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Landing on a comet

The Rosetta mission

SEP

Tom Lyons

Catching a comet

The Rosetta mission

Key words
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In 1802, the Rosetta Stone was first displayed at the British Museum, in London. The three scripts inscribed on the stone allowed the modern translation of Egyptian hieroglyphs. Fast forward 200 years to 2004, and the European Space Agency's Rosetta spacecraft is launched on an Ariane 5 rocket: its destination – Comet 67P/Churyumov-Gerasimenko; its goal – to understand more about the origins of life in our solar system.

Rosetta will arrive at Comet 67P in August 2014. In November, it will deploy a probe, called Philae, which will land on the surface of the comet. Rosetta has recently woken up from deep space hibernation but it has not been lazy on its ten year journey to the comet. It has had three Earth gravity assists and one Mars gravity assists on its way and it has flown by asteroid Steins and asteroid Lutetia.

Gravity assist

Gravity assists, also known as slingshot manoeuvres, are used to speed up the spacecraft and to allow it to achieve the correct orbit to rendezvous with the comet. The spacecraft's orbit brings it close to a planet so that it is pulled on and accelerated by the planet's gravity. Momentum is transferred from the planet to the spacecraft – this is essentially an elastic collision. The linear momentum gained by the spacecraft is equal in magnitude to that lost by the planet, though the planet's enormous mass compared to the mass of the spacecraft makes the resulting change in the planet's speed negligibly small. The direction of the spacecraft's orbit is also changed.

The Rosetta Stone, now in the British Museum, was used to decode Egyptian hieroglyphs. Scientists hope that the Rosetta mission will help to decode the history of life in the solar system.

Gravity assist	Launch	Earth-1	Mars	Earth-2	Earth-3
Date	02-Mar-04	04-Mar-05	25-Feb-2007	13-Nov-07	13-Nov-09
Velocity relative to the Earth (km/s)	3.547	3.863	8.809	9.362	9.379
Closest approach to centre of planet (km)	6771	8341	3650	11680	8861

Details of Rosetta's four gravity assist manoeuvres

The table gives the calculated velocities relative to the Earth for the four sling-shot manoeuvres. The declination of the orbit also has to be considered to ensure that the spacecraft achieves the correct orbit to chase the comet. (The declination is the angle at which the comet's orbit crosses the plane of the Earth's orbit.)

All planets have slightly elliptical orbits but most are very nearly circular and they all lie in roughly the same orbital plane. Comets on the other hand have highly elliptical orbits with significant degrees of inclination with respect to the orbits of the planets. Most comets orbit the Sun in a region called the Oort Cloud, at the edge of our solar system, and never come close to the Sun. However, some comets have shorter orbits and, at their closest approach to the Sun, have long tails which can sometimes be seen with the naked eye from the Earth.

Reaching the comet

Once Rosetta has caught up with Comet 67P it will orbit the comet to observe the light emitted from the nucleus and coma (the tail of the comet) and examine gas and dust particles given off by the interaction between the solar wind and the comet. Rosetta has 11 instruments from institutions from across Europe and the United States and the lander has 10 scientific instruments.

Rosetta's instruments

ALICE Ultraviolet Imaging Spectrometer
CONSERT Comet Nucleus Sounding
COSIMA Cometary Secondary Ion Mass Analyser
GIADA Grain Impact Analyser and Dust Accumulator
MIDAS Micro-Imaging Analysis System
MIRO Microwave Instrument for the Rosetta Orbiter
OSIRIS Rosetta Orbiter Imaging System
ROSINA Rosetta Orbiter Spectrometer for Ion and Neutral Analysis
RPC Rosetta Plasma Consortium
RSI Radio Science Investigation
VIRTIS Visible and Infrared Mapping Spectrometer

Philae the lander

How Philae may look after landing on the comet's surface

If successful, the probe Philae will be the first ever to land on the surface of a comet and take in-situ measurements. Scientists will be keen to compare the results with that of other cometary missions and with ground-based measurements of comets.

Philae will actually harpoon the comet so that it is tethered to the surface. This is because the mass of the comet is so low compared to a planet or a Moon that the gravitational attraction between the two is not enough to ensure a secure landing.

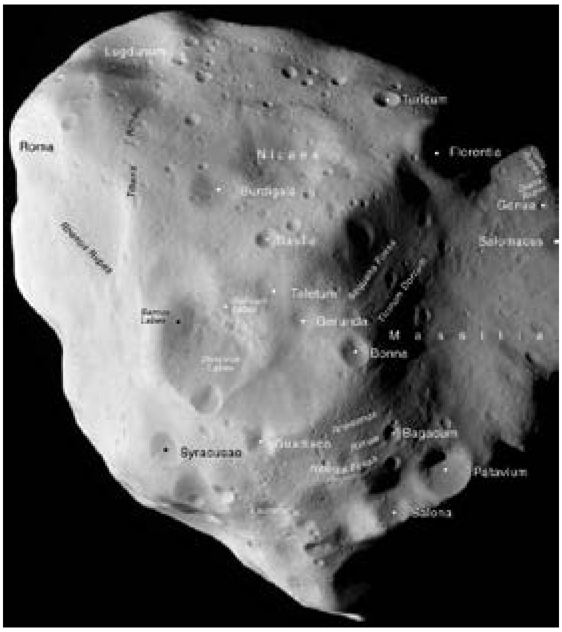
We can use Newton's law of gravitation to calculate the force F with which the comet will attract the lander Philae. Mass of Comet 67P $M = 3\times10^{12}$ kg approx.; mass of Philae m = 100 kg approx.; comet radius r = 2000 m; gravitational constant $G = 6.67\times10^{-11}$ Nm^2/kg^2.

$F = GMm/r^2 = 0.005$ N. This is roughly the weight of a 0.5 gram mass on the Earth (about the same as a paperclip) and far too small for the comet to hold on to the lander.

Ancient evidence

Comets and asteroids are the oldest objects in our solar system. They can provide information on what the solar system was like as it was forming, 4.5 billion years ago. Comets are also known as dirty snowballs because they are made up from a lot of ice, some silicates, carbon, hydrocarbons and a few more complex molecules, such as amino acids. Amino acids have also been called 'the building blocks of life'. It may be that life on our planet was seeded by a comet (or comets). It is also possible that the water on our planet originally came from the impacts of comets on the surface of the Earth.

Rosetta's flyby of the asteroid Lutetia has proved important in studies of the make-up of asteroids. Discovered in 1852, Lutetia was one of the first objects to be classified as an M-type (metallic) asteroid but subsequent measurements of the light reflected from the asteroid suggested more similarities with carbonaceous or C-type asteroids. Rosetta's flyby in 2010 allowed scientists to map the surface of the asteroid. It was found to have many large impact craters and several hundred large boulders on its surface. It was found to have a high density, suggesting a metallic core covered with a more rocky exterior.



Rosetta's map of the asteroid Lutetia which it flew past in July 2010

Rita Schulz, like other scientists working on the Rosetta project, gives public presentations about her work.

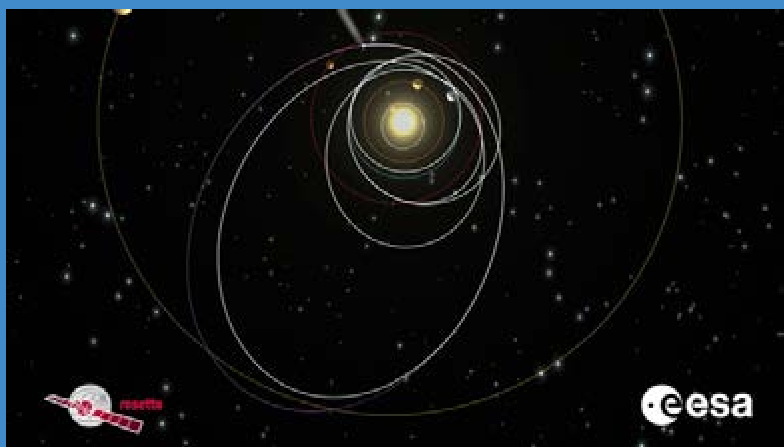
"This is a crucial step in understanding the asteroid belt," said Rita Schulz, one of ESA's Rosetta Project Scientist. "Having seen several members of the belt in the past that were all different in their own ways, we have now found a large and rather primordial body. Clearly, there is still much more to investigate before we understand the belt fully.

"The excellent scientific results of Rosetta's two asteroid encounters (Lutetia and Steins) also show how important it is – when possible – to add asteroid flybys to any mission," she added.

Rosetta mission: key dates

Event	Nominal date
Launch	2 March 2004
First Earth gravity assist	4 March 2005
Mars gravity assist	25 February 2007
Second Earth gravity assist	13 November 2007
Asteroid Steins flyby	5 September 2008
Third Earth gravity assist	13 November 2009
Asteroid Lutetia flyby	10 July 2010
Enter deep space hibernation	8 June 2011
Exit deep space hibernation	20 January 2014
Rendezvous manoeuvre	May 2014
Arrive at comet	August 2014
Start global mapping	August 2014
Lander delivery	November 2014
Closest approach to the Sun	13 August 2015
End of mission	31 December 2015

Spacecraft Operations Manager Andrea Accomazzo and his colleagues are jubilant when Rosetta reactivates after deep space hibernation in January 2014.



Look here!

An animation showing the journey of Rosetta including gravity assist fly-bys and its rendezvous with the comet: *bit.ly/1dkf1ky*

Tom Lyons has worked as an engineer on space satellite systems and as a physics teacher. He is now based at the National STEM Centre in York.

A life in science

Acoustic engineer

Acoustic engineers are concerned with sound and vibration and how they can be managed in the built environment. In this article, Nick Treby describes how he became one.

I really enjoyed science when I was at school – physics especially, but also chemistry. I always looked forward to practical sessions, where we would get to investigate all sorts of things just to see what happens.

I did a lot of music too. I played brass instruments, sang and even gave lessons. And as I reached A-level age, I was curious about the science behind music. Why do I sound better when I sing in the shower, than when I sing in a normal room? What makes the trumpet and the saxophone sound so different? Why does the police car siren sound change as it drives past you? I knew science could answer these questions, but I wasn't sure how.

Nick Treby preparing to measure the acoustic performance of a room

Careers advice

I asked a careers adviser how I could make my interest in science and music into a job. She looked confused – she didn't know. But a few days later she sent me the prospectus for Southampton University's Engineering Acoustics and Vibration degree. I read it, and was very interested. I phoned up and asked if I could visit in the summer before applying. They said yes, and so I went and was shown round what I now know to be the world famous Institute of Sound and Vibration Research. I saw their anechoic chambers, a demonstration of noise cancelling (before you could buy noise cancelling headphones in shops, the computers to do this filled a small room) and all sorts besides.

Acoustic engineers are concerned with managing vibrations such as those experienced by workers in the construction industry.

I did apply, was offered a place and after three years very hard work, came out with a degree. Though the subject is unusual, there were lots of options for me next. I could have gone on to research noise from jet engines as we try to make aeroplanes quieter. I could have worked in the motor industry helping with audio systems and trying to make the car engine and exhaust sound just right, and be quiet for the occupants. I could have gone to design loudspeakers and hi-fi equipment, design sound for computer games, record TV and radio with the BBC but I decided against all these.

Instead, I chose to become an Acoustic Consultant. We provide technical advice on noise and vibration for anyone who needs it.

Working with others

Mostly, I work with the construction industry, getting the acoustics of buildings just right. I have been working on every type of building you can think of – homes, schools, offices, theatres, cinemas and hotels, working with architects, mechanical engineers, structural engineers, interior designers and all sorts of other people, many of whom have science background, to help get things right.

Nick monitors traffic noise levels at the roadside.

I've worked in some odd places too. I have had to spend four days 150 miles east of Aberdeen – on an oil rig in the North Sea, helping to make sure that the accommodation where the riggers sleep is quiet enough; tricky when they are drilling for oil just a few metres away. I've worked on football pitches, calculating whether all the shouting will disturb the gardens and homes of the people who live nearby.

I've worked in public inquiries, helping argue whether planning permission should or shouldn't be granted, and in court dealing with some people who had complained about a church's clock chime and wanted it stopped, even though it had been happening for 300 years. We managed to keep the clock chiming there!

I was on TV for the clock chiming case, and I've helped *The One Show* as well, when they were researching a feature on noise issues from HS2, the proposed superfast train service from London to Birmingham.

I've been doing this job for 20 years now, and I've worked for companies in London and Bedfordshire, and been able to travel all over the world. I've been all over the UK and Ireland, Europe and the Middle East. In the last year my colleagues have been to the USA, Australia, Chile and Canada, amongst other places.

Football stadia, opera houses, country churches – acoustic consultants work in a wide variety of locations.

Day to day, my job is varied. I never quite know what I'll be doing next. It is terrific fun working in all these different places, on a huge variety of projects with all sorts of interesting people.

It comes from a good set of basics. Science and mathematics are the core of what I do, and then with a bit of experience and training, you never know where they will take you.

Nick Treby, BEng(Hons) MIOA MAES is a Principal Consultant with Spectrum Acoustic Consultants, who have offices in Bedfordshire and Lancashire. He studied Engineering Acoustics and Vibration at the University of Southampton, and has worked in Acoustic Consultancy since graduating in 1994. He is a Member of the Institute of Acoustics, and the Audio Engineering Society.

Look here!

Nick Treby worked on the acousitcs of one of the venues for the London 2012 Olympic games. Read his Catalyst article here: *http://www.catalyststudent.org.uk/cs/article/291*

Rhiannon Evans

From ancient to future solar fuels

Plants like these sugar beet capture the energy of sunlight using photosynthesis. Scientists are trying to do the same to do the same with artificial photosynthetic systems.

Key words
photosynthesis
catalyst
enzyme
solar energy

*With the world's population ever-expanding, energy demand is expected to double by 2050 and triple by 2100. In only 200 years, mankind has squandered what Nature has taken hundreds of millions of years to lay down as fossil fuels. The burning of these fossil fuels also releases carbon dioxide (CO_2), increased levels of CO_2 in the atmosphere being a direct contributor to global warming. For the survival of our planet the question is, can we generate energy from a widely available, cheap, limitless source and can this be done without the release of additional CO_2 into the atmosphere? **Rhiannon Evans** is part of a research team trying to do just that.*

Fortunately, the answer is yes! The Sun is an inexhaustible source of energy, providing enough hourly to meet the current annual demand – if only we could harness it for use day and night. Developing clean, cheap, renewable, transportable and storable energy supplies to replace fossil fuels is one of the most important scientific and technological challenges of our age.

No man-made system developed thus far meets these criteria. Photovoltaic cells and wind farms for example convert sunlight and wind power into electricity only intermittently, when the sun shines or the wind blows. For a continuous energy supply we must be able to produce a storable fuel that can be transported for use where needed. Plants and algae do this already through the process of biological oxygen-making photosynthesis. In fact, fossil fuels are the stored energy from ancient photosynthesis – ancient solar fuels.

Natural photosynthesis

In photosynthesis, energy from the sun is stored in the substances which are produced. It does this by splitting water (H_2O) into oxygen gas (O_2), hydrogen ions (H^+) and electrons (e^-). The electrons are excited by the sunlight in a process we call 'charge separation', and they flow through the biological machinery in the cell by various electron transfer processes. The ultimate fate of these energised electrons is to combine with carbon dioxide (CO_2), and H^+ to form organic molecules that the photosynthetic organism, and we ourselves, can use as a fuel such as carbohydrates. These are polymers and can be represented as ($[CH_2O]_x$). During the process oxygen is released; we breathe the O_2 and use it in metabolic respiration allowing us to break down carbohydrates to provide energy. We also use the O_2 in combustion of fuels such as fossil fuels in internal combustion engines. Both respiration and combustion release the energy stored in the fossil fuel or the carbohydrate in an exothermic reaction, producing water and carbon dioxide, the reverse of photosynthesis, see Figure 1.

Artificial photosynthesis

Ultimately, we would like to be able to exploit the chemical principles of natural photosynthesis such as light absorption, charge separation, electron transfer and fuel formation to develop efficient artificial solar fuel production. In order to develop these processes and tailor them to mankind's requirements, we must as scientists and engineers develop each fundamental component of the artificial photosynthesis (APS) system. The challenge is then to combine and refine the system.

The basic components of an APS system are summarised in Figure 2. We must have a light harvesting material capable of absorbing light and exciting electrons, a catalyst capable of efficiently replacing the electrons used in forming the fuel; an excellent source of those electrons is water. Water is

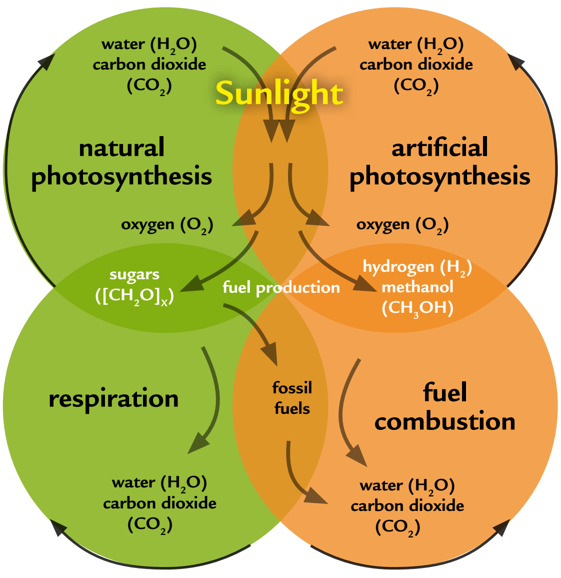


Figure 1 *The relationship between natural photosynthesis, respiration, and fuel combustion and the parallel principles of artificial photosynthesis*

rather an inert substance however, and its stability means that it takes a lot of energy to split it apart. Lastly, we must have a fuel-forming catalyst, which will vary depending on the fuel we want to form.

We can produce molecular hydrogen (H_2) through solar-driven processes:

- Hydrogen is an excellent energy carrier – its combustion in oxygen releases a huge amount of energy (286 kJ mol^{-1}) with only water as the by-product.
- The chemical bond of molecular hydrogen is very strong and so a catalyst is required to reduce the energy required to break this bond, otherwise the reaction is too slow.

Unlike fossil fuels, hydrogen is not a primary fuel that we can mine at source, it must be made. If hydrogen is to be used as a clean fuel, the methods of its production must be clean and the way in which we utilise hydrogen as a fuel, releasing the energy stored in its chemical bond must also be renewable and sustainable. Currently, industrially produced hydrogen is not a clean source of hydrogen – the majority is produced using the fossil fuel methane (CH_4) in a process known as steam reforming, with an additional H_2 molecule being recovered in the subsequent water-gas-shift reaction:

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

These processes are not a viable option for a clean future fuel as the hydrogen is derived from limited fossil fuel reserves and produces CO_2. Electrolysis of water is another way to produce hydrogen. The best catalyst for both hydrogen production and oxidation however is the expensive and rare noble metal platinum. Relying on platinum makes the processes expensive and not a long-term option.

Nature has already overcome this problem – microorganisms have utilised metals that are more readily available to them and contain hydrogen catalysts that make use of common metals such as iron (Fe) and nickel (Ni). These biological catalysts – enzymes known as hydrogenases (Figure 3) – are able to interconvert protons and electrons into hydrogen at rates that rival platinum. Hydrogen is used as a fuel by some microorganisms.

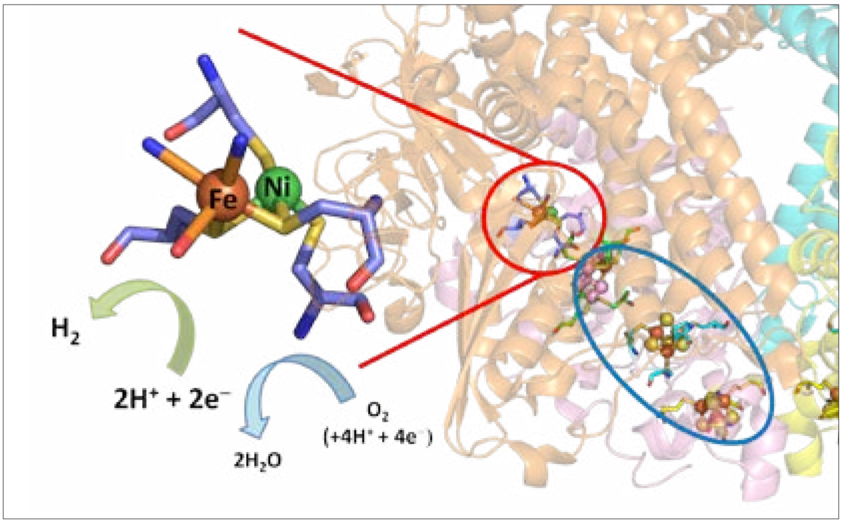


Figure 3 *Hydrogenase enzymes can make hydrogen using common and cheap metals at their active sites*

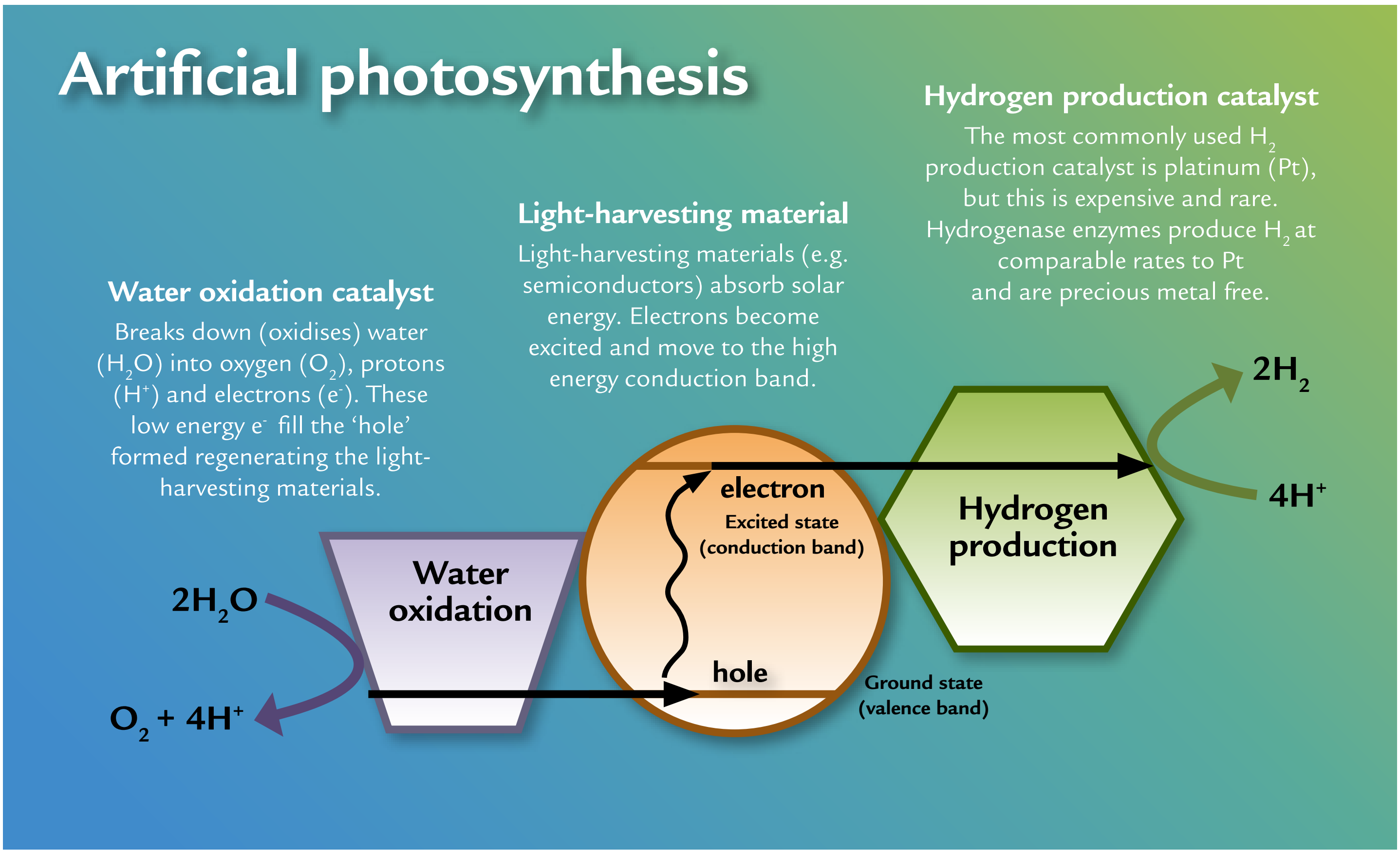


Figure 2 *The fundamental components of an artificial photosynthesis system*

The problem with oxygen

As is suggested in Figure 2, in an artificial photosynthesis system that uses water as its source of electrons and protons, oxygen is produced, just like in natural photosynthesis. Although they are amazing hydrogen catalysts, hydrogenases can be inhibited by oxygen.

Again, nature has a solution – oxygen-tolerant hydrogenases. Through the study of oxygen-tolerant hydrogenases, not only can we begin to understand the secrets behind their hydrogen catalysis capabilities, but also how they do this in the presence of oxygen. We have been able to show that these enzymes can use the electrons generated by the oxidation of hydrogen and store them in specialised clusters of iron and sulfur atoms (Figure 3 blue oval) ready to reduce the attacking oxygen to harmless water.

We study the enzymes using the technique 'Protein Film Electrochemistry' (PFE) where we adsorb the enzyme to a carbon electrode (Figure 4) and monitor the activity of the enzyme as an electrical current, with electrons flowing between the electrode and the enzyme via the iron-sulfur clusters.

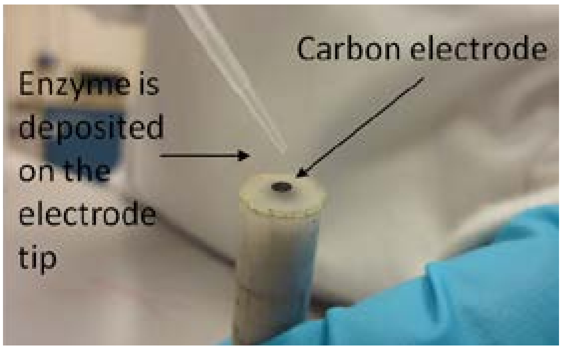


Figure 4 *An example of the carbon electrode being coated with an enzyme film (top) and a typical Protein Film Electrochemistry set-up (bottom)*

There are numerous examples of hydrogenase enzymes in biology. They can differ by the metal content at their active sites, by the rate at which they reduce hydrogen ions (make hydrogen) and oxidise hydrogen, and also by the conditions in which they do this most efficiently and without degradation. We can monitor and study all of these characteristics by PFE.

We have already shown that they can be capable of attachment to various light harvesting materials such as semiconductors (e.g. titanium dioxide, TiO_2) for solar hydrogen production. However, for commercial and industrial hydrogen production, isolated hydrogenases would not be a viable option – they take time to purify from the microorganisms and don't always last very long and so they are not financially feasible.

Research is now focusing on unravelling what makes hydrogenases so brilliant at hydrogen catalysis and this will lead the way to the creation of man-made catalysts based on the specialised chemistry of hydrogenases, and will enable the use of common, cheap metals such as iron and nickel.

The author at work: hydrogenase protein film electrochemistry is carried out in a glove box which is filled with an inert atmosphere of nitrogen so we can avoid exposure of the enzymes to oxygen and other inhibitors.

Dr Rhiannon M Evans is part of the Armstrong group, Department of Chemistry, University of Oxford and a Junior Research Fellow at Wolfson College, Oxford. This article was produced in collaboration with the Solar Fuels team at Oxford University.

Look here!

Previous Catalyst articles related to this one:

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http://www.catalyststudent.org.uk/cs/article/18

Hydrogen powered cars:
http://www.catalyststudent.org.uk/cs/article/310

Artificial photosynthesis
http://www.catalyststudent.org.uk/cs/article/26

Exploring the deep ocean
Discovering hydrothermal vents

Vicky Wong

There are not many places left on Earth which have not been explored. Humans have been to the top of the highest mountains and to every continent. But under the sea it is another matter. We know a very limited amount about the depths of the oceans and the creatures that live there.

The oceans are extremely deep in parts. The deepest known area is the Mariana Trench in the Pacific Ocean. This has been measured to be over 10 km deep, although some measurements suggest it may be more than 11 km deep. The pressure exerted at these depths is over 1000 times atmospheric pressure at sea level. We might imagine that the seabed is flat or gently sloping, but the longest mountain range on the planet is under the Atlantic Ocean.

Exploring the depths

Exploring in this environment is not a straightforward matter. For those who dive as a hobby, 30 m is the deepest recommended; specialist diving suits help withstand the pressure to 600 m. Deep sea submersible research vessels are required to dive anywhere deep enough for exploration of the ocean depths.

The two Mir research vessels can be used to depths of 6 km which allows them to reach 98% of the ocean floor. This allows scientists to observe the deep sea through multiple view ports, video records, instrument placement, sample collecting, and environmental monitoring. They have manipulator arms which allow them to collect samples. By contrast, Jason is a remote operated research vessel, so the scientists stay on board the ship and control it from there.

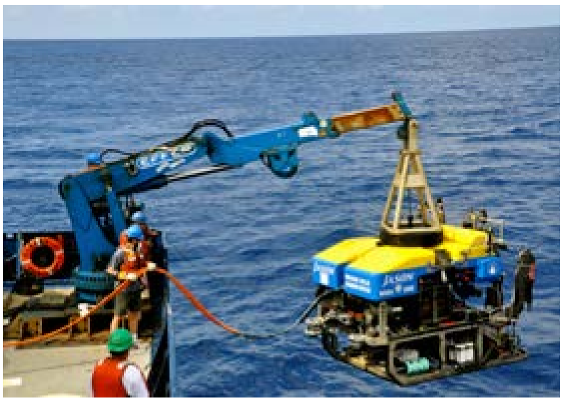
Dark discoveries

In the late 1970s, scientists using deep sea vessels found vents on the ocean floor which were gushing out hot water. These hydrothermal (hot water) vents form along mid-ocean ridges. A mid-ocean ridge is where the Earth's tectonic plates are moving apart, usually at a rate of about 6-18 cm a year. Magma wells up from below forming new crust. Cold ocean water in some places seeps through cracks in the sea floor to hot spots below, where it is heated and then forced back out. While inside the Earth's crust many minerals are dissolved in the hot water.

Sometimes in very hot vents the emerging water turns black forming what is known as a black smoker. These contain dissolved sulfides (sulfur compounds) of metals such as iron and copper. These instantly precipitate out of solution when they come into contact with the cold surrounding water and form tall chimneys.

The Mir explorer can reach 6000 m and carry three passengers.

The Mariana trench is deeper than Mt Everest is high; Everest is 8.8 km.



Jason is a remotely operated deep sea vessel.

The photo on pages 10-11 shows a black smoker hydrothermal vent along the Juan de Fuca Ridge in the Pacific Ocean.

Deep on the Pacific seabed, scientific instruments monitor a black smoker vent encrusted with tube worms.

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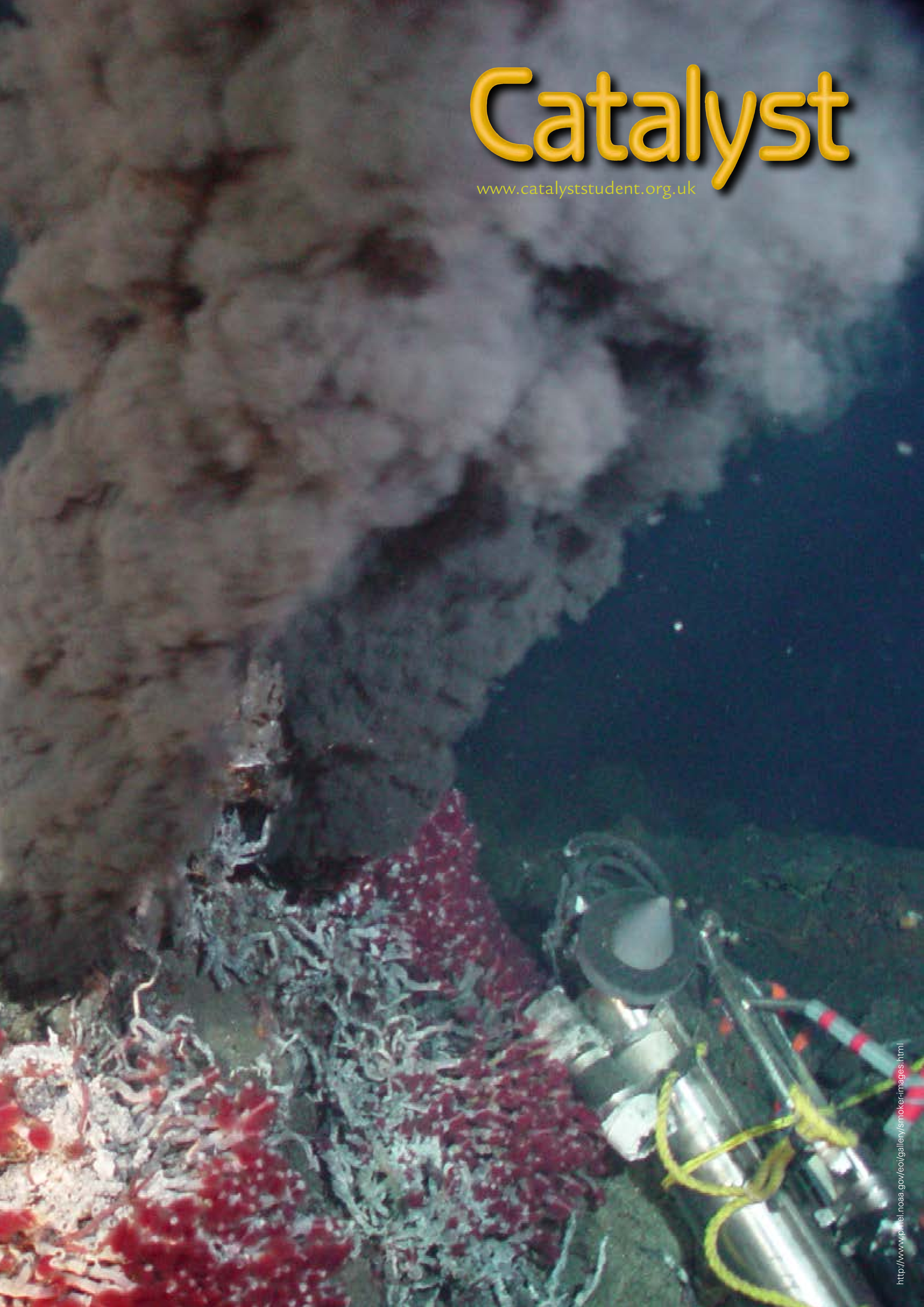
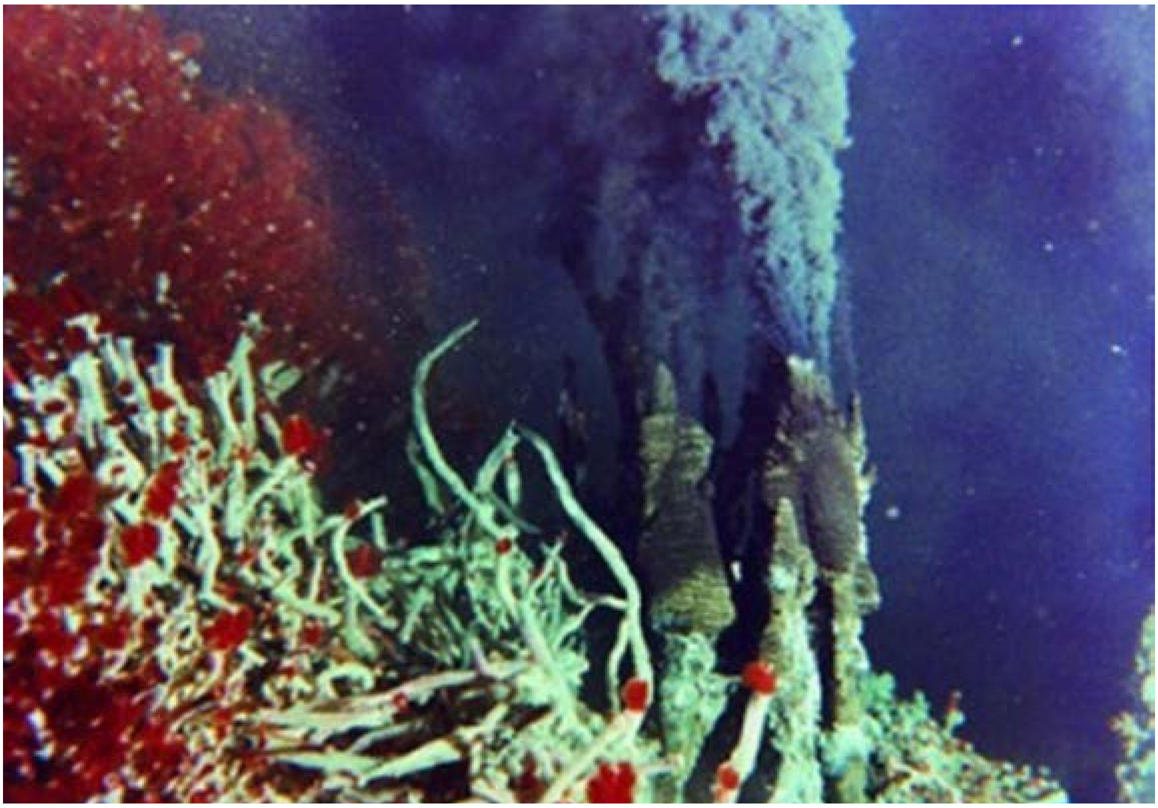


http://www.pmel.noaa.gov/eoi/gallery/smoker-images.html



Giant tube worms next to a black smoker

In the deep mid-ocean

The presence of hydrothermal vents had been predicted by an increasing understanding of plate tectonics, but they had never been seen before. This was exciting enough, but the scientists found that the area around the vents was full of extraordinary and unexpected life.

Up to this point it had been assumed that all life on Earth was dependent on photosynthesis from plants and energy from the Sun. Food chains all ultimately led back to plants and the Sun. But these life forms and food chains were different. It was far too deep for light from the surface to penetrate so they could not be using photosynthesis.

The food chain starts with bacteria living in and around the vents which extract their energy from hydrogen sulfide (HS) and other molecules in the water, giving out the element sulfur as a by-product as plants give out oxygen. Where plants use photosynthesis, these bacteria use chemosynthesis. Just like plants, the bacteria use this energy to build sugars out of carbon dioxide and water. The sugars then provide the fuel and raw material for the rest of the microbe's activities.

Up the food chain

These deep-sea bacteria form the base of a varied food chain that includes shrimps, tube worms, clams, fish, crabs, and octopi. All of these animals must be adapted to endure the extreme environment of the vents – complete darkness; water temperatures ranging from 2°C (in ambient seawater) to about 400°C (at the vent openings); pressures hundreds of times that at sea level; and high concentrations of sulfides and other noxious chemicals.

Tube worms are often found near hydrothermal vents. They do not eat but contain bacteria which provide them with all they need. They never leave their tubes which provide protection from the extreme environment.

The chemistry from these organisms is of great interest. One of the enzymes from heat-loving microbes is used in DNA fingerprinting and other uses are almost certain to follow.

The image on pages 10-11 shows a black smoker hydrothermal vent. Around the base is a colony of tube worms. There are two instruments which have been placed there by scientists. One is a hydrophone to record the sound of the vent; the other a probe to monitor some of the chemistry of the water.

The ocean floor remains largely unexplored – the last great frontier for discovery on Earth.

Vicky Wong is Chemistry editor of Catalyst. All photos courtesy NOAA.

Look here!

To find out more about exploring the deep sea: *http://tinyurl.com/ntmadtu*

Professor Susan Page

Tropical peatlands

Caroline Wood

Forest canopy – trees growing in tropical peatland

The word 'peat' may conjure up images of bleak, boggy hillsides across Northern Europe, Russia and the USA. But did you know that peatlands are also found in the tropics? These currently act as a significant store of carbon, yet these valuable ecosystems are under threat. As ***Caroline Wood*** *explains, their disappearance could have severe consequences for the global climate.*

Approximately 400 million hectares (3%) of the world's land surface is covered by peatlands. Although most of this is found in temperate zones, 10-12% is located in the tropics (see map). Similar to their northern counterparts, tropical peatlands are nutrient poor, or ombotrophic, systems with low drainage rates and high levels of precipitation. In northern peatlands, the vegetation is mainly moss (particularly Sphagnum moss). Tropical peatlands typically have an overlying forest, giving rise to unique biodiversity.

The global distribution of peatlands. Tropical peatlands are found in Southeast and Eastern Asia, Central America, the Caribbean, South America and South Africa.

How do peatlands form?

Both northern and tropical peatlands are found where there is high rainfall and drainage is poor. This leads to anaerobic (oxygen-free) conditions and acidification of the soil. This restricts the activity of aerobic microorganisms that break down organic matter. Consequently, the rate of plant production is greater than the rate of breakdown, causing partly-degraded material to accumulate over time.

Tropical peat forms more rapidly than northern peat due to the high productivity of the forest above it and can reach accumulation rates of up to 13 mm a year. Most tropical peatlands are between 3500 and 6000 years old, but some date back to the Late Pleistocene (13 000 – 11 500 years before present). This steady deposition produces dense mats, up to 20 m thick.

Meanwhile, peatland vegetation removes carbon dioxide (CO_2) from the atmosphere, but because these plants are not fully broken down, most of the carbon becomes stored in the peat. As a result, tropical peatlands represent a very concentrated store of CO_2. Compared with temperate forests, which store 150-250 tonnes of carbon per hectare, tropical peatland contain up to 10 000 tonnes per hectare. It is not surprising then, that tropical peatlands are estimated to contain 3% of the world's soil carbon stores, despite only covering 0.25% of the Earth's surface. Peatlands emit other greenhouse gases, including nitrogen dioxide (N_2O) and methane (CH_4), but only at a low rate and is more than compensated for the CO_2 that is stored. Tropical peatlands therefore play a valuable role in maintaining a stable global climate.

Tropical peatland also performs many other valuable functions. Many plants are endemic to

Key words

peat

carbon dioxide

methane

conservation

peatland and these systems also support rare animal life, including the orangutan, blackwater fish, false gharial and the Sumatran rhino.

They provide a source of timber, medicine, bark, resin. In addition, tropical peatlands filter and store water, combat erosion and reduce the effects of flooding. So, although tropical peatland may only have a small geographical distribution, its importance cannot be over-estimated.

Wildlife of peatlands

Tropical peat swamps support an amazing diversity of plant and animal life.

Sumatran orang-utan

blackwater fish

Sumatran rhino

false gharial

Peatland under threat

Climate scientists are highly interested in peatlands. As we have seen, they act as a huge store of carbon but also, under certain conditions, they can act as carbon sources instead of carbon sinks. Many areas of tropical peatland are threatened with land-use conversion into agricultural plantations (especially for oilpalm). Cultivated crops require drainage systems, but when these are introduced into peatland, the water table is lowered and oxygen enters the soil. This enables greater decomposition, releasing the carbon dioxide stored in the soil. Furthermore, conversion into plantations or pasture increases nitrogen dioxide emissions. Together, these cause peatlands to turn into sources of greenhouse gases, rather than sinks. Drained tropical peatland is currently thought to release 2000 million tonnes of carbon dioxide annually, equal to 8% of global emissions from fossil fuels.

Land-use conversion frequently involves deforestation (often illegally), which stops the input of organic matter into the peatland system. This also exposes the peat, leading to erosion and surface subsidence, making areas more vulnerable to severe flooding. If surface subsidence continues, up to 70% of peat lands bearing plantations may become unusable within 100 years. Perhaps the most unsuccessful example was the Mega-Rice Project started in 1996; this aimed to convert 1 million hectares of 'unproductive' peatland in Borneo into rice paddyfields. Draining the water from these peatlands, however, allowed oxidation of minerals contained within the soil, producing sulphuric acid. This caused widespread river pollution and the project was eventually abandoned in 1999.

Perhaps more worryingly, as peat dries, it becomes highly flammable and poses an acute fire risk. As well as releasing methane and carbon monoxide, peat fires produce noxious vapours that reduce air quality and can affect human health.

Fires burn in the Tripa peatlands of Sumatra.

The devastating peat fires of 1997-98 (known as the 'Sumatra Haze') released between 3000 and 9000 million tonnes of CO_2, equivalent to 13-40% of the annual European CO_2 emissions from fossil fuels. This could set in motion a vicious cycle, where rising global temperatures cause peatlands to dry out, introducing more oxygen and making them more vulnerable to fire.

Protecting peatland

A key challenge for climate scientists is to model the impact of peatland destruction on global and regional temperatures. This is complicated by the fact that uptake and release of greenhouse gases varies considerably across peatlands, depending on their structure, hydrology and ecology.

The effect of peatland conversion on gaseous emissions is being investigated by researchers based at the University of Leicester, led by Professor Susan Page. She confirms that her research shows "the carbon debt associated with recent wildfires and the conversion of peatlands to agriculture, particularly for plantations, is enormous", and so "the scale of greenhouse gas emissions needs to be taken into account in any assessment of the impact of land use change."

Members of the Sumatran Orangutan Conservation Project examine peat after a devastating fire.

Meanwhile, hydrological restoration projects are underway to investigate if damaged peatlands can recover. Raising the water table by removing drainage systems reintroduces anoxic (oxygen free) conditions and can decrease CO_2 emissions by up to 20%. Certain areas of northern peatland have even been restored to carbon sinks using this strategy. It has been found, however, that rewetted peatlands often show greater rates of methane (another greenhouse gas) release.

The best strategy therefore, is to prevent peatlands from being converted in the first place, but this could affect the economic development of local communities. One proposed strategy has been financial payments for reduced emissions from avoided deforestation and forest degradation (REDD). This would give peatlands an economic value, making them more valuable in their intact form rather than as oil palm plantations. It is hoped that greater awareness of the crucial role tropical peatlands play in supporting a stable climate and biodiversity will compel local communities to cherish them and governments to protect them.

Palm oil

The oilpalm tree is mainly grown as a source of palm oil, which comes from its fruit. This is used in many food products, including chocolate and margarine. Increasingly, however, palm oil is being grown for biodiesel; this demand has been heightened by European legislation ruling that, by 2020, 10% of fuel must come from biofuel sources. It is ironic therefore that biofuel, designed to offset carbon emissions, may actually increase these due to peatland devastation.

Planting out oil palm plants in Guinea-Bissau, Africa

The fruits of the oil palm are crushed to extract oil for food products.

Get involved!

If you want to learn more about tropical peatlands, or even contribute towards their preservation, then OuTrop (Orangutan Tropical Peatland Project) is the organisation for you. Based in Borneo, this charity operates a long-term biodiversity research programme, besides working with local communities to implement conservation measures. OuTrop also offers volunteer placements where students can immerse themselves in the tropical forest, assisting with ecological surveys and replanting schemes. See www.outrop.com for more details.

Caroline Wood is a postgraduate student at the University of Sheffield.

Will Marshall

Fire engineer

A decade of learning, more to come

Key words
engineering
consultancy
construction
career

It's been almost a decade since I graduated from a Masters in Mechanical Engineering from Brunel University in west London. Very shortly after I finished, I started work as a fire engineering graduate fresh to the specialist field of fire engineering consultancy. A decade on, I am managing a team of fire engineers, code consultants and modelling specialists as well as one of the largest and most complex fire engineering projects in Australia. Reflecting on this I want to explain where I have got to and, just as importantly, where I have to go in the future.

My current project is the Darling Harbour Live project, a 20 hectare site at Darling Harbour. This will include a conference centre, theatre, housing and commercial buildings, all of which must be designed for fire safety. But first I should explain just what someone called a 'fire engineer' does.

An architect's impression of the Sydney Convention Centre

What is fire engineering?

Fire engineers work on major construction projects. We have to think about many aspects of engineering, but we must also think about human behaviour.

At the start of a project, fire engineers will consider where and when a fire may occur and identify a credible worst case scenario. A fire occurring in an unoccupied area may grow to a larger size before it is discovered than a fire in an occupied space, but the fire in the unoccupied space may not have an impact on so many people so a smaller fire in an occupied space may be the worst case to consider.

We consider how the smoke generated from this fire could impact on building occupants and on the fire fighters sent to deal with it. The movement of smoke through spaces is a complex flow problem and can require detailed analysis to accurately predict the performance of the building when there is a fire. On the simplest end this might be using calculations on spreadsheets, but at the other extreme detailed Computational Fluid Dynamic (CFD) modelling to visualise smoke movement throughout the spaces may be used. With all this information it is possible to determine how long the occupants will have to escape from the building.

We must also take into account how the occupants are likely to react in a fire. This analysis includes determining the number of occupants, as well as the demographic characteristics of these occupants, such as age, gender, social or family groups etc.

and how we can use staff to control crowds of occupants and to ensure that they escape. Knowing how the fire might spread and how people will move we can check that they will be able get out before it is too late. Ultimately the aim is to demonstrate that occupants can escape and fire fighters can effectively carry out fire fighting operations.

Building design must take into account the safety of fire fighters who may have to tackle a blaze.

How do we assess how a building will work in practice? We will study architectural drawings, 3D models, technical input specifications from other engineering disciplines as well as architects and clients visions for the project. This information is collected through 2D and 3D drawings, meetings, telephone conversations, technical documents, codes, standards and promotional material.

The level of complexity involved in this analysis depends on the complexity of the project. The Darling Harbour project discussed in this article has involved multiple analyses following the process above for several worst case scenarios. In the design of the buildings the aim for the fire engineer is to optimise the building efficiency and flexibility, while still meeting the requirements of the code.

Once the analysis has been carried out, we prepare documentation reporting on the results. These documents must be concise and written in a language that the audience can understand. They include both technical results (such as calculations and research findings) and advice on what design features are necessary in the project.

The project

The Darling Harbour Live project involves the redevelopment of the existing facility in Sydney to provide a world-class convention, exhibition and entertainment facility. A consortium has been formed to develop and manage the precinct for the next 25 years. The company that I work with, AECOM, are providing the majority of the technical engineering consultancy services, including fire engineering on this project.

The design and construction phase of the project, where our advice relates primarily to, started in 2012 and will be completed in 2016. A project of this scale has more than 100 consultants working across the various teams on the project. Any way you look at this project, it is large and complex.

An aerial view of the Darling Harbour Live site as it will look after redevelopment

The team

The overall AECOM team comprises of over 50 staff and includes the following disciplines:

Mechanical Engineering
Electrical Engineering
Fire Services
Fire Engineering
Specialist Lighting
Communications
Security
Dangerous Goods
Vertical Transportation
Pedestrian modelling
Environmental
Sustainability
Blast Engineering

An overall AECOM project manager is responsible for coordinating all of these services. However, individuals from each of the disciplines interact directly with the rest of the design team.

My role

My role on this project, which marks my current level after a decade, is to lead the fire engineering aspects of the design. This includes several aspects such as providing technical advice to the design team and acting as the interface with them, attending meetings regularly and corresponding by email and phone daily. I am also responsible for verifying fire engineering documentation, responding to queries and making decisions on the fire engineering strategy.

I manage the input of the other fire engineers on the project. I rarely get involved in calculations (other than particularly challenging areas) or any of the advanced computer modelling and I rarely write reports or memos, but I will often check these to ensure the consistency of advice and quality of information provided.

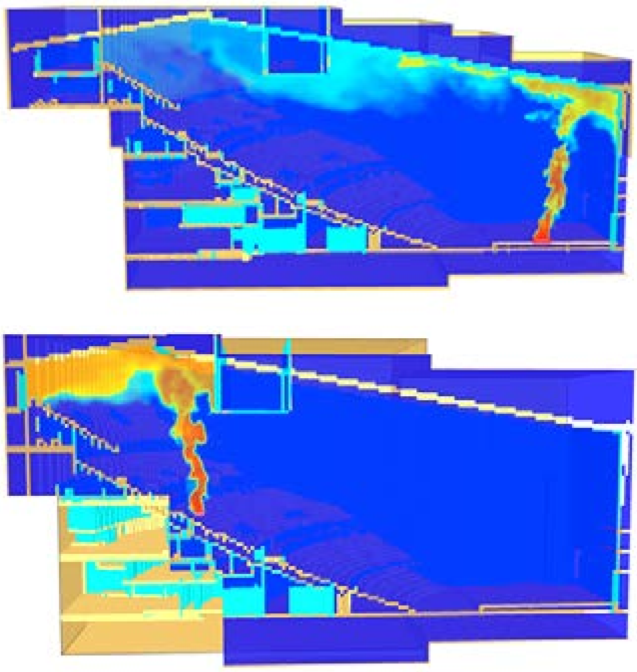
I am the registered Fire Safety Engineer on this project. To become registered one of the prerequisites is to achieve Chartered Engineering status, which in itself is a major milestone with an involved process (see my previous article in CATALYST).

All this happens while responding to the aspirations, constraints and challenges from each of the other disciplines within the design team.

The team's role

With a project of this scale it's not possible for all the fire engineering advice to be provided by a single person. I have been fortunate enough to have the assistance of several other very good engineers on this project. For example, a senior fire engineer managed all the advanced modelling. I was involved in setting the key parameters for the modelling, but not involved in any of the models, or their checking. The models were used to validate our earlier calculations and demonstrated that the strategy had been robustly developed.

The fire engineering team in Sydney



Smoke movement within the theatre can be modelled using Computational Fluid Dynamic (CFD) computer simulation; a fire breaks out on the stage (top) or in the audience seating area (bottom).

The roles of the other fire engineers within the team reflect the level of experience that they have, which is how it has been for me through my career progression. It's crucial to have put in the time learning the calculations and modelling techniques so that I can effectively oversee others carrying out these tasks and can manage them effectively. Skimping on building a strong technical base will only weaken your ability to manage and control others carrying out those tasks in the future.

The next decade and beyond

I see myself as a member of Generation Y, with great ambitions and high expectations. So far, my career progression expectations have been met to this point where I am leading the fire engineering input on this significant project.

One possible direction for my own career is to manage the engineering input for multiple disciplines, not just fire engineering. I am already doing this, but only on relatively modest projects. To do this on larger and more complex projects requires me to continue to expand my knowledge of the other engineering disciplines and therefore my ability to manage multi-disciplinary projects. Whatever way I choose to progress my career will involve continuing to learn more and continually build on my skills.

Will Marshall is Australia and New Zealand Fire & Risk Group Leader, AECOM

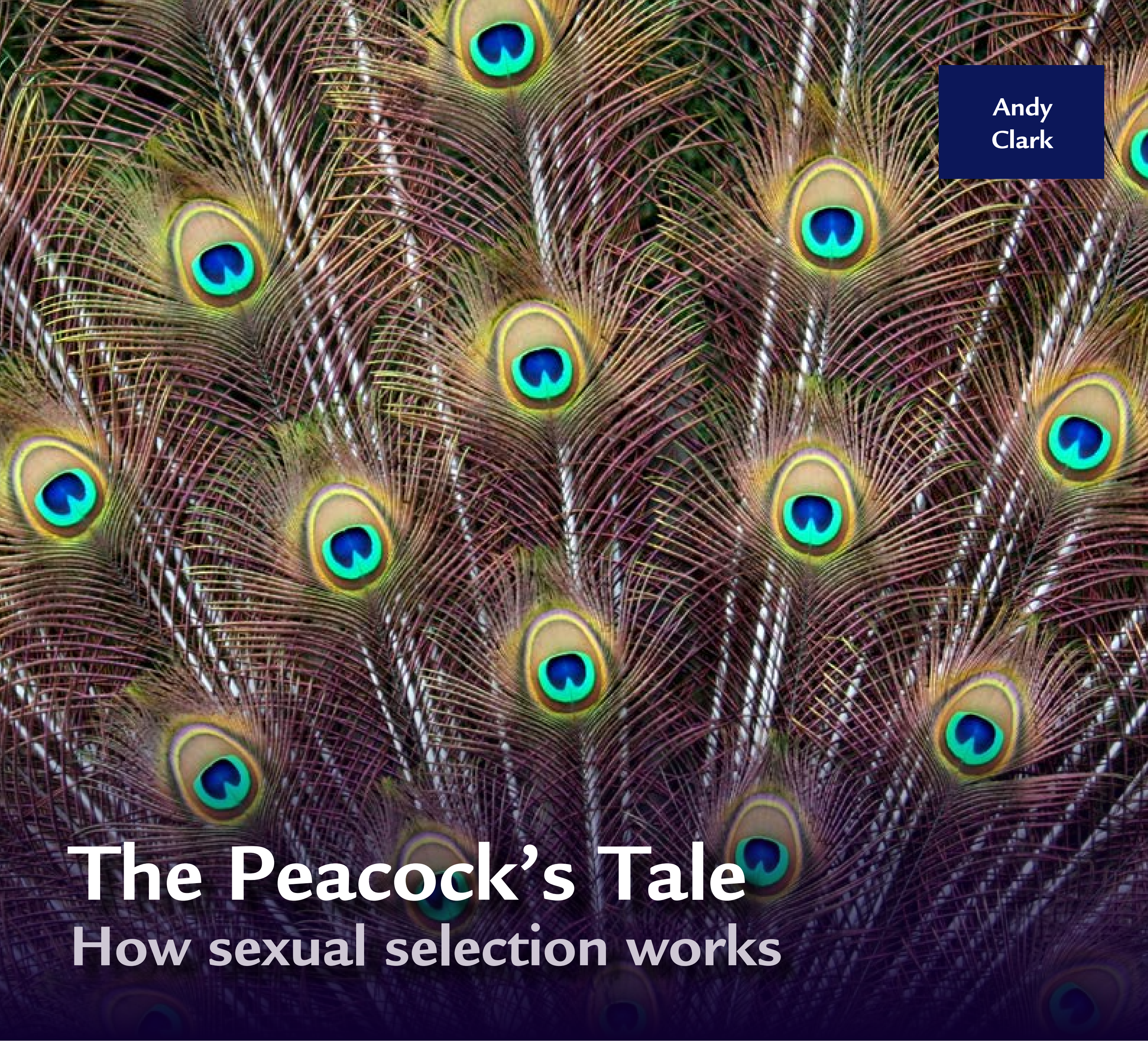
The theatre at Darling Harbour

Look here!

The Sydney International Convention, Exhibition and Entertainment Precinct: *www.siceep.com*

More about the engineering project Darling Harbour Live: *www.darlingharbourlive.com.au*

Will Marshall describes how he became a chartered engineer: *http://www.catalyststudent.org.uk/cs/article/83*



Andy Clark

The Peacock's Tale

How sexual selection works

Evolution occurs by natural selection, but this statement may make it appear deceptively simple when actually it is highly complicated. As ***Andy Clark*** *explains, natural selection operates in a number of ways and one fascinating mechanism is sexual selection.*

Key words
evolution
natural selection
sexual selection

An individual is given a set of genes at the start of its life, and if they are 'good' it might stay alive long enough to reproduce and pass on its genes to the next generation. In all sexually reproducing creatures, however, there comes a time when that individual must find a suitable mate to help it pass on its genes; this is hardly a romantic look at the proliferation of life. The fact is, reproduction is a selfish act.

What if those other genes let you down, and your offspring don't make the harsh cut under natural selection? This is where sexual selection comes in and is usually female-driven due to a higher investment in the process of reproduction. Female gametes store food for the developing embryo and consequently are bigger than the male gamete. Then in most species, she has to look after the offspring until they are mature.

Males, however, make a vast number of sperm – and quickly too! At its most basic, once a male has successfully got his sperm into the vicinity of an egg, his commitment is often over. The outcome of this imbalance of investment is a strategy which differs between the two sexes. Females have evolved a 'choosy' behaviour, where they select a mate who demonstrates that he is the 'fittest' around before she will invest in sexual reproduction with him. Whereas most males, due to their low investment, are not so choosy and operate a strategy which produces as many offspring as possible, i.e. through several matings.

Natural selection

Darwin's real achievement was to suggest the simple but very powerful idea of natural selection. This idea relies on just a few simple steps:

- Living things produce more offspring than are needed to replace themselves, but populations stay about constant.
- Members of a species vary, and this variation can be passed on from parents to offspring.
- Those with advantages tend to survive better and so leave more offspring who carry their advantageous features.

Only skin deep?

How can an animal tell the quality of its potential partner's genes? The challenge for the partner is to somehow prove that they have got the best genes. Nature ensures this happens in many ways that can be very bizarre; a good illustration of this is the peacock's tail. Male peacocks are highly colorful, but the female peahens are drab by comparison.

A peacock displays his tail to catch the attention of a peahen.

A male peacock's extravagant tail has no benefit whatsoever for its physical survival – in fact, it's far more of a hindrance. It doesn't help him to fly, catch his food or escape predators. but it takes a lot of energy to produce and then it has to be carried around behind him everywhere. The fact is that a male who is able to spend so much of his energy on growing that tail, and still be fighting-fit and not be eaten by a predator, shows that he must have 'good' genes for the other things that matter, i.e. general strength and health.

If there were any other advantage to survival of having elaborate tail plumage, the females would have it too. In this way, sexual selection goes against what would logically be 'weeded out' by natural selection. Females look for a male who has actively gone against the odds but has still survived.

Role reversal

In some species the males are the choosier sex. A good example of this is illustrated by the African Jacana bird *(Actophilornis africanus)*. The males are responsible for nest building, incubation and care of the young. In this case it is the male who makes the biggest investment in the young and the females are more brightly coloured and compete for the attention of the males.

The African Jacana (Actophilornis africanus)

Looks may not be everything

So what if males are willing to do more than just provide the genes? (This is where the romance comes back into it.) In some species, the female not only has to assess the quality of her mate's genes, but also how useful he'll be in helping look after the young. A male becomes attractive if he's more than just a sperm bank. Having him involved in raising the young reduces the cost to the female, and gives the offspring a better chance of survival, a double win for the female.

In the Olive Baboon *(Papio anubis)* some males behave 'paternally' toward infants they could not have sired as a way of currying favour with a female. This behaviour toward a mother and her infant can gain the male preferential access to that mother when next she mates.

A male Olive Baboon with young (photo copyright)

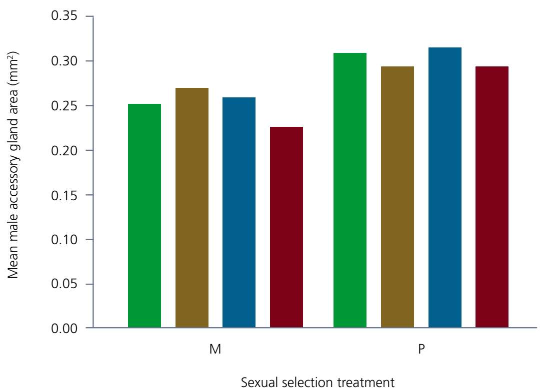
Some recent research

Some of the early work on sexual selection was carried out on fruit flies (*Drosophila* sp.). Recent research at Sheffield University on these flies has highlighted some of the costs and consequences to the male of engaging in the competition for females.

Males possess a pair of accessory glands associated with the testes, which produce a range of chemicals (accessory gland proteins), which are involved in reproduction.

These chemicals have been known to increase ovulation (egg-production) and oviposition (egg-laying) rates in females upon transfer. One such chemical called Acp70A also induces rejection behaviour towards subsequent males by the female. Exerting these kinds of effects on females can dramatically increase the number of offspring a male can sire in his lifetime. So these glands are crucial in the competition between males to father as many offspring as possible.

At Sheffield they have set up monogamous tubes (each containing only one male and one female) and promiscuous ones (one female and several males). This leads to a variation in the level of competition between males and, as predicted, the promiscuous situation results in larger accessory glands, as shown in the graph.



Sexual selection treatment has a significant effect on the size of the accessory glands of virgin male fruit flies. M = results for 4 trials of monogamous flies; P = results for trials of promiscuous flies.

The human case

How does sexual selection operate in humans? Which sex, if any, has the most investment in the reproductive process? Is either sex more choosy in selecting their partners and what characteristics do humans use in their selections? All these questions are material for current research. So far scant observations of human courtship have shown many characteristics displayed by both men and women.

For example, recent work on male beards has shown that both men and women view a beard as a sign of masculinity. The growth of a beard has no advantage and in fact requires energy, just like the peacock's tail.

Is Jude Law more attractive with stubble or a beard?

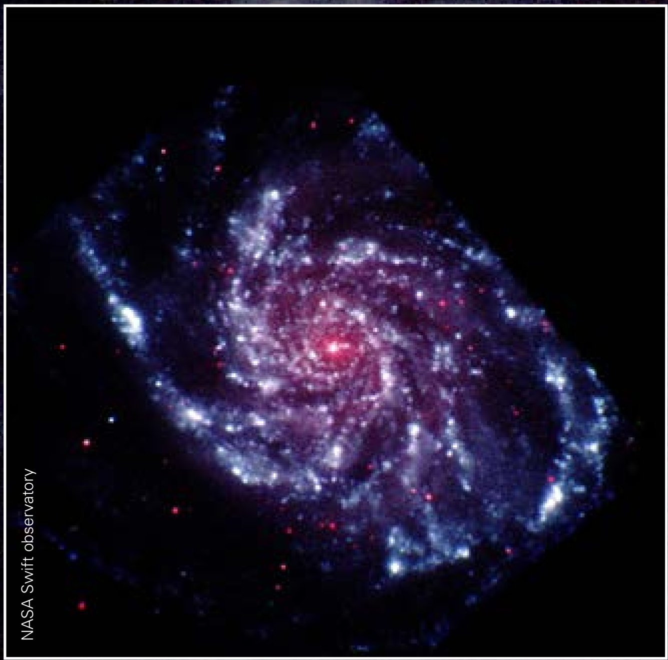
However, surveys show that women tend to prefer heavy stubble to a full beard as a sign of attractiveness. The researchers hypothesise that this is because picking a mate who is too masculine isn't necessarily a good thing. They may be more likely to get into fights, take risks and wind up widowing the wife and leaving her to raise his beardy babies alone. Going for a stubble-sporting mate may be a safer bet.

So from the bearded head to the extravagant tail, sexual selection seems to be a general driving force of evolution in the living world.

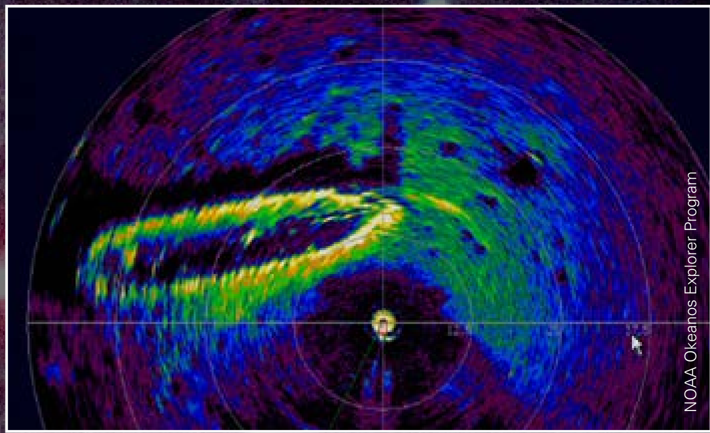
Andy Clark is an ecologist at heart because, he says, "the world is a vast, complex and brilliant place." Having recently graduated from reading biology at the University of St Andrews, he works in conservation with Operation Wallacea and so is able to share his love of the natural world with others, while actively being a part of protecting it.

FALSE COLOUR

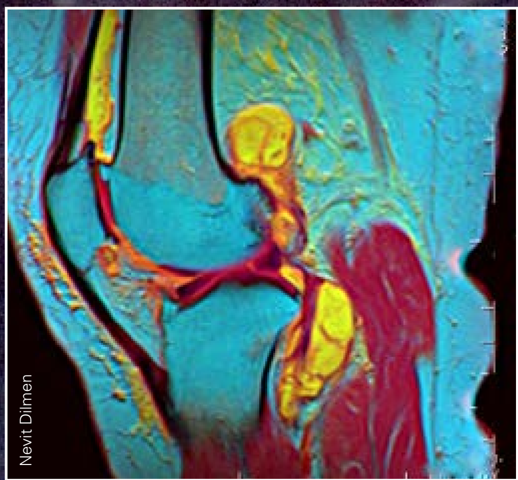
Our eyes detect visible light, just a small region in the electromagnetic spectrum. Using scientific instruments, we can detect many other types of radiation. Different colours are used to represent the different wavelengths of this invisible radiation. The result is images which we find it easier to interpret.



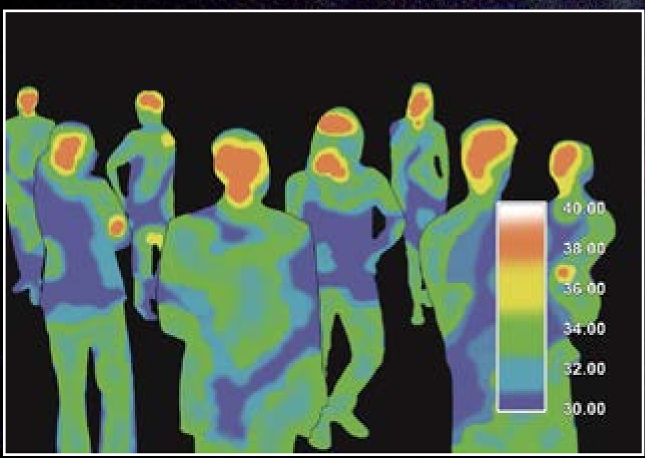
◄ *This image of the pinwheel galaxy M101 was constructed from multiple images taken at different wavelengths, including ultraviolet. Here, the shortest wavelength* ***ultraviolet*** *rays are represented as blue, and the longest visible light wavelengths as red. The bright patches in the spiral arms show where hot, young stars are forming.*



▲ *Sonar is like radar but using* ***sound waves*** *(which are not electromagnetic waves). Here, the wooden hull of an 18th century sailing ship sits on the seabed. It shows up clearly because colour is used to indicate the depth of the water.*



◄ ***Radio waves*** *are detected to make a magnetic resonance imaging (MRI) scan of a knee (left). By adding colour, different parts of the joint are more easily identified.*



Infra-red *radiation is detected to make a thermogram. Colour is used to show how the temperature varies across the scene.*

Land use in Hong Kong can be deduced by analysing the wavelengths of ***visible light*** *and infra-red reflected from the ground. After image processing, vegetation is coloured green while urban areas are pink.*