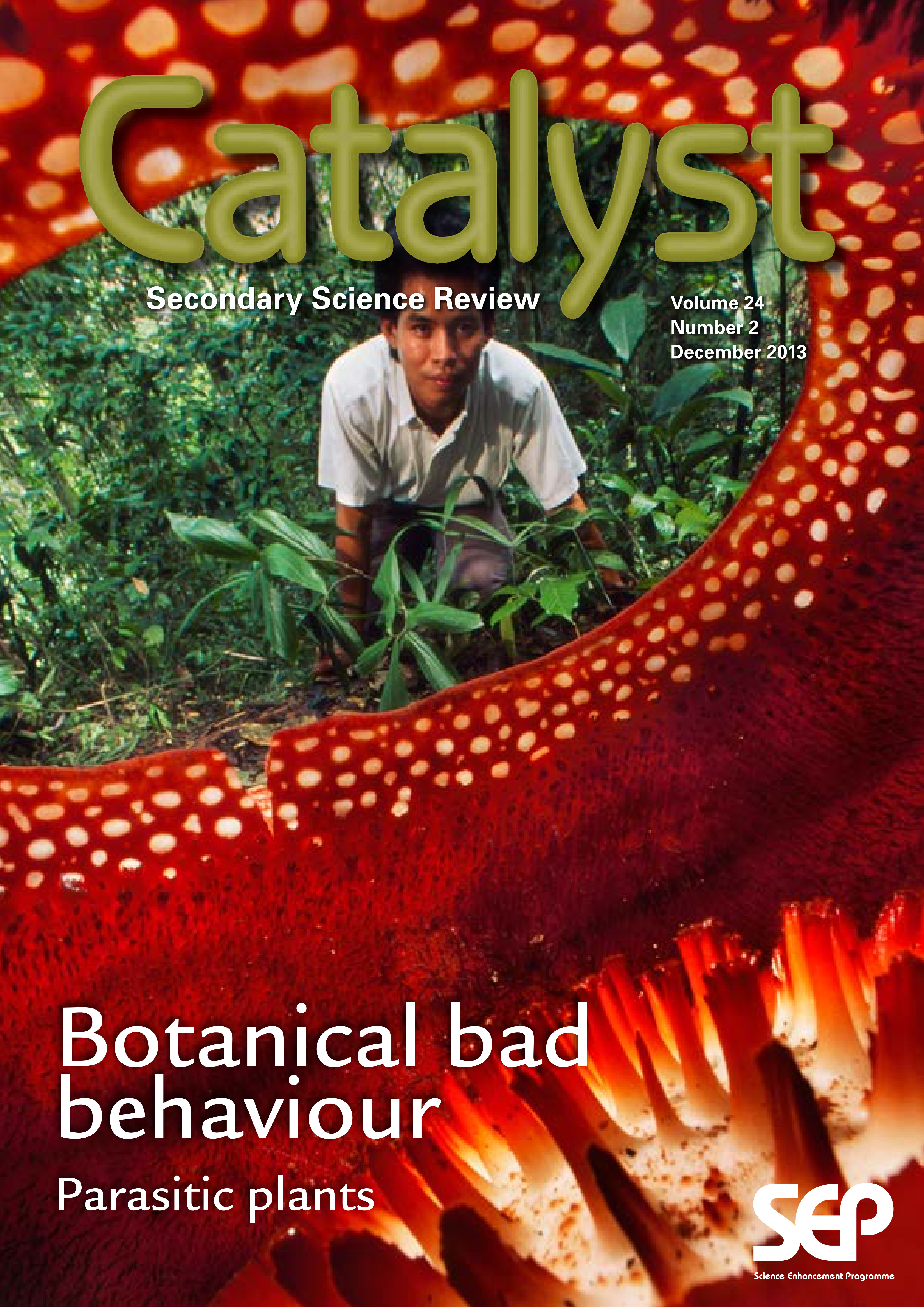

Catalyst

Secondary Science Review

Volume 24
Number 2
December 2013

Botanical bad behaviour

Parasitic plants

SEP
Science Enhancement Programme

Catalyst

Volume 24 Number 2 December 2013

Contents

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The cover image shows a botanist examining a flower of Rafflesia keithii in Mt Kinabalu National Park, Sabah, Borneo. Rafflesia is a genus of plant which livse mostly underground, drawing nourishment from the vine it parasitizes. Its spectacular flower appears above ground and is the largest of all flowers. See the article on pages 1-3. (Frans Lanting, Mint Images / Science Photo Library)

Going public

On Thursday June 30th, 1858, a famous scientific meeting took place in London. Papers were read describing the evolutionary theories of Charles Darwin and Alfred Russel Wallace. Both had, independently, developed a theory of evolution by natural selection. Their friends suggested that, to show that credit for the theory should go to both, their ideas should be presented at the same time to the Linnean Society, a distinguished scientific body.

This year is the centenary of Alfred Russel Wallace's death. On pages 9-12, James Wiliams describes Wallace's work including his extraordinary journeys around the Malay Archipelago in south-east Asia, travels which influenced his thinking in the same way that Darwin was influenced by his *Beagle* journey.

On pages 19-21, Caroline Wood describes a scientific conference of today. Such meetings are a vital way in which scientists share their ideas, partly by listening to talks and partly by talking to colleagues in between the formal sessions.

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The world of parasitic plants

Caroline Wood

Key words
plant
parasite
crop pests
resistance

Beautiful parasite – the West Australian Christmas tree, Nuytsia floribunda *is a hemi-paraiste, sucking water from the roots of other plants.*

Most people are all too familiar with the idea of animal parasites, including tape worms, ticks and lice. But did you know that plants can also act as parasites, exploiting resources from unwilling hosts? Rather than being rare anomalies, however, there are over 4000 known species of parasitic plants, with representatives in 19 families of the plant kingdom.

Types of plant parasites

Plant parasites can be divided into two broad groups, hemi-parasites and holo-parasites. The former group is capable of photosynthesis and only extracts water from the host. Holo-parasites, on the other hand, completely lack chlorophyll and rely on their host for both sugars and water. Besides this, plant parasites can attach either to the stem or roots of the host.

Plant parasites encompass an extensive size range, including trees and the plant which produces the largest individual flower, *Rafflesia arnoldii*, a parasite of tropical vines. They also include the mistletoe family, which mainly act as hemi-parasites on tree and shrub species. The seeds are dispersed by birds feeding on the mistletoe berries; when the seeds are later excreted, they attach to the branches of trees due to a sticky, glue-like covering. This allows them to directly invade a new host. A common British parasitic plant species is Yellow Rattle *Rhinanthus minor*, a hemi-parasite which gets nutrients from the roots of plants close by. It has a useful role in creating wildflower meadows as it suppresses the growth of rapid-growing grasses that would otherwise dominate the ecosystem.

Rafflesia arnoldii *produces the world's largest flower, yet remains obscured for most of its life as a holoparasite of the vine* Tetrastigma *in the tropical forests of Sumatra and Borneo.* Rafflesia *does not form stems, leaves or roots and grows within the host as thread-like strands. During its reproductive phase, the parasite produces buds which break through the bark of the host.*

Common parasitic plant species include mistletoe (top) and Yellow Rattle (below).

Definitions

Epidermis: The outer layer of cells that cover an organism.

Root exudate: A substance made up of compounds secreted by plant roots into the soil. These can include organic acids, gases (e.g. CO_2), amino acids, sugars, inorganic ions and vitamins.

Marker assisted breeding: This uses molecular markers to determine if a plant carries a gene for a desirable trait. The 'markers' are specific genetic sequences closely associated with the gene of interest. A key advantage to this technique is that DNA can be isolated from seeds and screened to identify plants possessing a key trait without having to grow mature plants.

The invasion process

Plant parasite seeds can remain dormant in the soil for many years until stimulated to germinate by molecules released by host plants. Upon germinating, parasitic plants must rapidly locate a suitable host before their seed reserves are exhausted. This is helped by the parasite being sensitive to diffusible compounds released as airborne molecules or as part of host root exudates. Little is known, however, about the molecules which promote germination and directional growth in plant parasites.

Host contact triggers the development of a specialised invasive organ called the haustorium. This penetrates the epidermis of the host root or stem, growing between the cells to reach the xylem and/or phloem vessels. In the case of hemi-parasites, xylem vessels are entered via the pits within their walls; cells in the centre of the haustorium then differentiate into xylem vessels to ensure a continuous connection between host and parasite. Haustoria cells typically show high metabolic activity, with numerous mitochondria, which is thought to help water and nutrient uptake. Successful invasion results in greatly reduced growth of the host plant, as vital supplies are diverted to the unwelcome guest.

Dodder-laurel, seen here with its haustoria invading a black wattle

This photomicrograph shows a parasitic plant's haustoria (in black) invading the cells of a host plant.

Commercial implications

Parasitic plants have devastating effects on agriculturally important crops. Yields from timber tree species can be significantly reduced by mistletoe infestations. Meanwhile the genus *Cuscuta* contains over 150 species of holo-parasitic Dodder plants distributed worldwide, which infect both commercial crops (such as alfalfa, potatoes and tomatoes) and ornamentals.

One of the most notorious parasitic plants however is the hemi-parasite *Striga hermonthica*, also known as 'witchweed' due to the devastating losses it causes in plants of the grass family (*Poaceae*) and some legumes. It is a particularly acute problem in Sub-Saharan Africa, where it infects the major crop staples rice and sorghum. Striga is estimated to cause global losses of $7 billion and to be the main limiting factor for food security in Sub-Saharan Africa. As Striga is a root parasite, a farmer cannot tell if his field is infected until the purple flowering stems emerge from the soil, by which point it is too late. By diverting valuable water supplies from the host, Striga causes the crop plants to be stunted, resulting in overall yield reductions of 20-100%. Furthermore, each plant can produce up to 50 000 seeds, which can remain viable in the soil for 20 years until stimulated by host compounds. This makes it extremely difficult to control Striga once fields become infected. Applying nitrogen fertiliser can reduce infestation, as the parasite prefers nitrogen-deficient soils, but this option is too expensive for most subsistence farmers, who have to rely on cruder methods such as hand weeding.

The devastating parasitic weed Striga

A farming family inspect their maize crop, devastated by Striga, accompanied by a researcher from the International Institute of Tropical Agriculture.

Science to the rescue?

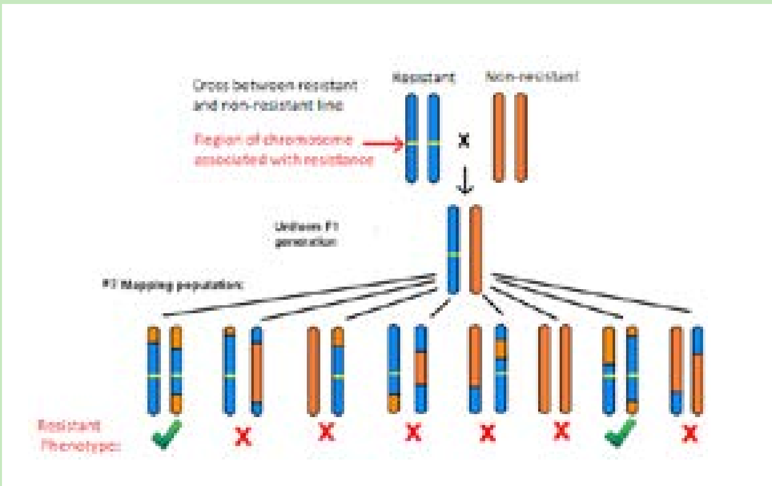
Scientific research has yielded some small successes in identifying ways to supress Striga infestations. These include the use of trap crops (or 'false hosts'), such as cotton, which produce molecules which stimulate Striga seeds to germinate. These plants, however, cannot themselves be infected, causing the young Striga plants to die. This can reduce the resident seed population within the soil before the main crop is planted.

Other strategies include using species that naturally produce compounds which repel Striga. An example is the legume *Desmodium uncimatum*. When this was planted together with maize (a technique known as 'intercropping') in field trials this reduced Striga infestation levels by 40 times.

Meanwhile, researchers are hoping to identify strains of crop plants showing natural resistance to Striga, which can then be interbred with high yielding lines. To identify areas of chromosomes associated with resistance, a mapping population is first created by breeding a resistant and non-resistant line together to generate a homogenous F1 (first generation) population (see Box below). Breeding together the F1 offspring promotes recombination events during meiosis, where sections of DNA are exchanged between the parent chromosomes. This can separate the region associated with resistance from the rest of the parent genome.

By screening each successive generation for resistance, the relevant genetic locus can be mapped with increasing precision. Once the area is identified, this can be used in marker assisted breeding programmes. Continuing this research will be important in the efforts to secure a sustainable food supply for future generations.

A mapping population is used to identify genetic loci (places) associated with resistance. A resistant line is interbred with a non-resistant line, generating a uniform heterozygote F1 population. When the F1 plants are bred together, sections of parental DNA are recombined during meiosis, which can separate the region containing the resistance genes. F2 offspring which are homozygous (both loci the same) for these genes will display the resistant phenotype. The DNA can then be tested with markers that distinguish between the parental genotypes to determine which parts of the genome originated from the resistant parent. The process can be repeated, breaking up the parental genomes further, to locate the resistant loci with greater precision.



Caroline Wood is a postgraduate student at the University of Sheffield. She is currently investigating the interactions between parasitic plants and their hosts.

Mary
Finnegan

What is geothermal energy?

The Blue Lagoon geothermal spa is one of Iceland's top tourist sites.

Key words
geothermal energy
radioactive decay
electricity
power station

Geothermal energy is the heat is produced by decay of radioactive isotopes deep within the Earth. The temperature at the centre of the Earth is thought to be around 5000 °C, with the temperature reducing toward the surface. It is estimated that 99.9% of the planet is above 100 °C. Geothermal energy is considered a renewable source as the amount available is much greater than the demand.

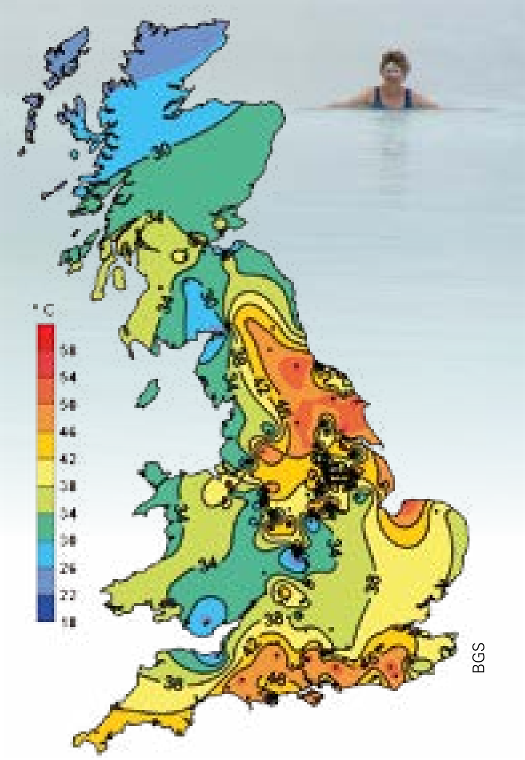
Hot springs are caused by geothermally heated water rising to the Earth's surface. These have been used for heating since Roman times and humans have been bathing in them since the beginning of our existence.

Temperature and depth

The top 10 to 15 meters of the Earth is heated by the Sun. It warms over the summer and cools during winter. This heat can be concentrated using heat pumps and used to heat buildings, but is not an example of geothermal energy.

Deeper into the Earth's crust the temperature is not affected by the Sun and remains stable throughout the year. In the UK this is about 9-13 °C. The temperature increases with depth, known as the geothermal gradient. This is caused by heat flow from the Earth's interior and varies in different areas based on the thermal conductivity of the rock.

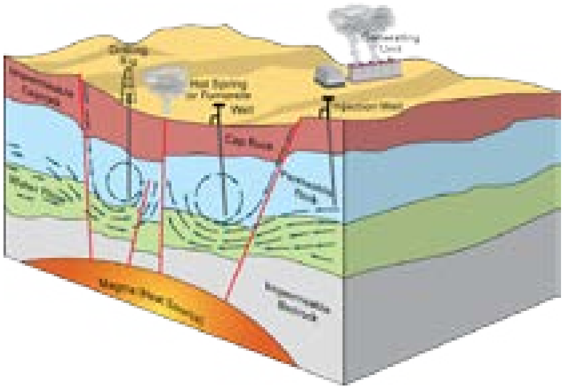
In the UK the temperature typically increased by around 26 °C every km, but there are hot-spots in the south and north-east of England.



Temperatures at a depth of 1000 m across the UK – black dots indicate measurement points.

Harnessing geothermal energy

Geothermal energy is extracted from the ground using water, which absorbs and stores heat due to its high heat capacity. Hot water aquifers are found when permeable underground materials (e.g. soil, sediment or porous rock) allow water that is geothermally heated deep within the Earth to travel to a relatively shallow depth. Svartsengi and other geothermal power stations in Iceland use hot water aquifers.



A geothermal power plant uses hot water or steam produced deep underground.

Enhanced geothermal systems (EGS) are a new development in geothermal energy. Where a natural aquifer is not present, water is heated by injecting it through into hot, dry rocks. The Habanero EGS power plant in Australia began generating power in May 2013.

Another source of geothermally heated water is decommissioned mine systems which have filled with water over time. The water absorbs and stores heat from the surrounding rocks, which can be extracted and concentrated using heat pumps to heat to nearby towns or cities.

Geothermal electricity and heating

Geothermal power stations use geothermally produced steam to power turbines and generate electricity, much like conventional thermal power stations. Alternatively, lower temperature geothermally heated water can be used to evaporate an organic solvent (with lower boiling point than water), which then drives the turbine. This system is used at the Landau power plant in Germany.

Geothermal electricity production is most suited to countries where the Earth's crust is thin, such as Iceland and the Philippines where around 30% of the electricity is produced geothermally. Geothermal heating requires a less intense heat source and is more efficient than geothermal electricity production.

But just how sustainable is geothermal energy? Despite geothermal energy being considered a renewable resource it is possible for local geothermal heat sources to be affected by high demand and consequently their output reduced. Longevity of geothermal electricity production is demonstrated in Wairakei, New Zealand where power has been generated since 1958. However there has been some localised environmental effects such as subsidence.

Rotorua geothermal power station in New Zealand

District Heating schemes

District heating (DH) schemes distribute heat produced in a central location to residential and commercial buildings in a community. This is popular in many countries in Europe including Sweden and Denmark where DH accounts for over 50% of heating, whereas the UK it accounts for less than 2%.

Geothermal projects in the UK

Heating is responsible for 46% of the UK's energy consumption and is the single biggest use of energy in the UK. The government has set a target of 12% renewable heating by 2020: a big increase from just 1% in 2009.

Southampton district energy scheme: The UK's most established use of geothermal energy began in 1986 in Southampton. A 1800 m deep well extracts water from a geothermal aquifer and uses this to heat fresh water and contribute to the district heating and electricity scheme (see Box above) which provides electricity and heating to a number of public and private buildings in the city centre. The scheme saves a total of 10 000 tonnes of CO_2 each year compared to the annual emissions reported by Southampton City Council of about 27 600 tonnes.

Glasgow Mine Water System: The British Geological Survey recently publicised the results of a study into the geothermal potential of the water in the mines beneath Glasgow, with the conclusion that they could provide up to 40% of the city's heating by extracting around 20 GWh/km^2 each year (about 1% of the total stored energy).

Other projects: The Eden project in Cornwall plans to create an EGS to extract geothermal energy from granite rocks in order to generate electricity. The power will supply the Eden Project and potentially a further 3500 households. Another suggested source of geothermal energy is defunct oil wells in the North Sea. The wells are situated at a point where the Earth's crust is relatively thin (around 10 km thick) and therefore reach high temperatures. Geothermally generated electricity could be produced on the well platform and redistributed to the mainland via undersea cables.

Look here!

North sea geothermal wells: *thinkgeoenergy.com/archives/11618*

British Geological Survey: *www.bgs.ac.uk/research/energy/geothermal/home.html*

Southampton district energy scheme: *www.southampton.gov.uk/s-environment/energy/Geothermal/*

New Zealand Geothermal Association: *www.nzgeothermal.org.nz/nz_geo_fields.html*

Mary Finnegan recently completed a PhD at the Engineering department, University of Warwick.

Jez Wells

Sonic husbandry

Creating hybrids of sounds

olly2/ rocksuzi/bigstockphoto.com

Key words
sound
electronic music
resonance
frequency

Electronic musical instruments are getting better and better at mimicking and behaving just like their acoustic counterparts, but they can also create a wealth of sounds that would be difficult or impossible to achieve with acoustic instruments. ***Jez Wells****, a music technologist, explains how you can join in.*

One area of interest for producers and sound designers is how to create sounds that somehow combine characteristics of more than one acoustic instrument. Want to know how to combine the sound of a flute and an oboe to create a floboe? Want to find out how to make the sound of the ocean talking? Then read on …

Until the second half of the last century, sounds made by electronic instruments were very rare. Now we are surrounded by synthetic sounds and there are whole genres of music (electronica, drum and bass, ambient to name just a few) that would sound very different without them and might well not even exist!

When they first appeared, electronic instruments were analogue and one of these, a device for combining two sounds, was called the vocoder. The word vocoder is short for 'voice coder' because it was originally developed for making telephone calls more efficient. However it was quickly realised that the same technology could be used to combine speech with other sounds, to make it sound as if the objects that made those sounds were talking! Vocoders have been used in studios to create interesting sounds and effects for many years.

Acoustic or electronic?

Sound is a disturbance in the air that surrounds us. This disturbance travels through the air as a wave and as it meets other substances and objects (such as our eardrums) it causes them to move. When our eardrums move at frequencies in the range of 20 times per second (Hz) to 20 kHz we perceive this movement as sound. An acoustic instrument makes sound directly: when it is played (e.g. struck, bowed or plucked) it begins to vibrate and produce sound as a direct result of this interaction.

An electronic instrument creates waves that are disturbances in an electric current, that is, a flow of electrons. These disturbances can be very easy to control and we can create an astonishing variety of them, but we cannot hear them. We need an amplifier and a loudspeaker in order to be able to hear these waves. The loudspeaker cone moves backwards and forwards in the same pattern as the variation in the electron flow in the instrument, but with much greater power (thanks to the amplifier). This forwards and backwards motion converts the wave from an electrical one into an acoustic one, a disturbance that travels through the air and that we can hear.

Analogue or digital?

The difference between analogue and digital electronic instruments is how the wave is represented in the electronic components. In an analogue instrument the pattern of the wave is directly represented in the patterns of electron flow. The word 'analogue' has the same root as the word 'analogy' – the wave pattern in the analogue instrument is a direct analogy of the wave pattern that is produced by the loudspeaker that it's connected to. In a digital instrument the wave is represented by a series of numbers (just like those that might make up a bar chart). Digital instruments are much easier to control but analogue instruments can offer subtle textures and behaviours that are hard to achieve via digital methods.

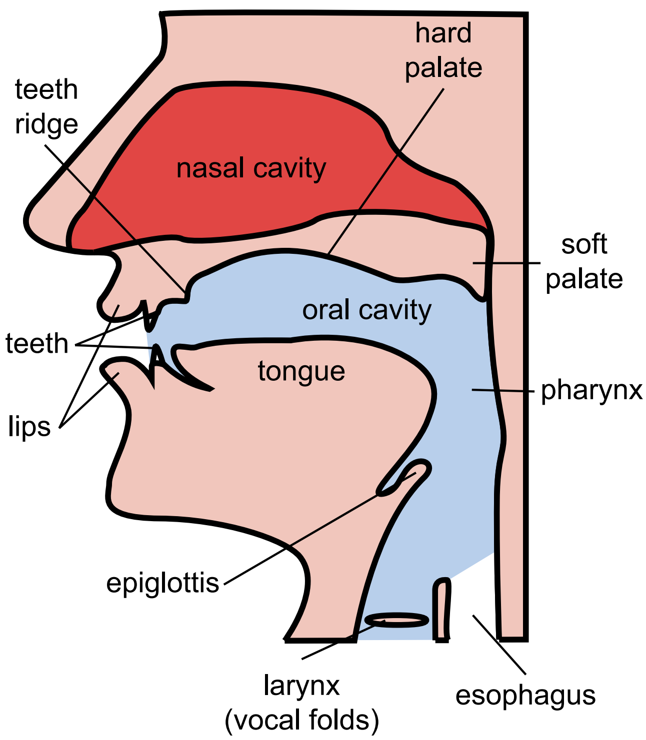
An analogue synthesizer from the 1970s. The piano-style keyboard used to control which notes it plays can be seen, along with knobs to shape the waveform produced and cables to move the signal from one part of the shaping circuitry to another. Digital synthesizers use computer-based technology which can make them smaller, more reliable and software-based, meaning that they can be run on a personal computer, tablet or even smartphone.

Making a hybrid

To understand how we can make a hybrid of the voice and another sound first we need to think about how speech is produced. Our vocal folds make a buzzing sound when we speak (you can feel this happening if you gently hold your throat – at the point where the Adam's apple is on a male – and speak). The space between the vocal folds and our lips (i.e. the top of the throat and the mouth) is called the vocal tract.

The different vowel sounds (eeee, aaahhh etc.) are produced by us changing the shape of our vocal tracts, by moving our tongue and jaw. By changing the shape of our mouths we change the frequencies at which our vocal tracts resonate. When an object, or a system, resonates it responds more strongly to some frequencies than it does to others. The buzzing sound our vocal folds make is made up of lots of different frequencies and the resonance of the vocal tract makes some of those frequencies much louder than others. As we change the shape of our tracts different frequencies are affected and this changes the character of the sound (in this case from vowel to another).

A vocoder works by attempting to retain the resonant properties of the speech sounds, but replacing the vocal cord buzzing that feeds into that resonance with a different sound. For example, if we can replace the vocal cord buzzing



The anatomy of speech: the vocal tract comprises the oral and nasal cavities. By changing the shape of these we change the frequencies and strengths of resonances to create different vowel sounds.

with sound of the ocean then we will hear that ocean producing the different vowel sounds produced by the changing resonance! But how, without performing some pretty drastic surgery, can we replace our vocal cords with a roaring sea? This is where electronics come in.

Firstly we need to capture our two sounds, the ocean waves and human speech, and then process and combine the electronic versions of the sound waves. The vocoder analyses the sound of the speech and works out at which frequencies the resonances occur. It does the same with the sound of the ocean, but it attempts to remove any resonances (i.e. it tries to ensure that the amplitudes of all of the different frequency components are the same). Then it applies the resonances it measured from the speech to the resonance-free version of the ocean. As those resonances vary over time so we hear the sound of the ocean talking: the vocoder has combined different attributes of two sounds to produce a single hybrid sound. Of course, it doesn't have to be the sound of the ocean; it can be any other sound. For example, by replacing the ocean with the sound from a synthesizer, a robotic effect can be created which has been used on many records over the last few decades.

If we apply the same method to remove the resonance of an oboe's body from its vibrating reed and then feed this sound into the resonance of flute's body, then we have a curious hybrid that is neither an oboe, nor a flute, more of a floboe really. For a hybrid to be effective and interesting it is usually best to find a sound that contains lots of different frequencies across a wide range and combine that with a sound that has distinct resonances. Its resonance that gives the character of one sound, but to hear that resonance there must be energy at being fed into it at (or near) those resonant frequencies.

Of course, we could attempt an acoustic hybrid of an oboe and a flute, by building a new instrument comprised of an oboe reed connected to a flute body, but this could be very time consuming and costly and the result might be impossible to play. Vocoding is probably a more cost-effective and controllable way to get into creating hybrid sounds!

Whilst analogue vocoders can achieve sound hybridisation with good results they can be expensive and bulky. Digital vocoders, with all the power and precision of modern computing behind them, can identify the resonances with much more accuracy and better separate these from the other parts of the sound. Many digital vocoders are available as 'plug-ins' for music technology software (such as Audacity, Reaper, Logic and Cubase) for recording and mixing sound, and some of these plug-ins are available for free. If you are interested in the fascinating world of combing sounds to create brand new ones then see if you can find some of these online.

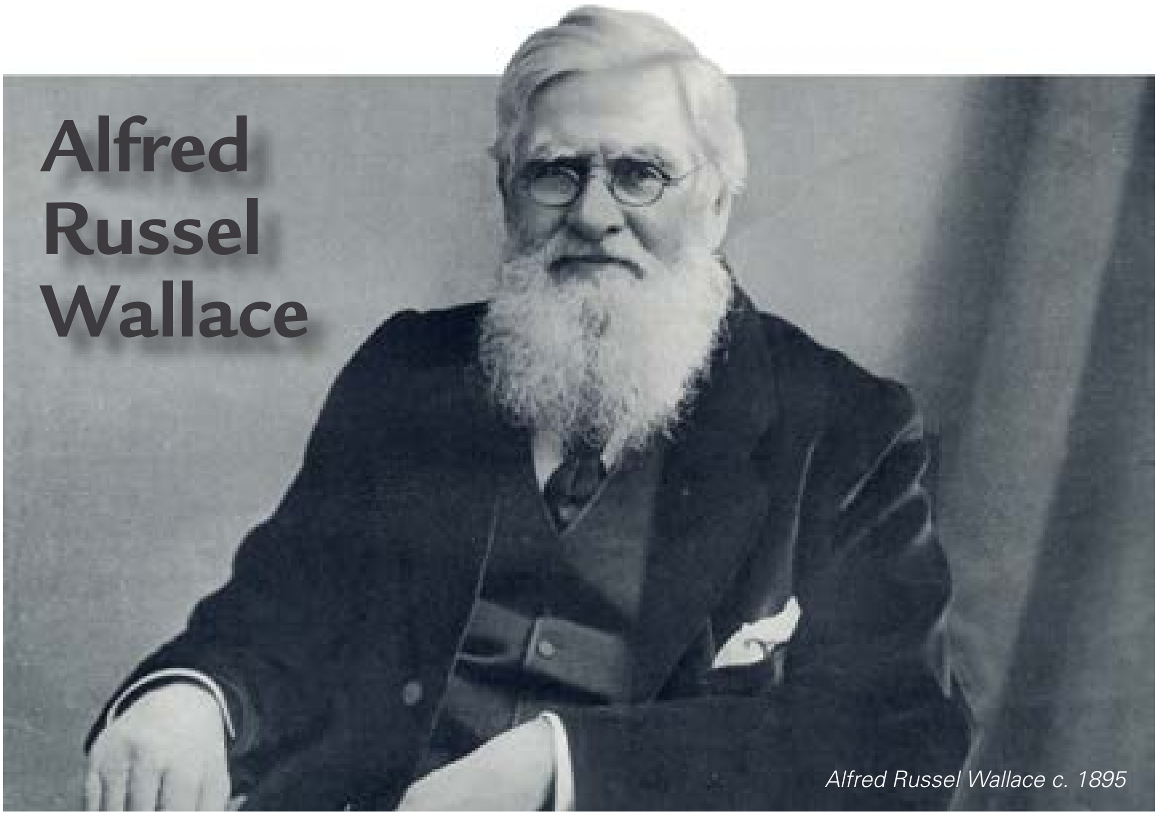
A horn-violin. Although common in countries such as Romania, this hybrid is unusual elsewhere in the world. Making hybrid instruments like this would be costly and difficult - electronic musical instruments offer much more convenience and flexibility in trying to combine the sound of two instruments.

Programs such as Audacity allow anyone to manipulate electronic sounds on a computer.

Jez Wells *teaches music technology at York University. He is also a recording engineer, DJ and composer: www.jezwells.org*

Alfred Russel Wallace

James Williams



Alfred Russel Wallace c. 1895

Alfred Russel Wallace (1823–1913) isn't a name many people know. As a scientist he was interested in lots of different things, from how different species came into existence to the question of whether ghosts really do exist. His greatest achievement was to come up with a theory of evolution suggesting that natural selection was how new species came into being. The theory of evolution is usually just credited to another great naturalist – Charles Darwin. The intriguing thing is that it was Wallace who sent his own theory of evolution to Charles Darwin asking if it was good enough to be published.

Young Wallace

Wallace was born on the 8th January 1823 at Kensington Cottage near Usk, Wales. He was the eighth of nine children.

When Wallace was five, his family moved to Hertford where he attended the local Grammar School. He was taught arithmetic, algebra, English grammar, geography, French and classics – but no science. Science in those days was not a subject studied in schools.

He left school at the age of 13 and joined one of his brothers, William, a surveyor. When work was scarce, Wallace practised his surveying skills (good training for fieldwork as a scientist). He wandered the countryside and, using a botany book, learned to identify many of the common plants he found.

For a while he taught at Leicester Collegiate School. Here he met another naturalist, Henry Walter Bates (1825–1892) and the two men became good friends.

In search of the Origin of Species

Using money saved from various work projects Wallace, with Bates, travelled to the Amazon. Unlike Charles Darwin, Wallace set out with the idea of coming up with a theory about the origin of species. During his travels he collected specimens of many new species. He also produced the first detailed map of the Rio Negro.

The trip lasted four years, but ended in tragedy. Wallace's younger brother, Herbert, had travelled to the Amazon to become a collector. Soon after arriving, he contracted yellow fever and died. Wallace was heartbroken and decided to pack his collection and head home.

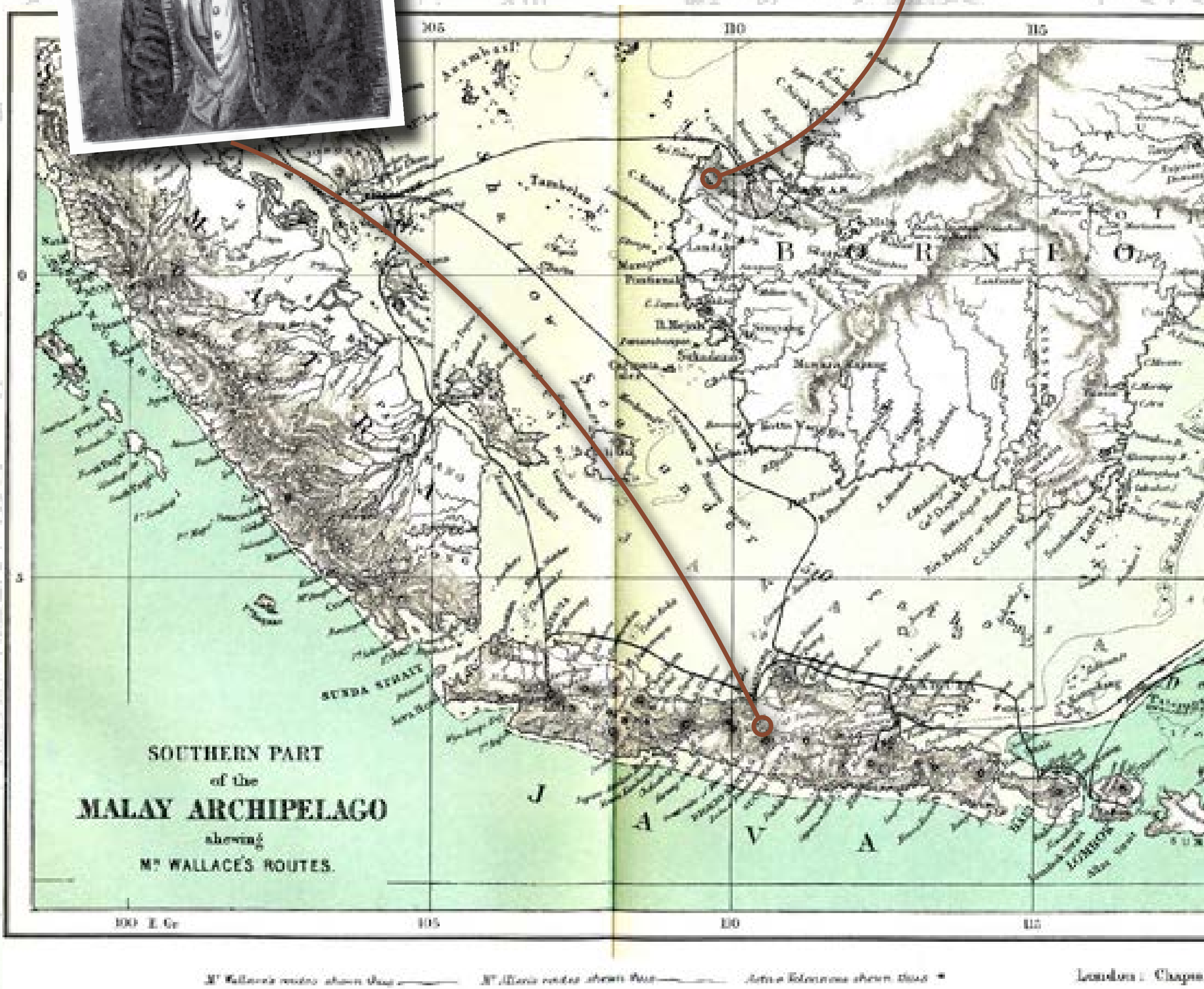
Twenty-six days into the voyage, part of the ship's cargo, balsam packed into wooden kegs, caught fire. The ship sank and all the cargo was lost, including all of Wallace's collections. He saved a few drawings of fish and palm trees, and the thin calico suit he was wearing. After 10 days adrift, the survivors were rescued.

ARW and the Malay Archipelago

In 1854, aged 31, Alfred Russel Wallace set off on an eight year journey of exploration of the Malay Archipelago (now Malaysia and Indonesia). He collected over 100 000 specimens, including thousands of species unknown to science. During this time, he came up with his theory of evolution.

Santubong in Sarawak where ARW wrote the first paper in which he mentions evolution. At this stage (September 1855), he understood the result of evolution but not yet how it might work.

◄ Illustration of a native of Java, from ARW's book *The Malay Archipelago*



The Island of Ternate in the Northern Moluccas. From here ARW sent Darwin his famous ‘Letter from Ternate’, including an article about evolution. The ideas in the letter came to Wallace whilst he was suffering from malaria. He wrote:

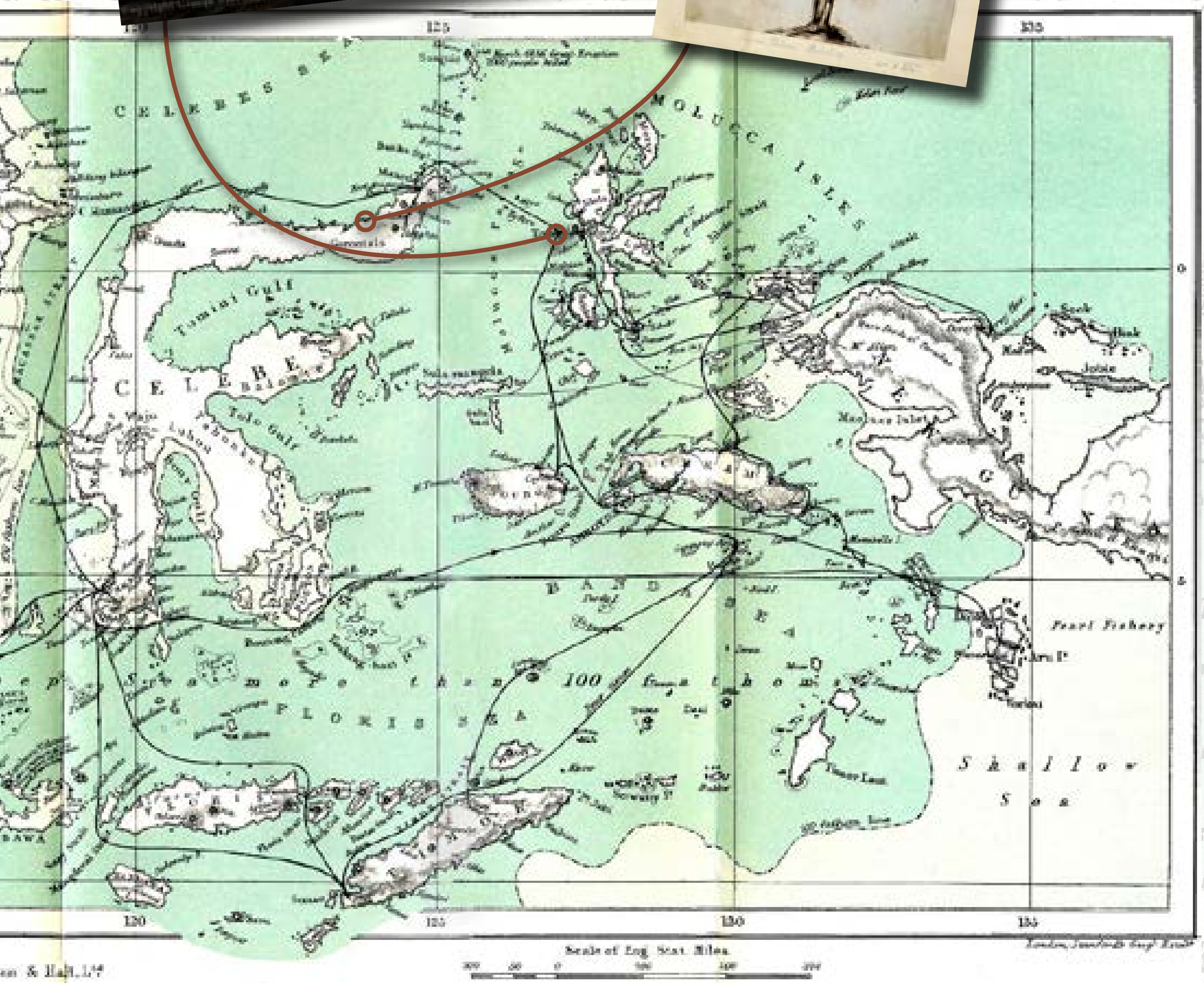
Then it suddenly flashed upon me that this self-acting process would necessarily improve the race, because in every generation the inferior would inevitably be killed off and the superior would remain—that is, the fittest would survive ... The more I thought over it the more I became convinced that I had at length found the long-sought-for law of nature that solved the problem of the origin of species.

Catalyst

www.catalyststudent.org.uk

For lots more information about Wallace’s life and work see the Wallace Memorial Fund’s website http://wallacefund.info/

Drawing by ARW of a sugar palm on Celebes (now Sulawesi) from *The Malay Archipelago*



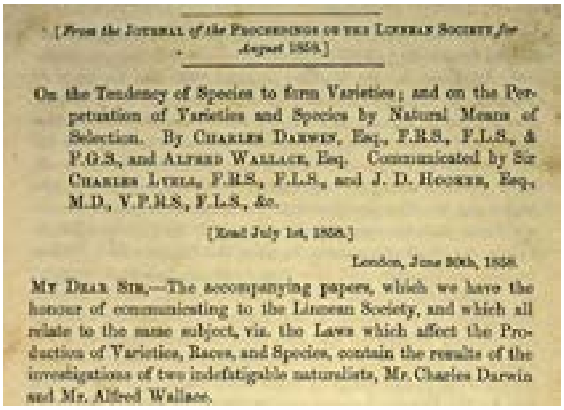
Wallace's theory of evolution

In February 1858, while suffering from malaria, Wallace was suddenly struck by an idea of how evolution works. His idea was remarkably similar to the idea of natural selection which was separately being developed by Charles Darwin. The following June he sent an essay outlining his ideas to Darwin.

This caused Darwin a great deal of anguish. How could he publish his theory of evolution knowing that Wallace had hit upon the same idea? Darwin's friends, the geologist Charles Lyell and the botanist Joseph Hooker came to his rescue.

In July 1858 both men's ideas were presented to the Linnean Society of London and in August a scientific paper containing Wallace's and Darwin's ideas was published. Darwin then set out to write his now famous book, On the Origin of Species, published in November 1859.

Wallace was unaware of what was happening back in London. Yet at no point did he ever complain that 'his' idea had been stolen. In fact he felt honoured to have been published alongside Darwin.



[*From the* Journal *of the* Proceedings of the Linnean Society *for August* 1858.]

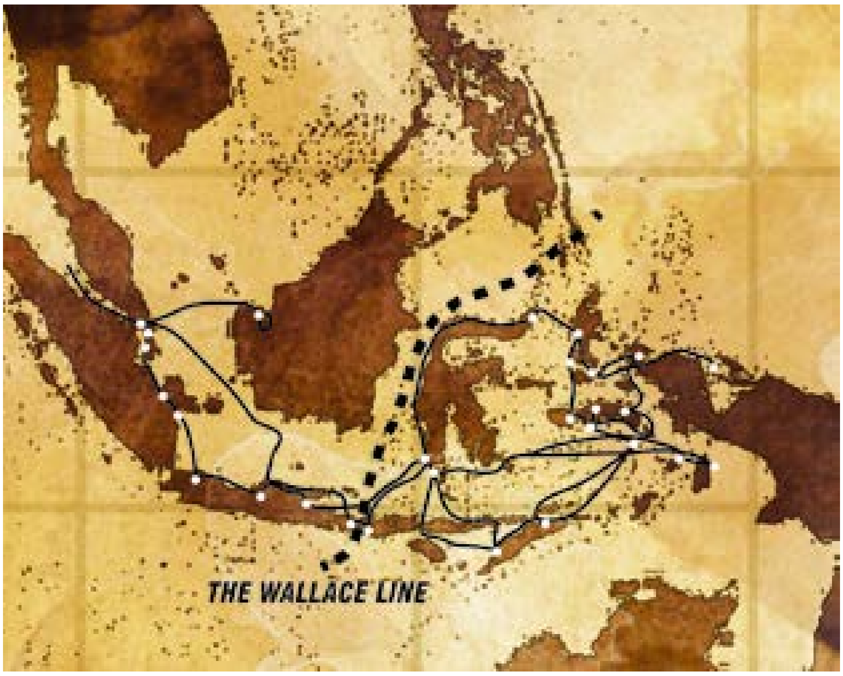
On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection. By Charles Darwin, Esq., F.R.S., F.L.S., & F.G.S., and Alfred Wallace, Esq. Communicated by Sir Charles Lyell, F.R.S., F.L.S., and J. D. Hooker, Esq., M.D., V.P.R.S., F.L.S., &c.

[Read July 1st, 1858.]

London, June 30th, 1858.

My Dear Sir,—The accompanying papers, which we have the honour of communicating to the Linnean Society, and which all relate to the same subject, viz. the Laws which affect the Production of Varieties, Races, and Species, contain the results of the investigations of two indefatigable naturalists, Mr. Charles Darwin and Mr. Alfred Wallace.

Darwin and Wallace's joint 1858 paper on natural selection



A modern map of ARW's travels. He drew the 'Wallace Line' separating two regions with very different populations of plants and animals.

Psychics and spiritualism

While in Leicester, Wallace discovered 'psychical research' and 'mesmerism'. He found that he was good at hypnotising people. This led to an interest in spiritualism. When he returned from the Malay Archipelago he attended séances, witnessed door 'rapping', 'tapping' and table movements. He also claimed to have seen these under 'test conditions'.

At first he thought that reports of mediums contacting the dead and séances were the ravings of madmen. But having witnessed some of the phenomena in person, he was more persuaded. He recorded his observations in a letter which he sent to TH Huxley, another well-known scientist who frequently defended Darwin's ideas. Huxley wrote back:

"I am neither shocked nor disposed to issue a commission of lunacy against you. It may be true, for anything that I know to the contrary, but really I cannot get up interest in the subject."

Wallace wasn't trying to persuade other scientists that spiritualism was true. What he wanted to do was encourage scientific investigations of the phenomenon.

Alfred Russel Wallace was one of the great Victorian naturalists. The science of biology owes him a great debt of gratitude.

A spirit photograph featuring Alfred Russel Wallace and the 'spirit of his mother', taken on 14th March 1874.

James Williams is a lecturer in science education at the University of Sussex. Thanks to Dr George Beccaloni of the Wallace Memorial Fund for supplying the images used in this article.

Talkative microbes
A route to new antibiotics

Suzy Moody

Streptomyces bacteria – the red colour shows the presence of a membrane-bound antibiotic which is released into the growing media when the cells get old.

Key words
bacteria
antibiotics
health
drug development

When you think of bacteria and fungi, you don't tend to think of them being particularly talkative, social organisms. In fact, microbes are constantly communicating with each other, their neighbours and the environment. ***Suzy Moody*** *explains.*

Microbial communication happens by small bioactive molecules which the cells release into and receive from the environment. In this way, they gather valuable information about what is going on in the world around them and then respond appropriately. While our knowledge of the phenomenon of microbial signalling is not new, the impact this constant stream of information has on medical microbiology and the hunt for new antibiotics is only just being understood.

Professor Dame Sally Davies (the Chief Medical Officer for the UK) recently described the threat from antibiotic resistant infectious disease to the welfare of UK citizens as on a par with the terrorist threat. The indiscriminate use of currently available antibiotics in agriculture and predominantly in

In response to its environment, this colony of Streptomyces coelicolor *has produced beads of bioactive compounds (molecules that have an effect on living cells).*

Morbidity means the rate of incidence of a particular disease.

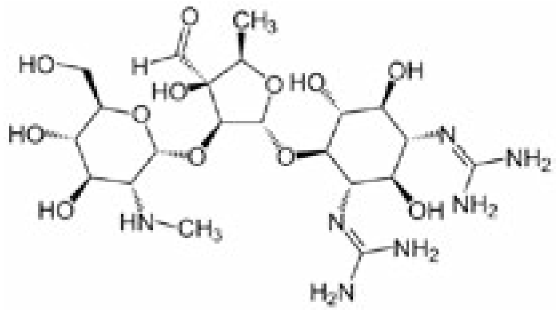
medicine has led to many common pathogens developing multi-drug resistance, making their treatment and eradication from the body impossible. The mortality and morbidity rates associated with multi-drug resistant infection are increasing steadily as a result, and new classes of antibiotics are urgently needed to treat people effectively. How can microbial signalling help in this situation?

Growing together

In the laboratory, microbes are usually grown in monoculture. i.e. one species is grown in isolation in a flask or on a plate. This is a very artificial scenario as in nature microbes are do not live on their own; they form mixed communities of several different species in one ecological niche. These communities signal to each other, and produce all sorts of compounds in response to their neighbours and changes in the immediate environment. Scientists have now realised that many of the pathways microbes have for production of useful compounds are switched on as a result of this interactive lifestyle, and indeed many of the signalling molecules themselves, when purified, act as potent antibiotics. By growing microbes in monoculture in the laboratory, we have missed a whole raft of bioactive molecules that are only produced when the microbes are grown in mixed culture.

A microbiologist plating bacteria. Using single colonies of bacteria have led to many interesting compounds being missed.

Over 60 % of all clinically used antibiotics are derived from a single genus of bacteria, the *Streptomyces*. These bacteria have been intensively studied following the discovery, more than sixty years ago, that *Streptomyces griseus* produces an antibiotic, streptomycin, which was the first successful anti-tuberculosis antibiotic. It is still in use today.



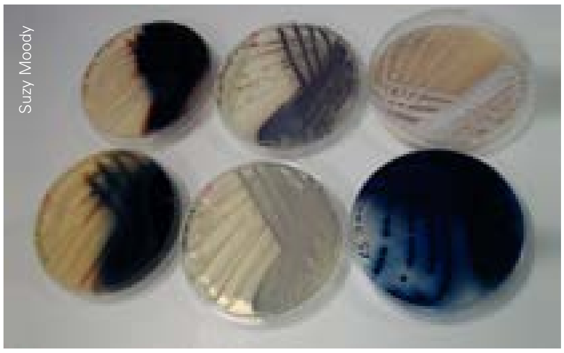
The molecular structure of streptomycin, the first anti-tuberculosis antibiotic. It was discovered by a student, Albert Schatz, in 1943.

Since then, many *Streptomyces* species have been found to produce bioactive molecules useful to humans. Many of the compounds have applications in both medicine and veterinary use, and include antibacterial, antifungal, antiprotozoal, and anticancer drugs, as well as immune suppressants. Yet even in this well-studied genus, growing these bacteria in mixed culture has already proved fruitful with novel compounds being produced.

Microbes interacting

What makes this so very interesting is that the mixture of compounds produced by some species depends on which other species it is cultured with. In other words, these bacteria send out different signals and produce different molecules depending on who is in the neighbourhood. For a microbiologist, it is really exciting to realise how interactive these organisms are and how much detail they can detect in their environment.

Streptomyces are often used in antibiotic discovery



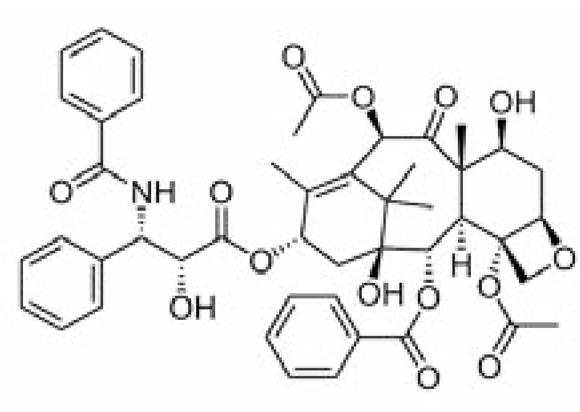
Streptomyces coelicolor *produces a range of coloured antibiotics depending on the medium it is grown on. Changing the content of the medium has been a key part of antibiotic discovery. The red and blue pigments seen here are coloured antibiotics, and whether they are produced depends on what they are grown on.*

programmes because the genomes of *Streptomyces* species that have been sequenced show coding for numerous proteins needed to make all sorts of antibiotics and other interesting compounds. While genome sequencing has revealed the possibility of making these molecules, it does not tell us how to switch on the pathways to produce these bioactive molecules in the laboratory. Mixed culture techniques, where more than one species is grown on a plate at a time, may now give a new approach to activating some of these mysterious pathways so that new molecules are produced by the bacteria. Mixing *Streptomyces* with more distantly related bacteria can also prompt novel antibiotic production. Bacteria such as *Rhodococcus* and *Corynebacteria* contain an unusual molecule, mycolic acid, in their cell wall. Mixing these mycolic acid-containing bacteria with *Streptomyces* has also led to the production of novel antibiotics by the *Streptomyces* species.

Some of the compounds produced by Streptomyces *that are used in medicine. Compound names are shown in black, the class of compound is shown in blue.*

Fungi talking

The role of signalling in switching on the production of new molecules is not only found in bacterial species – fungi exhibit the same properties. *Paraconiothyrium* is a fungus that inhabits yew trees and it is responsible for production of the potent anti-cancer drug paclitaxel. Using two other fungi that also live on yew trees in a mixed culture has led to large increases in the amount of paclitaxel produced.



The molecular structure of paclitaxel (tradename Taxol). The complex structure of many bioactive molecules prevents them being made synthetically. We rely on bacteria and fungi to make many of our pharmaceuticals.

Streptomyces bacteria – *the blue pigment is an antibiotic produced by the bacteria which is released into the growing media.*

Another fungal example is *Candida albicans*. This is a yeast which sometimes lives on human skin and can cause disease. This fungus was cultured with some fungi that live on the skin and do not harm the person. In the mixed culture, *Candida albicans* produced a whole selection of known and new compounds, some of which have potent antimicrobial activity.

A promising approach

This new approach to switching on antibiotic production pathways is really promising. Not only does is tell us a huge amount about the ecology and social life of microbes, it promises a relatively easy way of searching for new antibiotics. Traditional approaches to antibiotic discovery have involved large screening programmes, trial and error with culture conditions, complex genetic engineering or isolation of new organisms from increasingly inhospitable environments. The mass of genome sequencing data being accumulated, while useful in identifying possible antibiotic pathways, has also become a source of frustration to scientists as switching these biosynthetic pathways is very difficult.

The mixed culture approach is offering a new, simple way to explore the bacterial world for compounds that can be used as pharmaceuticals. Most of the species mentioned here are common organisms worked on by many laboratories. Mixing appropriate 'neighbours' in the laboratory and analysing the compounds made has already led to the discovery of new bioactive molecules. By recognising that microbes are social organisms, designed to communicate with each other, we can harness their signalling and response behaviour in our search for much needed new antibiotics.

Suzy Moody is a microbiologist at Swansea University who has worked on both bacteria and fungi.

All illustrations in this article courtesy of the author.

Try This

Making ice cream without a freezer

You can freeze an ice cream mixture using ice and salt rather than a freezer.

You will need:

- 1 tablespoon sugar
- 120 ml milk, 120 ml double cream
- ¼ teaspoon vanilla extract
- About 1 kg ice cubes
- 7 tablespoons salt (see below)
- 2 re-sealable food bags (e.g. zip-lock)
- Towel
- Bowl or large jug
- Whisk

(The salt with big crystals used in salt grinders is best; if you use normal table salt add another couple of spoonsful.)

What you do

Whisk the milk, cream, sugar and vanilla in a bowl or large jug. Pour the mixture into one of the re-sealable bags and set it aside.

Put some of the ice and the salt into the second bag. Put the sealed bag with the ice cream mixture inside the ice bag and then add more ice and salt. The ice cream mixture should be sealed in its bag and not get in contact with the salt.

Wrap this bag in a towel and shake until the cream mixture has frozen. This will probably take about 10 minutes. Eat it straight away.

The ingredients

Look here!

Ice cream can be made even faster using liquid nitrogen, which is at -196 °C. Look here to see the chef Heston Blumenthal and a record breaking litre of ice cream: *http://tinyurl.com/q6bvkfb*

How it works

Ice has to absorb heat energy in order to melt and change from a solid to a liquid – it is an endothermic process. If you hold ice, you can feel your hand get cold as the ice absorbs heat from your hand. In the same way, the heat from the ice cream mix is absorbed by the ice and so it cools and freezes.

When you add salt to the ice, it lowers the freezing point of the ice, so even more energy has to be absorbed from the environment (and the ice cream mix) in order for the ice to melt. This makes the ice colder than it was before, which is how your ice cream freezes. You use large salt crystals as they take more time to dissolve in the water around the ice, which allows for even more cooling of the ice cream.

Vicky Wong is Chemistry editor of Catalyst.

Whisk the ice cream mix and place inside a bag. Place this bag in a second bag filled with ice and salt.

Ice cream mix in a bag

Ready to eat

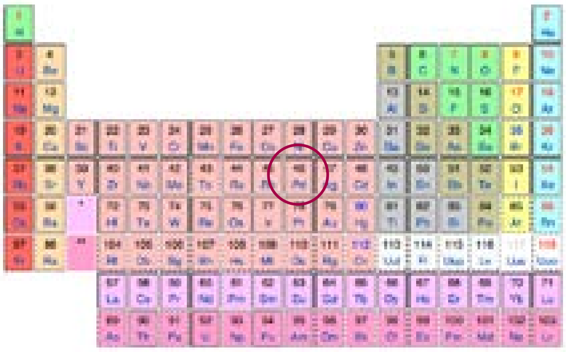
Focus on palladium

Nessa Carson

ppart/bigstockphoto.com

What do dental fillings, catalytic converters, mobile phones and jewellery have in common? They all make use of the metal palladium.

Palladium (chemical symbol Pd) is a precious metal found in the transition metal series of the Periodic Table. With a low relative abundance, there is just over 200 tonnes of this rare element available for use on our planet. However, palladium is needed for a huge range of applications, and particularly valued by scientists as a catalyst for chemical reactions.



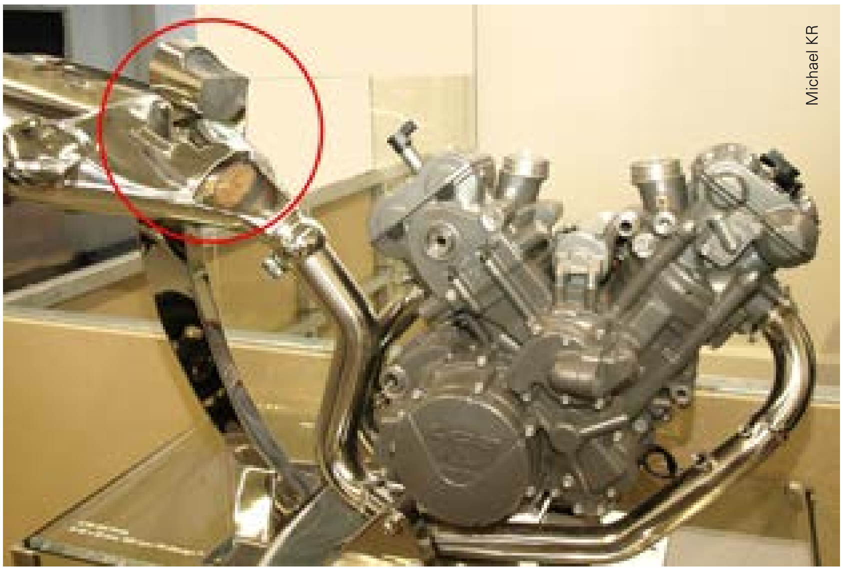
Palladium is in a group of the periodic table with nickel and platinum. Like them, it is used for a diverse number of applications including jewellery and catalysts.

Palladium can react with up to 900 times its own volume of hydrogen gas (H_2), mostly without changing the metal's physical properties. When the palladium-hydrogen product is heated, the hydrogen is released again, returning to its original volume so it can be used. Chemists are studying the way that palladium does this in order to mimic it in new devices to store hydrogen for use as an environmentally-friendly replacement for petrol and diesel.

Transition metal catalysts, such as palladium, are of interest because they can change the number of other atoms they are connected to at any time (this is called their valency). Molecules which are bound to the metal can undergo reaction much more easily than an unbound molecule. The molecule then separates away as a changed product. In this process, the molecule is reduced or oxidized - electrons are transferred either to or from the molecule. In a catalytic cycle where the metal is not used up, the palladium then regains its original valency. Thus, a tiny amount of palladium can make product from a large amount of substrate molecule.

A crystal of palladium with a mass of about 1g and about 1cm in length

Unreacted palladium metal has its greatest use in catalytic converters. These are employed in cars and other vehicles to reduce the amount of toxic and environmentally damaging pollutants that emerge from the exhaust pipe. For example, palladium transforms the damaging greenhouse gas nitrous oxide (N_2O), found in exhaust gases, to nitrogen (N_2) and oxygen (O_2) gases which are non-toxic and already common in the atmosphere. It also accelerates the very slow reaction of deadly carbon monoxide with atmospheric oxygen into the far less dangerous gas carbon dioxide.



The engine from a KTM 990 Super Duke motorbike, showing the catalytic converter

Palladium is also used in fine jewellery. It has a similar look to platinum but although it does not tarnish, it forms a faint bronze-coloured patina (oxide coating) when exposed to water vapour in the air. It can also be alloyed with gold to form a mixture called white gold. At less than half the price of platinum, palladium is becoming a very popular jewellery metal. These same properties also make the metal useful in dental fillings.

Ear-rings made from white gold, an alloy of gold and palladium; the gemstones are diamond and emerald.

A one ounce ingot of high purity palladium – a valuable commodity

Many rare metals, including Pd, are used in microelectronics for devices such as mobile phones and laptop computers. With increasing demand for more and more functions per device, components have to get smaller, requiring the use of specialized metals such as this. As such devices are now everyday objects the recycling of their rare metal components is now becoming paramount to their continued production. 'Urban mining' refers to the recycling of everyday personal devices for the tiny amounts of metal they have in their components – recycling your mobile phone is imperative for the future of technology.

Palladium is mined in Russia, South Africa and the Americas. It occurs naturally as an alloy (mixture of metals) with other precious metals such as gold or platinum, from which it must be separated by electrolysis before use. Although electrolysis is usually reserved for the extraction of the most reactive metals, it is also appropriate for the separation of two fairly similar metals, which would otherwise be difficult to separate.

Despite the appeal of this metal for all these purposes, supplies of palladium are running out, and the efforts to find cheaper alternatives are increasing. Chemists are developing catalysts made from cheaper metals such as iron and cobalt as alternatives to palladium. However, the usefulness of this beneficial metal is not due to run out any time soon. Recycling will mean that chemists as well as car-drivers and jewellery-wearers will be able to use it for decades to come.

Nessa Carson is a British postgraduate chemistry student at the University of Illinois. She works with metals – including palladium – as catalysts to invent new chemical reactions.

What is a scientific conference?

Caroline Wood

Key words
conference
communication
physiology
publishing

With so many research groups across the world, it can be difficult for scientists to keep on top of the latest developments and findings. As well as publishing in journals (such as Nature or Science), researchers communicate their results at scientific conferences. These range in size from small, specialist meetings of about 20 people, to huge international events attended by thousands. So what exactly happens at these gatherings? ***Caroline Wood*** *reports from the 37th meeting of the International Union of Physiological Sciences (IUPS), held in July 2013 in Birmingham.*

A small, specialist scientific meeting may attract about 20 people. The IUPS 2013 meeting was much bigger than that – over 3000 people attended. It was held at the International Convention Centre in Birmingham. Physiologists study how living organisms function; in particular, how organs, cells and tissues work to carry out essential life processes.

The entrance to the IUPS 2013 meeting, at Birmingham's ICC

The stairs are marked to show the long history of IUPS conferences, held every four years.

Arrival and registration

Delegates typically register months in advance. They sign in and collect their welcome pack on arrival. Conferences are advertised in scientific journals or through posters and emails sent to research departments. Some are singular, one-off events whereas others occur on a yearly basis; the IUPS conference happens every four years and requires considerable preparation, as Nick Boross-Toby, Director of Events and Marketing for IUPS explains:

"IUPS 2013 was eight years in the planning. An event of this nature; including over 100 symposia, 35 keynote lectures, 700 speakers and over 3000 participants requires meticulous attention to detail, a robust project plan and a very thick skin! This was truly a team effort involving every single member of the Society's staff, a number of Society Members and our superb team of volunteers."

Delegates sign in and collect their welcome packs.

The conference programme

Each delegate is given an Abstract Book which includes a short summary for each seminar and lecture. At a large conference, multiple sessions may be held at once, so attendants must choose which events best suit their research interests. The Abstract Book also contains an inventory of the poster displays, allowing scientists to find colleagues working on similar topics.

Delegates study the conference programme at IUPS 2013.

Plenary lectures

Each day is usually divided up into plenary lectures and seminars. At plenary lectures, distinguished scientists are invited to speak on a keynote topic of broad interest; as these are attended by many delegates they are held in the main auditorium. At IUPS 2013, the plenary lecture themes included the circadian clock, the effects of hypoxia in the womb, and the ecological impacts of climate change.

Plenary lectures were held in the main auditorium at IUPS 2013.

Seminars

Research seminars cover more specific topics than plenary lectures and are held in smaller rooms. They consist of a series of short talks, each lasting between 20-45 minutes, given by leading experts in the field. Each speaker describes the latest findings from their laboratory and what they hope to investigate in the future. After every talk the floor is opened for discussion and the audience is invited to ask questions. This is a valuable way for scientists to share ideas and research strategies. Dr Daniel Whitcombe, speaking at IUPS 2013 on the physiological basis of Alzheimer's disease, describes the process of compiling a talk for a research seminar:

"You're given an indication of a remit...the next part of the process is thinking about what you want your key message to be. Often you have very limited amounts of time to explain to an audience not as familiar with your research as you are. The main challenge is to put across your message in a simple, clear, concise way."

Public outreach

Some conferences hold public outreach events to promote their particular branch of science. At IUPS 2013, a mobile 'lab in a van' offered the public the chance to measure their lung volume, estimate their fitness with a heart rate monitor or explore the structure of the inner ear using a giant model. Hannah King, from the University of Bristol and one of the organisers of the mobile van, enthused:

"It's a really good way to link universities and real scientific research to the general public. They might give money to a charity for research into a disease and this is a good way for them to meet real scientists to see where that money goes. It gives children hands-on activities that they may not get the opportunity to do in schools. By raising awareness in the public of how their bodies work, hopefully we can inspire them to make better choices about how they live their lives."

Hands-on activities at the 'lab in a van' at IUPS 2013

A visitor has their blood pressure measured.

Posters

Most conferences give the opportunity for PhD students and early career scientists to present their work in the form of posters. Each person is given a specific session where they must be present to "defend" their poster and answer questions from those who are interested in their work. These are good networking opportunities, as they allow young scientists to meet researchers from labs they may like to work with in future. Prizes are usually awarded to the best posters, with the judges often being selected from the speakers at the research seminars. Dr Susan Deuchars, from the University of Leeds and a poster judge at IUPS 2013, describes what she looks out for:

"The presenting student must be able to justify their approaches and put their results in the context of the work of others and have feasible ideas for moving their research forward. There should be one strong message, the poster shouldn't be over-cluttered."

The poster exhibition at IUPS 2013; prizes are awarded for the best posters presented by students.

Trade stands

Larger conferences often invite companies producing scientific equipment to exhibit their wares, giving researchers the opportunity to try out the latest, cutting-edge technology. Scientific journals may also have stands to encourage scientists to publish their results with them. Libby Collingburn, European Manager of the company Proteintech ™ explains how conferences are a vital link between researchers and companies:

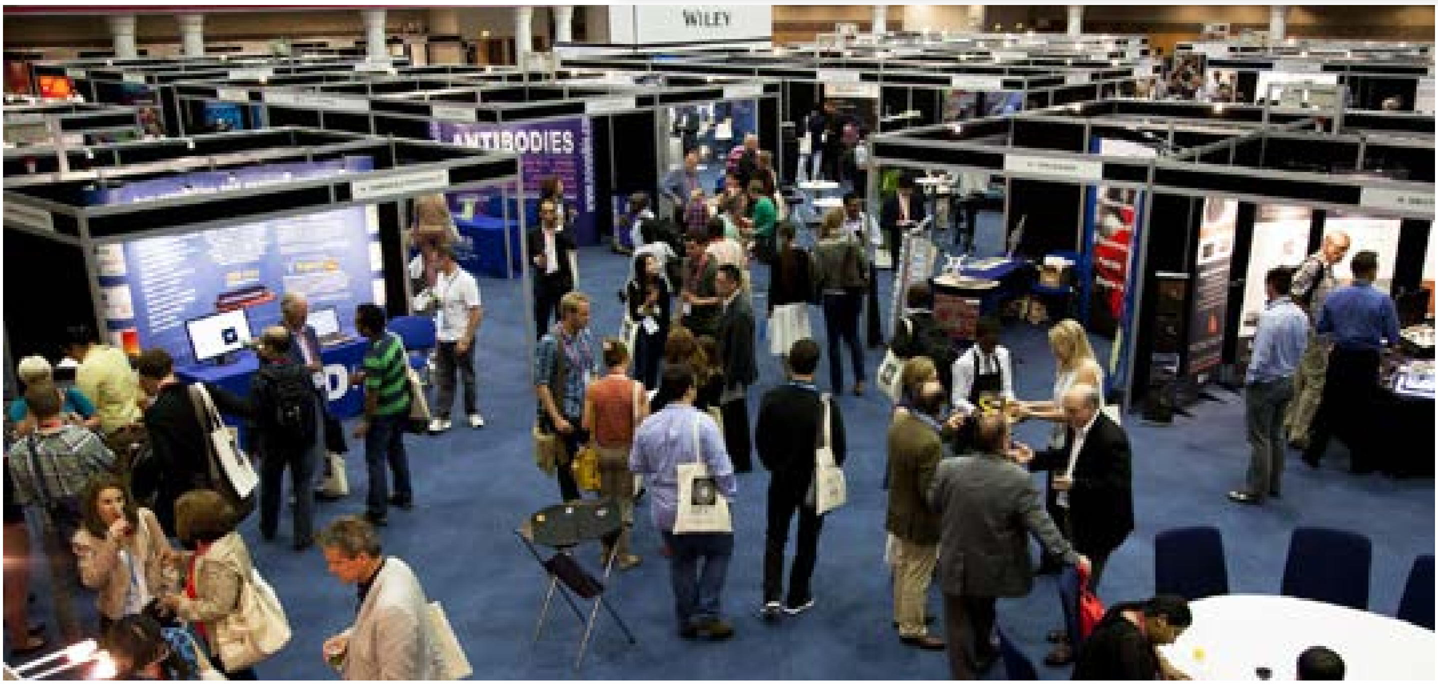
"(Hosting a stand at a conference) gives the opportunity to meet scientists doing real work at the forefront of research and to discover the new techniques and applications they are working on and how your products are involved. It also means that we can open up to the brand to a wider audience."

Trade Stands at IUPS 2013

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

Look here!

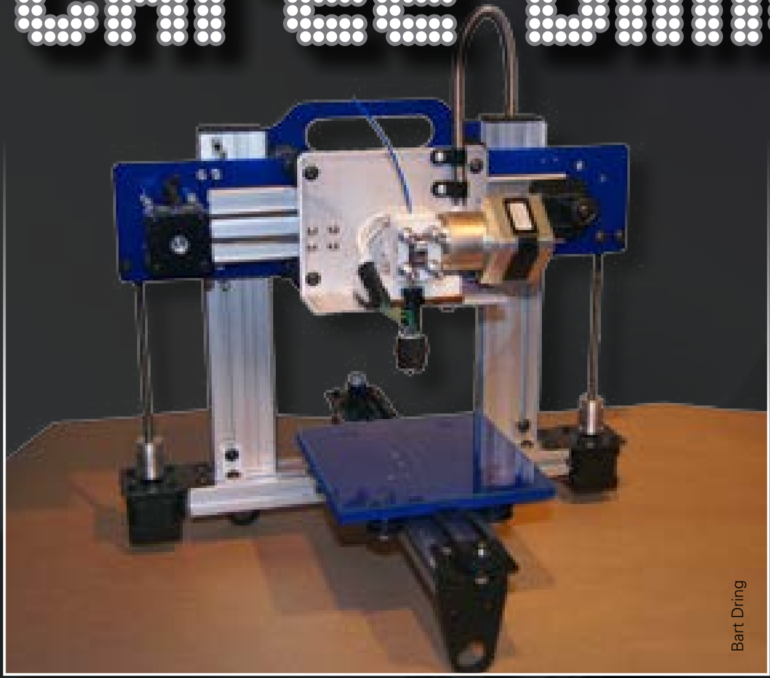
It must be true – I read it in the paper! Catalyst September 2007 pp 16-17
Publish or perish – Getting into print Catalyst September 2009 pp 9-12



The hall where commercial organisations exhibited their wares at IUPS 2013

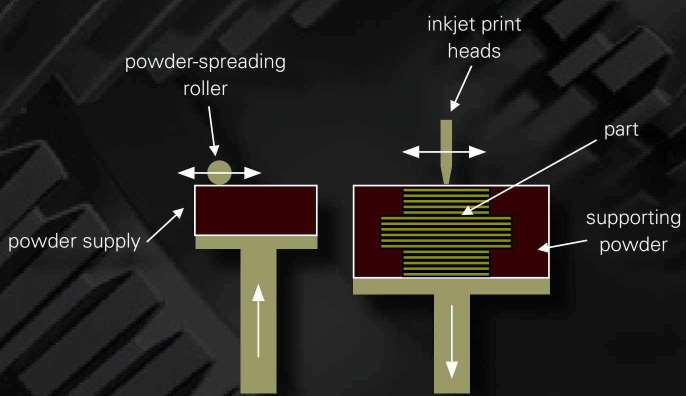
Printing in Three Dimensions

3D printing is a new technology which is rapidly finding applications. It's probably too slow for mass production but it is useful for producing prototypes and tailor-made items.



Up and down, back and forth A 3D printer, showing the nozzle through which polymer beads are passed to form the printed object. The position of the nozzle is controlled in three dimensions by a computer.

Accurate copy A 3D laser scanner images a Viking belt buckle. The data file was used to 3D print a replica of the buckle.



Now for metals Metals can also be used in place of polymers. This test piece is made of titanium; its dimensions are accurate to one millimetre.

How it works In a 3D printer, layers of polymer beads are printed one on top of the other. Heat melts the polymer beads so that they form a solid structure. A powder is used to fill spaces where no polymer is required and is removed later.

In the future The European Space Agency is devising a 3D-printed lunar base for astronauts on the Moon. They set up a tubular structure; a 3D printer then covers it with layers of lunar soil. A salt solution binds the particles together to form a rock-hard solid.

Better bodies 3D printing is allowing rapid production of replacement body parts. Jake Evill of Victoria University, New Zealand, devised this cast for a broken arm. The design can be adapted to give a precise fit to the individual patient.