become lactose intolerant.

When processing the milk, lipids (fat) are absorbed in the pottery clay wall and trapped. Even if you wash it, you can still see that the inside of the pottery is darker than when it was new – it's a bit fatty. When you break the pottery by accident, you put the shards into the rubbish pit.



9500 year old skeleton of a domesticated aurochs, the ancestor of modern dairy cattle.

Neolithic pots found during an archaeological dig

Analysing fatty acids

Many thousands of years later, archaeologists are excavating the site that you were living in. Their discoveries include animal bones and jaws with teeth and pottery; lots of broken potsherds. The study of animal bones and teeth by archaeozoologists shows that young goats (kids) were often killed, indicating a milk exploitation strategy. For a cooking pot, it is impossible to say what kind of foodstuff was prepared in it without crushing few grams of the potsherd to open the pores and extract the lipids (fats) with solvents. After analyses by gas-chromatography or mass spectrometry, which allow the separation of compounds and their characterization, we usually find some molecules which are very common in plants and animals; these are called fatty acids.

In fresh foods, fatty acids are found as parts of larger molecules called triacylglycerols or TAGs (tri=3, 3 fatty acids attached to a glycerol), which are themselves the building blocks of meat fat and dairy fats. When fats in pots are degraded, because of the time and the burial conditions, fatty acids become detached from the triacylglycerol, yielding glycerol and three free fatty acids (see Figure 1). These are the fatty acids we recover from the archaeological pottery.

When fresh, it is easy to distinguish dairy from meat fats, as they have different compositions; there is a much broader range of TAGs in dairy fats than in meat fats. However, when they are degraded, the smaller molecules get lost and the range of TAGs in milk becomes narrower, to resemble meat fats. Palmitic (containing 16 atoms of carbon) and stearic acids (with 18 atoms of carbon) are usually the main fatty acids that are left behind in the potsherds.

A chemist searches for molecular and isotopic 'fingerprints' in an extract from an ancient pottery sherd.

Carbon isotopes

So how can we distinguish milk from meat in sheep/goat/cattle (ruminant) fats? We have to use something that does not change with time and will allow us to distinguish between all these types of fats. Their isotopic composition is the answer. These fatty acids are mainly made of carbon (together with hydrogen). The majority of this carbon is ^{12}C (98.9%), followed by ^{13}C (with one neutron more than ^{12}C, 1.1%) and ^{14}C (present in trace amounts). ^{14}C is radioactive, so once the animal dies the amount of ^{14}C decreases, and this property can be used to date organic remains via radiocarbon dating. ^{13}C and ^{12}C are stable, which means that their ratio, $^{13}C/^{12}C$, remains constant through time. The concentration of carbon in the atmosphere is roughly 7‰ (parts per thousand).

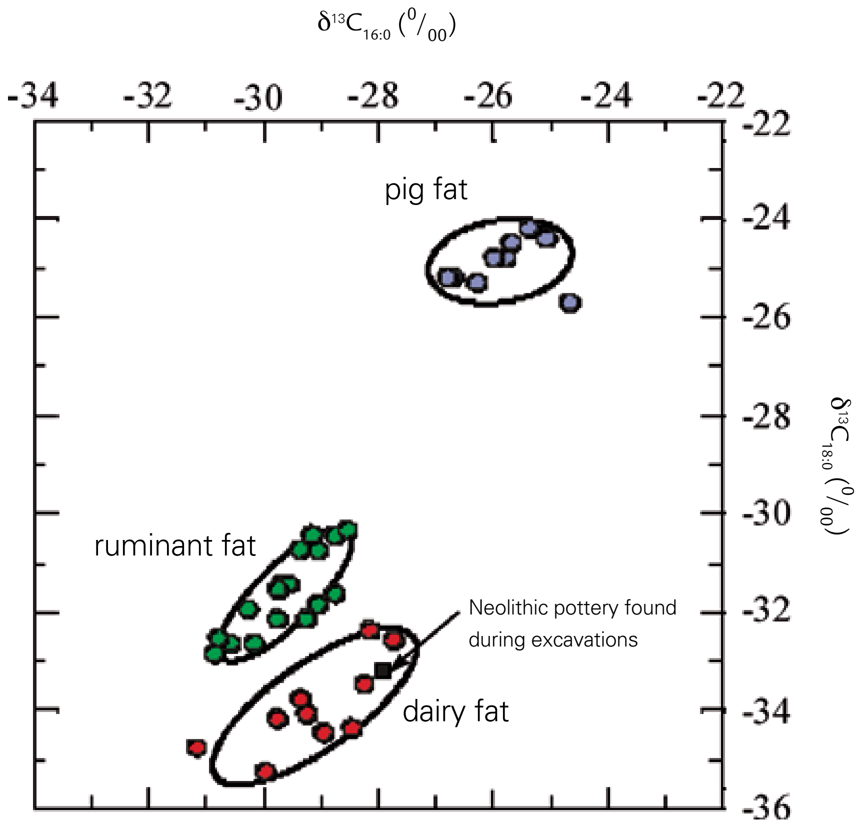


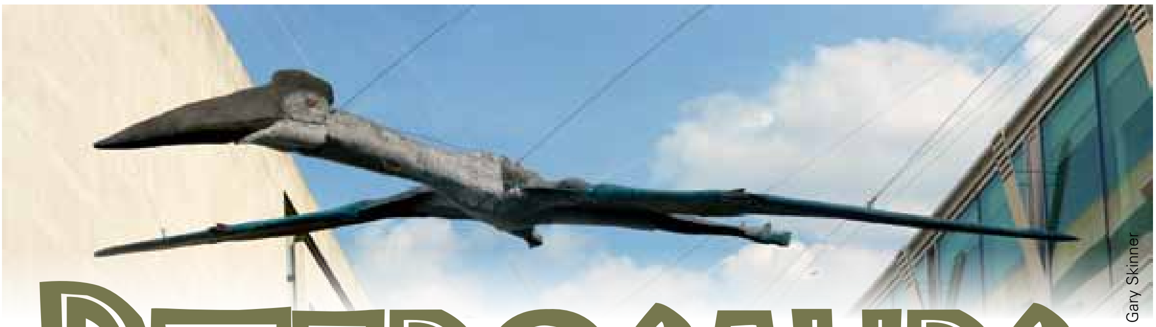
***Figure 2** Fatty acids from different sources have different proportions of the carbon isotope ^{13}C, as indicated by the $\delta^{13}C$ values. This chart shows the $\delta^{13}C$ values for modern reference fats, represented by plain circles. The ellipses indicate the areas where different fats coming from archaeological pottery are expected ('ruminant' = cow, sheep, goat).*

When incorporating the carbon from the air using photosynthesis, plants take up less ^{13}C because it is heavier than ^{12}C. So, proportionately, less ^{13}C is absorbed into the plant than is available in the source (air). This phenomenon called 'fractionation' is reflected in the animal's fatty acids with the exact value depending on the plants animals eat, the type of animal (ruminant or non-ruminant) and the type of fats (meat or dairy). The isotopic composition is measured by the $\delta^{13}C$ value, which shows how much less ^{13}C there is, relative to a carbonate standard. When we measure the $\delta^{13}C$ values of palmitic and stearic acids (the two major fatty acids found in pottery) of different modern animal fats, we find that they divide into different groups (see Figure 2). By undertaking the same analysis on archaeological pottery, it is now possible to distinguish ruminant from non-ruminant fats, and even meat from dairy fats!

One of the sherds recovered from your archaeological site is represented as the black square on the graph (see Figure 2). So, were you boiling your goat's milk in this pot?

Mélanie Salque is a PhD student at Bristol University working on the emergence of dairying in Prehistoric Europe through the analysis of lipids preserved in pottery vessels.

Mark Witton



PTEROSAURS

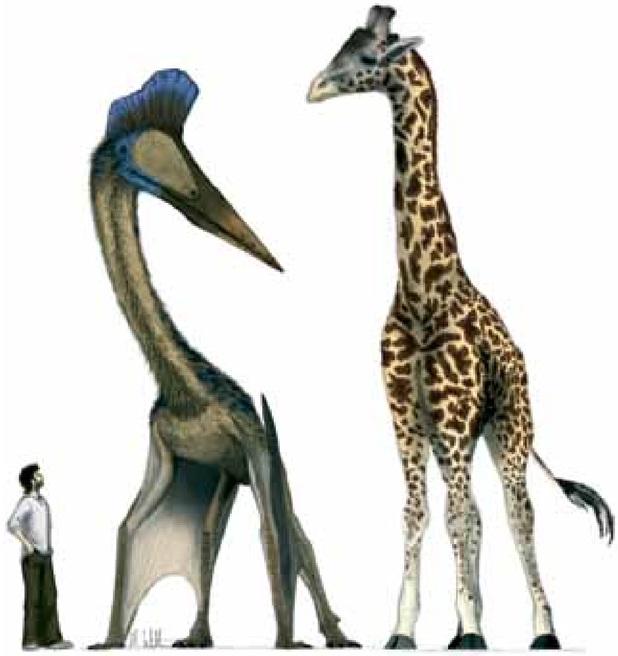
FLYING REPTILES

Key words
dinosaur
pterosaur
palaeontology
evolution

Bird watching during the Mesozoic Era, the expanse of time stretching between 245 and 65 million years ago, would have been a very different experience to what it is today. ***Mark Witton*** *of Portsmouth University explains why.*

Strictly speaking, birdwatching could only have begun 145 million years ago; prior to this point, only bird-like feathery dinosaurs, were around, These bird-ancestors were the pterosaurs, a group of flying reptiles with membranous wings, fuzzy bodies, and often savage-looking teeth. They disappeared with all the non-birdy dinosaurs 65 million years ago.

Pterodactyls were one specific group of pterosaurs.

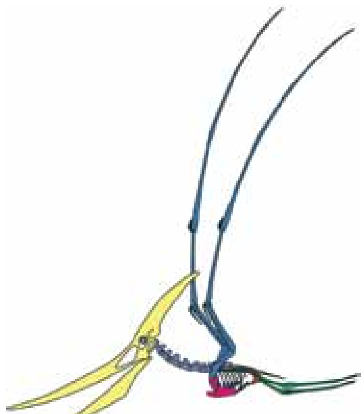


Pterosaurs were sometimes gigantic. The largest spanned 10 m across the wings and stood over 5 m tall, shown here alongside a Masai giraffe and a man of average height.

Although the fossil record is extremely patchy, palaeontologists have documented around 130 different species. The configuration of the pterosaur skull is definitively reptilian, and they are probably related to modern crocodiles and birds.

The inside view

Like birds or bats, pterosaur anatomy was primarily geared to meet the demanding requirements for flight. Their shoulder girdles and upper arm regions were large and complex to house enormous flight muscles, while further out on their forelimbs the bones became slender and elongated to create the leading edge of their wings. Much of the wing length was comprised of an elongated finger (the equivalent of our ring finger) that folded away when the animal was grounded.



The skeleton of a 7-metre wingspan Pteranodon

The flight surface itself was a thin but complex membrane that stretched from the tip of the wing finger to the ankle. As pterosaurs evolved, their necks and heads became increasingly large and their tails shorter. With such oversize arms, the bodies and legs of most pterosaurs look small.

As with modern birds, many pterosaur bones were pneumatised – that is, full of air. Air sacs in bones were probably linked to the lungs, so it seems that pterosaurs had an ultra-efficient, bird-like breathing apparatus where air is continuously pushed through a solid lung by contraction of different air sacs. This may explain how pterosaurs achieved wingspans of up to 10 m while birds and bats have, at most, managed 7 m and 1.5 m wingspans, respectively.

The distribution of air sacs (shown in blue, green and grey) and lungs (red) within the pterosaur body

Pterosaur brains also share many similarities with those of birds, highly developed in regions that deal with muscular coordination and response control. Wrapping all these features up was a layer of fuzz or 'pycnofibres', a hair-like integument that covered their faces, necks, bodies and the tops of their limbs.

Getting high

How did pterosaurs fly? Today, we have convincing evidence that pterosaurs could take off from land and sea from a standing start using all four limbs and, once airborne, flapped powerfully to propel themselves through the sky.

A 7 m span Pteranodon pushes itself into the air using its arms like an oversize vampire bat.

Larger pterosaurs could exploit thermal upwellings, ocean winds or updrafts and so could cover thousands of kilometres in single flights if necessary. Some species were adapted for marine or terrestrial soaring, highly agile in-flight predation of insects or, by contrast, high-velocity bursts of very directional flight.

When they weren't flying

Research since the 1980s has revealed that early pterosaurs were adept climbers and would have spent much of their time scampering around trees or rock faces, but their descendants quickly became efficient walkers, runners and waders. Pterosaur trackways are easily recognisable thanks to their almost human-like footprints and bizarre, sideways-facing handprints.

Once thought to be exclusively fish-eating, modern analyses suggest that different pterosaurs specialised in eating specific foodstuffs, including small vertebrates, animal carcasses, fruits, shellfish, plankton and insects.

Mark Witton is a pterosaur researcher at the University of Portsmouth.

Mark Witton explains how he became a scientist and artist

I've been a keen artist from the time when I could hold a pencil, but have almost always felt that science, and particularly palaeontology, was the way I needed to head professionally. As such, I gave up Art lessons at the age of 16 and, instead, trained in biology and palaeontology. However, my artistic hobbies seem to have followed me through the science door and, if I have any name for myself at all, it's as a guy who conducts and then illustrates his own research on flying reptiles.

On the back page, Mark describes how flying reptiles took over London's Southbank Centre.

Fossils show that pterosaurs were predated or scavenged by other animals. Here, an 8 m span azhdarchid pterosaur is being scavenged by groups of Velociraptor-like dinosaurs, birds and another pterosaur.

Look here!

A blog put together by pterosaur researchers and artists: *pterosaur.net*

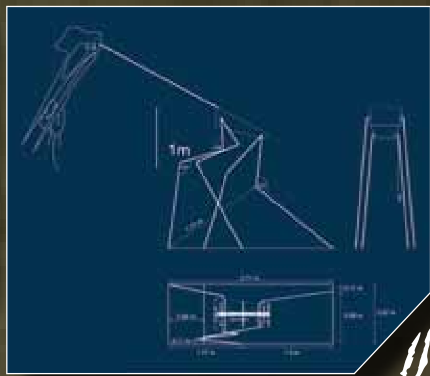
The University of Portsmouth is one of Britain's leading pterosaur research labs: *www.port.ac.uk/pterosaurs*

An excellent book: *The Pterosaurs from Deep Time* by pterosaur guru David Unwin *(2005, Pi Press)*

Building Pterosaurs

In June 2010, the Portsmouth University pterosaur research team showed their life-size model pterosaurs at the Royal Society Exhibition at London's Southbank Centre.

Start with a pterosaur fossil – it's not much to go on



Sketch the bone structure – look for muscle attachment sites

Build a skeleton of steel, or aluminium for a 'flying' model, and clad with Styrofoam muscles

Cover with metal mesh and fibreglass; add fibreglass wings and a layer of fur to the head and neck

It took a team of over a dozen people all night to install the models in their temporary home