Catalyst

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Icy laboratory

Working in Antarctica

SEP
Science Enhancement Programme

Catalyst

Volume 18 Number 4 April 2008

The front cover shows an Antarctic research scientist wearing protective clothing to prevent contamination of ice cores (see the article on pages 9-12) (JG Paren / Science Photo Library)

Contents

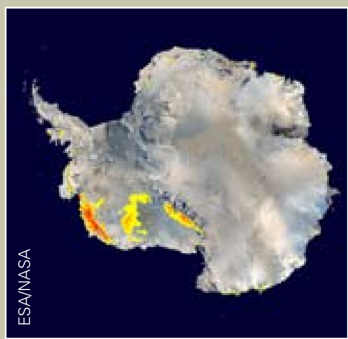
Science, pure and applied

The picture below is the latest satellite image of Antarctica, the Earth's southernmost continent. The image has warned scientists that the ice is melting much more rapidly than before, a sign of global warming. Because the ice sits on top of rock, when it melts and flows into the oceans, it will contribute to rising sea-levels (unlike the Arctic ice, which floats on the sea).

This issue contains three linked articles:

- The Big Picture (pages 9-12) looks at what we can learn about our changing atmosphere from studies of Antarctic ice cores.
- Eric Wolff's Life in Science (pages 4-5) describes the work of one of the scientists who analyses and interprets these ice cores.
- David Catling's article (pages 16-18) tells us about the 4.5 billion year history of the atmosphere.

Finding out about the Earth's geological past is a fascinating detective story, with many vital clues still to be turned up.



Red and yellow areas on this satellite image of Antarctica show where ice is melting most rapidly.

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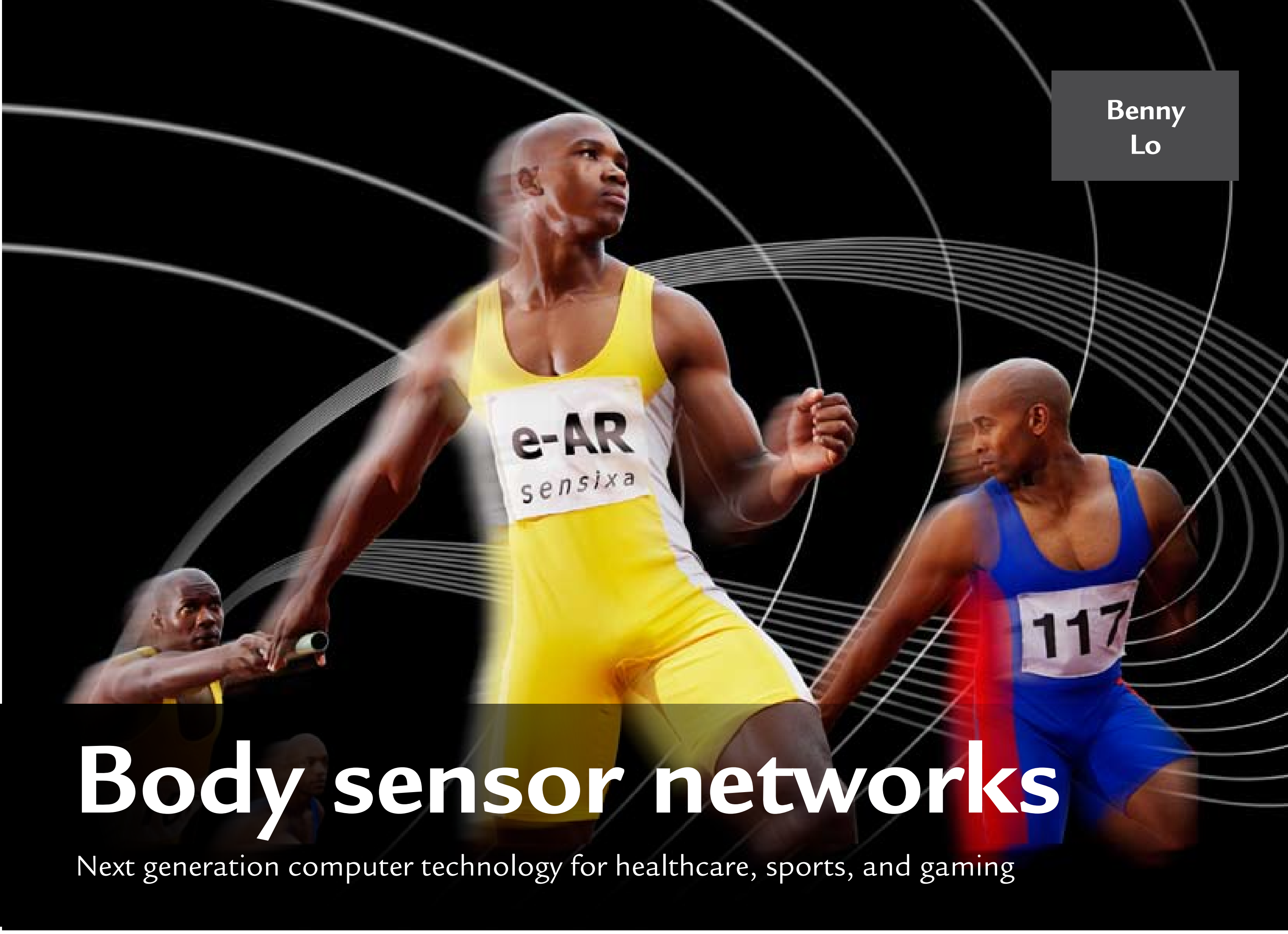
Benny
Lo



Body sensor networks

Next generation computer technology for healthcare, sports, and gaming

As electronic devices get smaller and more powerful, they are finding new uses in monitoring human activity. In this article, Dr Benny Lo of Imperial College London describes a project to develop sensors with uses in medicine, sport and electronic gaming.

Key words
sensor
processor
wireless communication

Some patients, especially patients with chronic diseases such as heart disease, require continuous monitoring of their condition. Wearable devices for patient monitoring were introduced many years ago – for instance, wearable ambulatory ECG (electrocardiogram) recorders commonly known as Holter monitors (Figure 1) are used for monitoring cardiac patients. However, these monitors are quite bulky and can only record the signal for a limited time. Patients are often asked to wear a Holter monitor for a few days and then return to the clinic for diagnosis. This often overlooks transient but life-threatening events. In addition, we don't know under what condition the signals are acquired, and this often leads to false alarms. For example, a sudden rise in heart rate may be caused by emotion, such as watching a horror movie, or by exercise, rather than by a heart condition.

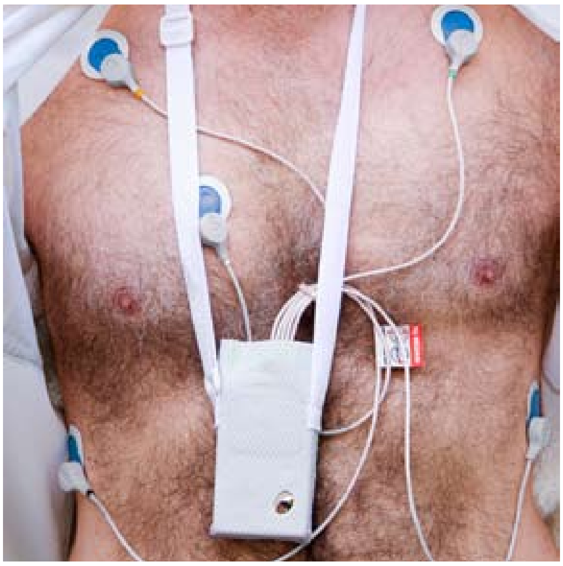

Sheila Terry/SPL

Figure 1 *A patient wearing a Holter monitor (a portable electrocardiogram).*

Body sensing

To address these issues, the concept of Body Sensor Networks (BSN) was first proposed in 2002 by Prof. Guang-Zhong Yang from Imperial College London. The aim of the BSN is to provide a truly personalised monitoring platform that is pervasive, intelligent, and

The chip in your mobile phone has more computing power than the first generation of desk-top computers in the early 1980s.

invisible to the user. Figure 2 depicts an example BSN system. It represents a patient wearing a number of sensors on his body, each of which consists of a **sensor** connected to a small **processor**, wireless **transmitter**, and **battery pack**, forming a **BSN node**. The BSN node captures the sensor data, processes the data and then wirelessly transmits the information to a local processing unit, shown as a personal digital assistant (PDA) in the diagram. All this has been made possible by rapid advances in computing technology.

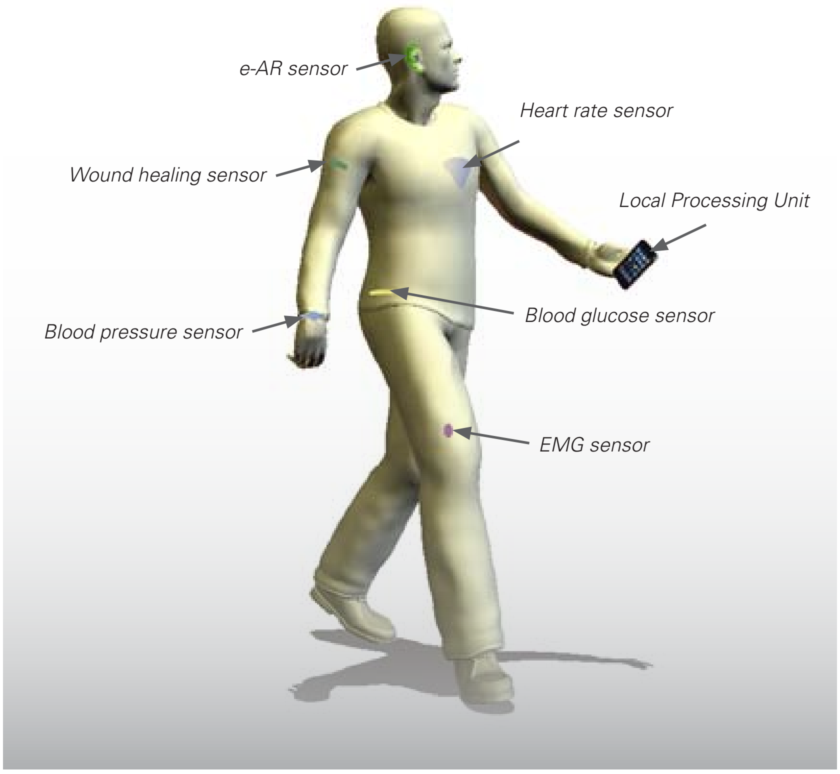


Figure 2 *An example Body Sensor Network (BSN) system*

To demonstrate the concept, different sensor nodes are depicted in the diagram. These are:

- the e-AR (ear-worn Activity Recognition) sensor (for capturing the posture, gait and activity of the patient)
- the wound healing sensor (for monitoring the progress of healing for burn patients)
- the blood pressure sensor (for measuring the blood pressure for patients with hypertension)
- the EMG (electromyography) sensor (for capturing the muscle activities of orthopaedic patients)
- the blood glucose sensor (for measuring the glucose level of diabetic patients)
- the heart rate sensor (for detecting abnormal heart conditions of cardiac patients).

Sensing activity

Following the concept of the BSN, a number of novel devices have been proposed. One example is the Imperial e-AR (ear-worn Activity Recognition) sensor. Physiological measurements, such as the body temperature and heart rate, are important. However, the mobility and activity of patients are also important indicators of health. For instance, the level of activity of a patient after surgery is often used to assess the recovery process after surgery. To enable the sensing of daily activities, the e-AR sensor was developed. Figure 3 shows the design of the sensor and how it can be worn by the user. The ear worn sensor is basically a tiny computer with a sensor and a wireless communication link.

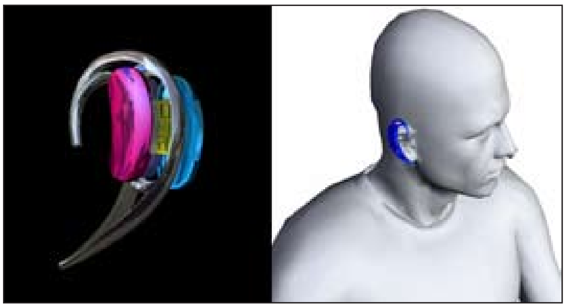


Figure 3 *The e-AR (ear-worn Activity Recognition) sensor*

The design of the e-AR sensor was inspired by the human inner ear. The human inner ear consists of an auditory system (the cochlea) and a balancing (vestibular) system, as shown in Figure 4. Within the vestibular system there are two sensory mechanisms, called the semicircular canals and the otoliths for sensing the rotational and translational motions. The semicircular canals consist of three half-circular interconnected tubes positioned in three near-orthogonal planes for sensing the three degree of rotations. Inside the canals, there are many tiny little hairs (cilia) and canals are filled with a fluid called endolymph. When the head rotates, the fluid flows along with the rotation and bends the little hairs inside the canals. This sends a signal along nerves to the brain where it is translated into the sense of the rotation. The otoliths, on the other hand, consist of the saccule and utricle for sensing the vertical and horizontal movements. Similar to the semicircular canals, the vertical and horizontal translations are also captured by tiny little hairs with fluid movements inside the saccule and utricle.

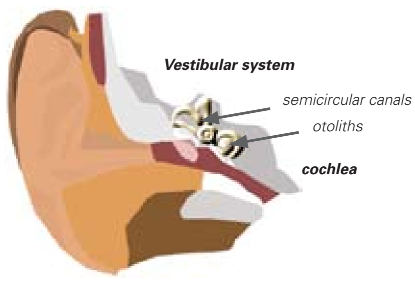


Figure 4 *Human inner ear*

To emulate the sensory functions of the human vestibular system, the e-AR sensor is equipped with a MEMS (Micro Electro-Mechanical System) 3-axis accelerometer which is capable of detecting acceleration in 3 dimensions (up and down, left and right, back and forth). An accelerometer consists of a mass, and when the sensor is moved, the mass moves. Electronic sensing components determine the acceleration. By positioning the accelerometer on the ear, the e-AR sensor can pick up similar information to the vestibular system, and this records the posture and activities of the user.

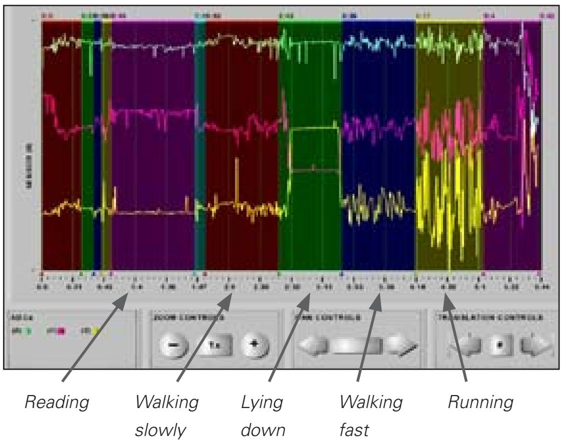


Figure 5 *The e-AR sensor's three accelerometers give three signals, shown here as three traces. Different activities give different characteristic patterns.*

Keeping it small

The main challenges for designing an ear worn sensor are the size and weight of the sensor. The sensor has to be extremely light and small, such that it can be worn comfortably by the user. Currently, the battery is the biggest and heaviest component in a sensing system. The power consumption is the most important consideration in designing the ear worn sensor. If the power consumption of the sensor can be reduced, the size and weight of the sensor can be minimised.

An ultra low power wireless transceiver (a device which can act as both a transmitter and a receiver) and a computer processor (Figure 6) are incorporated in the design of the sensor. To enable real-time monitoring, wireless communication is required, such that real-time information can be sent and viewed by the user. However, wireless communication is power demanding, and a typical wireless transceiver can take up ten times more power than the accelerometer. To reduce the power consumption, the amount of information transferred has to be reduced, hence the need for the computer processor. If the sensor can perform detailed analysis and output only the detected results, such as sending an alarm when abnormality is detected, the amount of information transferred and the energy consumption will be greatly reduced. However, due to the size and power constraint of the sensor, the on-sensor processing remains an active research topic.

Figure 6 *A prototype Application-Specific Integrated Circuit (ASIC) chip for a body-sensing node held by Prof. Guang-Zhong Yang – Imperial College London*

To study the feasibility of using the e-AR sensor for healthcare, we have conducted a number of patient trials. From the results of our pilot study on post-operative care, we have found that the sensor can allow us to monitor patients' recovery after surgery. For some patients, this means that they will be able to go home earlier from hospital; the medical team will be able to monitor their progress remotely.

Fun and games

In addition to healthcare applications, the concept of body-sensing nodes has recently been extended for well-being, sports and gaming applications. because it can gather detailed information about posture and gait, the e-AR sensor has been applied in sports applications. It has been shown that the easy-to-wear e-AR sensor can allow us to monitor athletes in their normal training environment and give a detailed analysis of their movement. In addition, a few simple games had been developed to demonstrate the design concept of the sensors and its potential functions for gaming (Figure 7). The game player wears a sensor and their movements control the game on a monitor screen.

Figure 7 *A student tries out a prototype computer game – he is wearing an e-AR sensor.*

Next developments

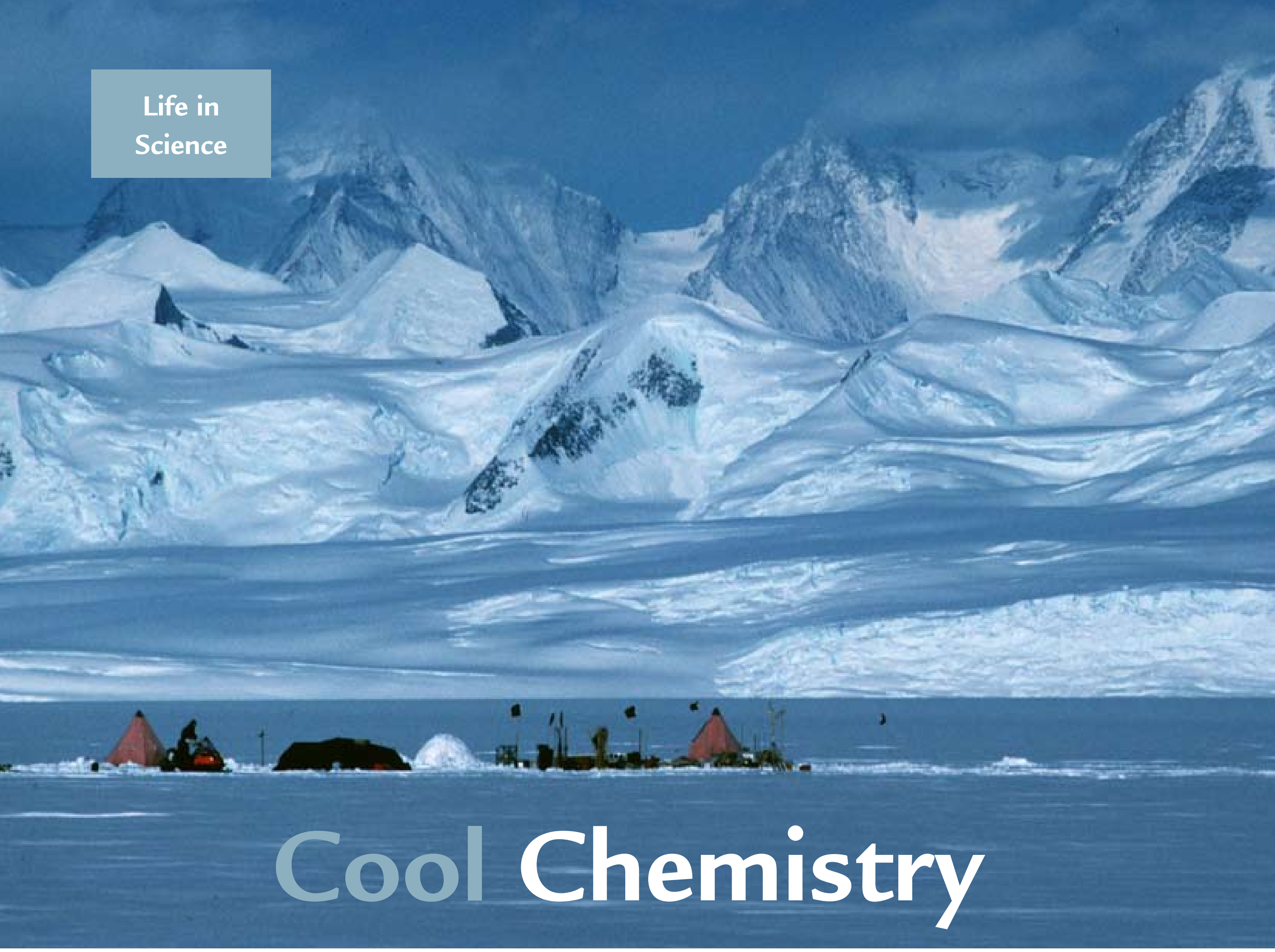
The next generation BSN sensor will be integrated in the form of a silicon chip of sub-millimetre size. By integrating analogue processing and digital control onto the silicon chip, significant power reduction and increase in computation power can be achieved. Such inexpensive, flexible and infinitely customisable BSN sensors will get more and more pervasive, and sooner or later they will gradually 'disappear' into the fabric of our lives.

Dr Benny Lo *is a research fellow in the Department of Computing, Imperial College London.*

Look here!

More about body sensor networks:
www.sports-bsn.org

Dept of Computing, Imperial College London:
www.doc.imperial.ac.uk



Tony Sanchez/Bigstockphoto.com

Cool Chemistry

Dr Eric Wolff learns about past climate by studying ice cores from Antarctica. He is a senior scientist at the British Antarctic Survey (BAS) in Cambridge. BAS is the organisation that organises and carries out most of the UK's scientific studies in Antarctica. Here he tells us about his life in science.

In 1978, I was completing my degree in Natural Sciences (specialising in chemistry) at Cambridge University. I had enjoyed my degree, and thought I would probably take a job in an analytical laboratory, perhaps for a pharmaceutical company. One day I read an advert for a chemist to work at the British Antarctic Survey (BAS). At first I just nodded and ignored it. Unlike some of my future colleagues, it had not been my lifelong ambition to go to Antarctica. I liked mountains but I wasn't a tough guy, or an "outdoors" type. It sounded exciting, and it was about the environment, which I was interested in when green issues were not so well-known. But surely this job was not for someone like me? However, in the following days, it dawned on me that I met all the qualifications for the job, and maybe they just wanted someone who would be a good scientist. So I applied.

NGS

Of course, once I started reading about the Antarctic, I was hooked, and would have been very disappointed if I had not got the job. However, luckily I did and the pharmaceutical industry lost me for ever! My role was to analyse lead in Antarctic snow in order to find out how levels of pollution had changed with time. After a year of preparation and method development, I started a 7 month stint away, travelling from Southampton all the way to Antarctica by ship, and spending 2 months in a tent with one other colleague in the middle of nowhere (but what a beautiful nowhere it was).

When I came back, I started doing the painstaking analyses and further developing the analytical methods. I had been employed on a fixed term contract, and after a couple of short extensions, I had to look for another job. I worked briefly at the Water Research Centre at Medmenham, studying the effects of European legislation on water quality (well, after all, ice really is just frozen water). But then an open-ended job came up at BAS, and I was back like a shot.

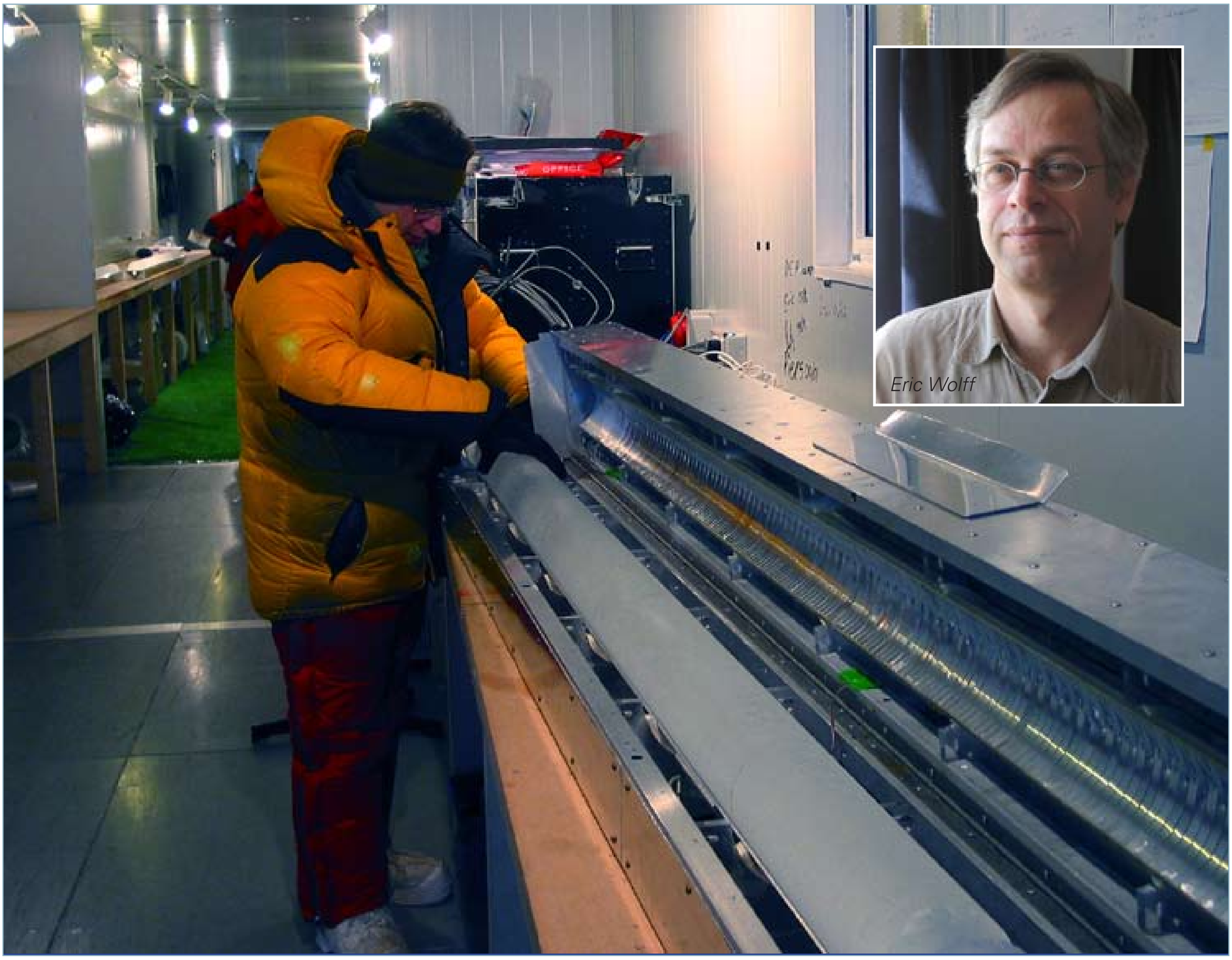
And here I have been ever since. For the kind of academic research that I do, a PhD opens doors, and I was able to obtain my doctorate while working for BAS. And the science I do has moved from studying pollution; now I am working on that most topical area of all, climate change (using ice cores from Antarctica to understand past climate). I also study the atmospheric chemistry of Antarctica, with an emphasis on the interesting chemical reactions that occur on snow surfaces.

I often joke that I am stuck in a rut, but what a glorious rut it is. I have been to Antarctica 6 times now and to Greenland twice. Only the first trip involved the long sea journey; mostly I go away for about 10 weeks at a time. On my last trip, I led a party of 15 scientists from 7 different countries drilling the oldest ice core ever retrieved, containing 800 000 years of climate record. But the fieldwork is just a bonus: most of the time I am doing research in Cambridge, trying to work out how climate worked in the past, and therefore help us to understand how it will change in the future. And I get to discuss the "hottest" (forgive the phrase) topic of the century with the world's experts, who all want to know what the ice cores are telling us.

One of the subjects I have studied recently is whether it is possible to learn how much sea ice there was around Antarctica in the past by measuring how much sea salt is in ice cores. Understanding how such an indicator might work involves seawater chemistry, microchemistry and microscopy to understand where salt is located on sea ice surfaces, aerosol chemistry and meteorology.

I have been to the "ends of the Earth", and I have been asked to give lectures at meetings on glaciology (the study of ice), geology and climate. However, I am still based in Cambridge and I still consider myself a chemist. It seems that I have travelled a long way without moving at all!

Read Eric Wolff's article on pages 9-12 to find out more about Antarctic science.



Eric Wolff

Eric Wolff analyses an ice core during a trip to Antarctica

Ann Skinner

Spanishalex/Bigstockphoto.com

To sleep... ... perchance to dream

(Hamlet)

Key words
sleep
brain activity
scientific theory
falsifiable

To fall asleep is to enter a fascinating night-time world that has intrigued people for centuries. We all spend over a third of our life sleeping and yet few of us understand its fundamental characteristics. And nobody really knows what it is for!

Why do we sleep? Why do we sleep so much? What happens to us when we are asleep? How much sleep do we really need? Why do we feel compelled to do it on a regular basis but missing a few night's sleep does not seem to do us any lasting damage? Or does it? Start talking to anyone about sleep and these questions come tumbling out. For some people the question might well be, 'Why can't I get to sleep?'. The world of the insomniac is a tragic place to visit.

What is meant by *sleep*?

Sleep is a distinct state, as these two dictionary definitions show:

- A natural and periodic state of rest during which consciousness of the world is suspended. (Source: WordNet)
- A natural periodic state of rest for the mind and body, in which the eyes usually close and consciousness is completely or partially lost, so that there is a decrease in bodily movement and responsiveness to external stimuli. (Source: thefreedictionary.com)

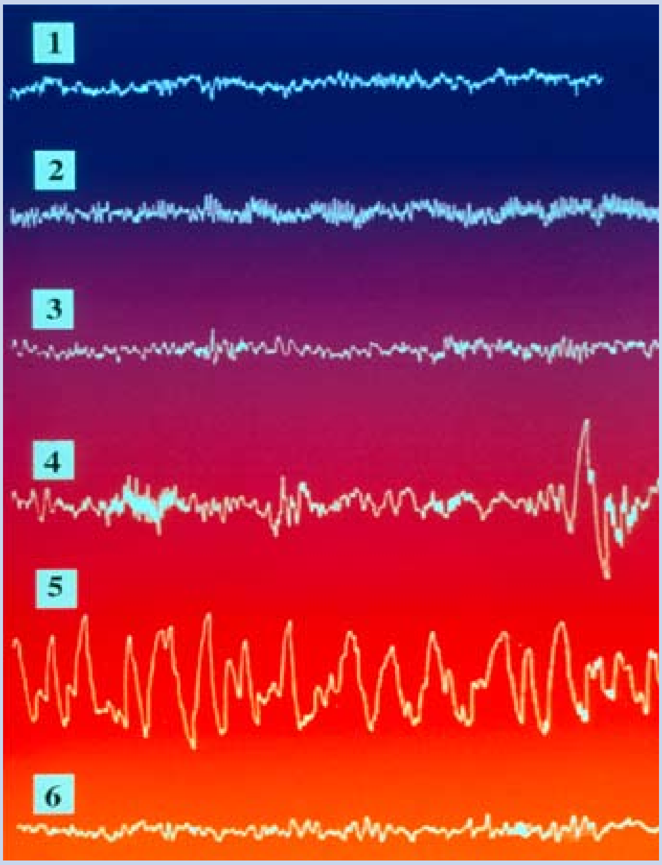
So sleep is a very special state of consciousness, quite different from simply resting.

A scientific look at sleep

When scientists first used an electro-encephalograph or EEG machine, they were surprised to discover that our brain shows different forms of activity at different times during sleep. Electrodes are attached to the subject's scalp. These measure the electric potentials (voltages) on the surface of the scalp and display the activity of the brain in terms of 'brain waves' – see Box 1.

CC Studio/SPL

A subject undergoing EEG examination. Voltages detected by electrodes attached the skin of the head are recorded electronically.



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BOX 1
Understanding brain waves

Sleep is cyclic with the sleeper moving through specific stages each of which is characterised by a unique brain wave profile, see table.

Trace 1: When we are awake and alert, the brain exhibits high frequency, low amplitude waves called *beta* waves.

Trace 2: As we relax, these waves are replaced by slower frequency but higher amplitude *alpha* waves.

Trace 3: The transition into the first stage of sleep is marked by the appearance of yet slower waves called *theta* waves.

Traces 4 and 5: brain waves continue to slow down into stage two sleep and even more as we enter stage three when *delta* waves appear.

Trace 6: REM or paradoxical sleep.

Level of consciousness	Types of waves	Frequency (hertz)
Alert	beta	Over 13
Relaxed	alpha	8 to 13
Stage 1 sleep	theta	4 to 7
Stage 2 sleep	theta	1 to 3
Stage 3 sleep	20-50% delta	0.5 to 2
Stage 4 sleep	more than 50% delta	0.5 to 2
REM sleep	alpha and beta	

The REM paradox

There is a yet another remarkable stage of sleep, called REM (**R**apid **E**ye **M**ovement) sleep because of the rolling of the eyes inside their sockets. Adult humans spend 20-25% of their sleep time in this REM stage spread over 4 or 5 separate periods each night. When in REM sleep there is a paralysis of all the body's muscles and the senses barely respond to changes in the external environment.

The EEG also shows that this stage is unique, with a brain wave profile that resembles a very active brain, hence its other name, *paradoxical sleep*, because the EEG shows an active brain whilst the body appears very much asleep as shown by the fact that it is very hard to awaken someone in REM sleep.

Through the night

During a typical night's sleep we progress through these stages in a regular pattern. Initially we travel through stages 1, 2, 3, and 4 and then back up to 3 and 2 before we enter our first REM session, which is the shortest of the night. Off we go again back down to 3 and 4 and back up again to experience another REM. After these first two cycles stage 3 and 4 are not generally seen and we move from stage 2 to REM and back to 2 again until we eventually wake up when some aspect of the brain seems to be satiated.

Along with these brain wave changes there is a sequence of body changes: slowing down of heart and breathing rate and even changes in temperature.

What do we gain by sleeping?

There is an enormous variety sleep patterns in the animal kingdom. Some dolphin species allow half of the brain to sleep at a time. Others have many brief 'microsleeps' which add up to about 7 hours a day.

However, in some animals like the koala, sleep is used in a completely different way. They sleep for around 16 hours a day and for them it is a strategy to conserve energy because their diet of gum-tree leaves is low in nutrition.

A sleeping koala

There are many theories of sleep, and there are even more theories of dreaming.

Sleep is a highly-complex form of behaviour exhibited by nearly all higher animals. Since the sleeper is in a vulnerable state, one would imagine that it must be serving a vital function. What happens if people and other mammals are deprived of sleep?

The evidence from experimental studies is not straightforward. Experiments with rats and cats have shown that sleep deprivation is fatal but these animals suffered enormously stressful conditions in the attempt to keep them awake so they probably died from this rather than simply from a lack of sleep. Human deprivation studies, for obvious reasons, are not common – see Box 2.

Theories of sleep

It has proved difficult to devise a scientific theory of sleep. In the 1970s, Ian Oswald of Edinburgh University put forward the *restoration theory* of sleep. This suggests that sleep is essential for the physical restoration of the brain and the body. However, this still leaves us to explain why we need to be unconscious for this to happen.

The Meddis *ecological theory* of sleep suggests that it is a process that has evolved to adapt animals to their particular lifestyles. Herbivores need to eat continually and so sleep very little, while predators with protein rich diets can sleep a good deal more. However the complication is that it is possible to explain both long and short sleep requirements in the same way. A koala may need to conserve energy, because of a poor diet, so that it sleeps most of the time, whereas another herbivore might be assumed to hardly ever sleep because its diet is poor so that it needs to spend all its time eating! Such a theory is said to be **unfalsifiable**. Because there is no way to show that it is wrong, the theory cannot be tested and so it is **unscientific**. More theories needed!

Ann Skinner *teaches psychology.*

The scene at the Selby rail crash, the result of one driver's lack of sleep.

Credit York Post/Corbis

Box 2
Sleep deprivation and its effects

Two classic studies of the effects of going without sleep showed contrary outcomes.

In 1959, a disc jockey called Peter Tripp decided to engage in a "sleepathon" and stayed awake for eight days. By the end of this marathon effort he showed severely disturbing symptoms of delusions and hallucinations; so much so that the planned tests of his psychological functioning had to be abandoned.

However, in 1965 a 17 year old student, Randy Gardner, decided to challenge the Guinness Book of Records and achieved 264 hours and 12 minutes without sleep and, although he had some difficulty in performing some tasks he did not show the disturbances experienced by Peter Tripp. After only 14 hours and 40 minutes of sleep he appeared completely recovered.

Most people accept that going without sleep can be harmful, and the devastating rail crash (February 2001) near Selby in Yorkshire demonstrates the folly of thinking we can do without sleep. Gary Hart dozed off at the wheel of his Land Rover, plunging off the M62 on to railway tracks and causing a collision between a GNER passenger express and a coal train. 10 died and over 70 others were injured. The jury rejected Hart's claims that he needed little sleep and was used to staying up all night. Jim Horne, a sleep researcher from Loughborough University, said, "Sleep doesn't come spontaneously from nowhere. You can't be driving along alert one minute and falling asleep the next. There's always adequate time to realise how sleepy you are." Hart was convicted on ten counts of causing death by dangerous driving and sentenced to 5 years.

Ancient air in an Antarctic ice core

Eric Wolff

I work in Antarctica, studying the ice which covers this landmass. In most of Antarctica, when snow falls, it doesn't melt: it just builds up year by year. In the middle of the Antarctic ice sheet, the ice reaches over 3 km thick. By drilling out an ice core (a cylinders of ice typically 10 cm in diameter), we can sample each year of snowfall in sequence. In practice, we collect the ice a few metres at a time using a drill on a long cable. The cores are several meters long when they are removed, but we slice them into sections for analysis.

Ice cores and air bubbles

You can see bubbles in the ice. These are full of air which is hundreds of years old. How do these bubbles form? As the snowfalls get buried, the weight of the layers of snow squeezes snow crystals together until eventually they form a solid network with bubbles of air trapped inside. The impurities in the ice and the air bubbles tell us how the composition of the atmosphere and the climate have changed over time.

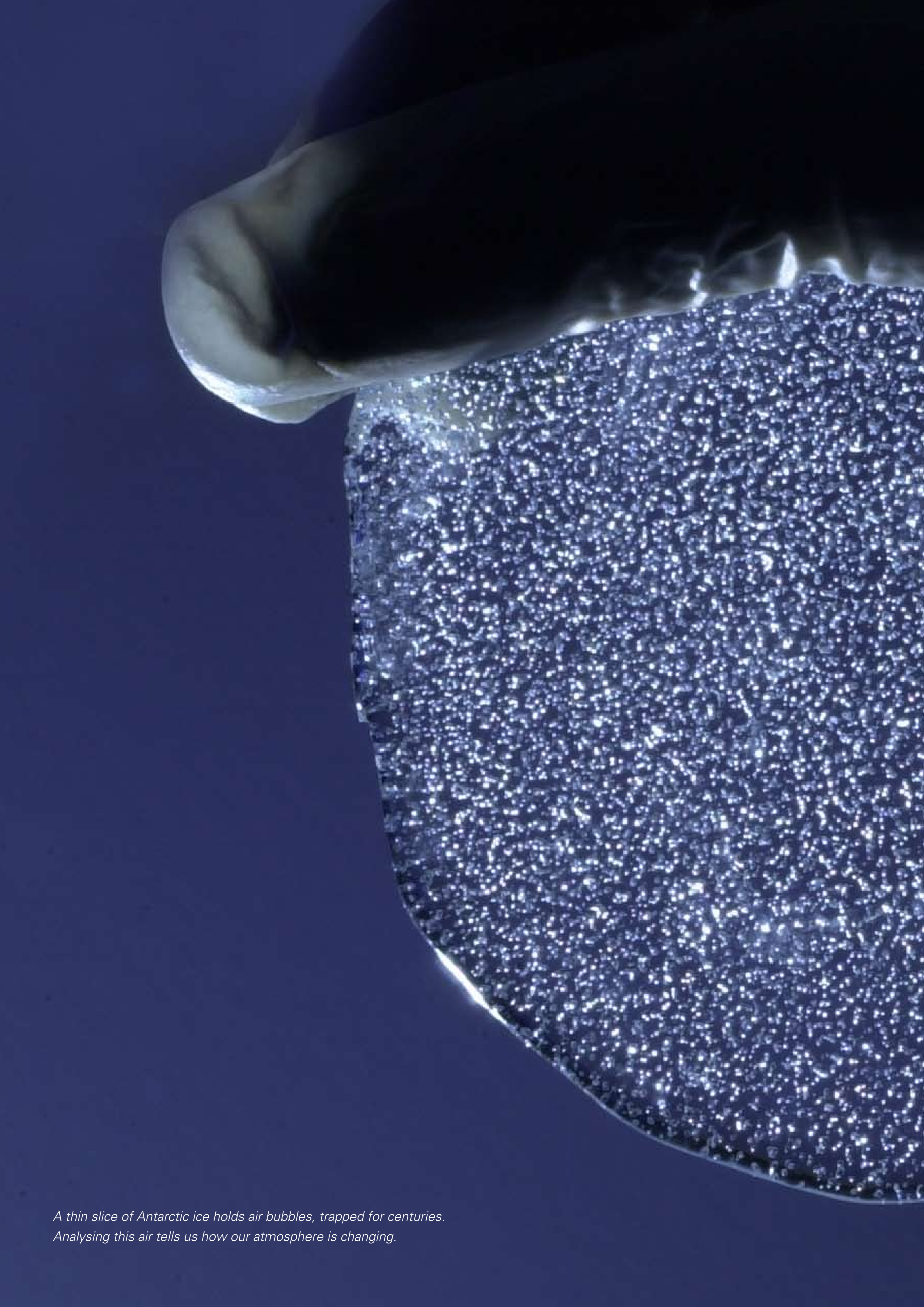
A scientist in the Antarctic drills out an ice core

An ice core as it is removed from the Antarctic ice

What to look for

The image on pages 10-11 is of a thin piece of ice cut from an ice core drilled out of the Antarctic ice sheet. The bright spots are bubbles of ancient air trapped in the ice as it was compressed. Each of the bubbles is a few tenths of a millimetre across, and each of them contains a sample of air that can be cracked open and analysed in order to find out the composition of the atmosphere in the past. In this particular picture, the ice is only around 1000 years old (and the air just a few hundred years old), but ice cores as old as 800 000 years have been retrieved and analysed from Antarctica.

The photograph overleaf shows a section from an ice core. By analysing it, scientists can find out useful information about the concentrations of gases and pollutants which were in the atmosphere at the time the air was trapped.



A thin slice of Antarctic ice holds air bubbles, trapped for centuries.
Analysing this air tells us how our atmosphere is changing.

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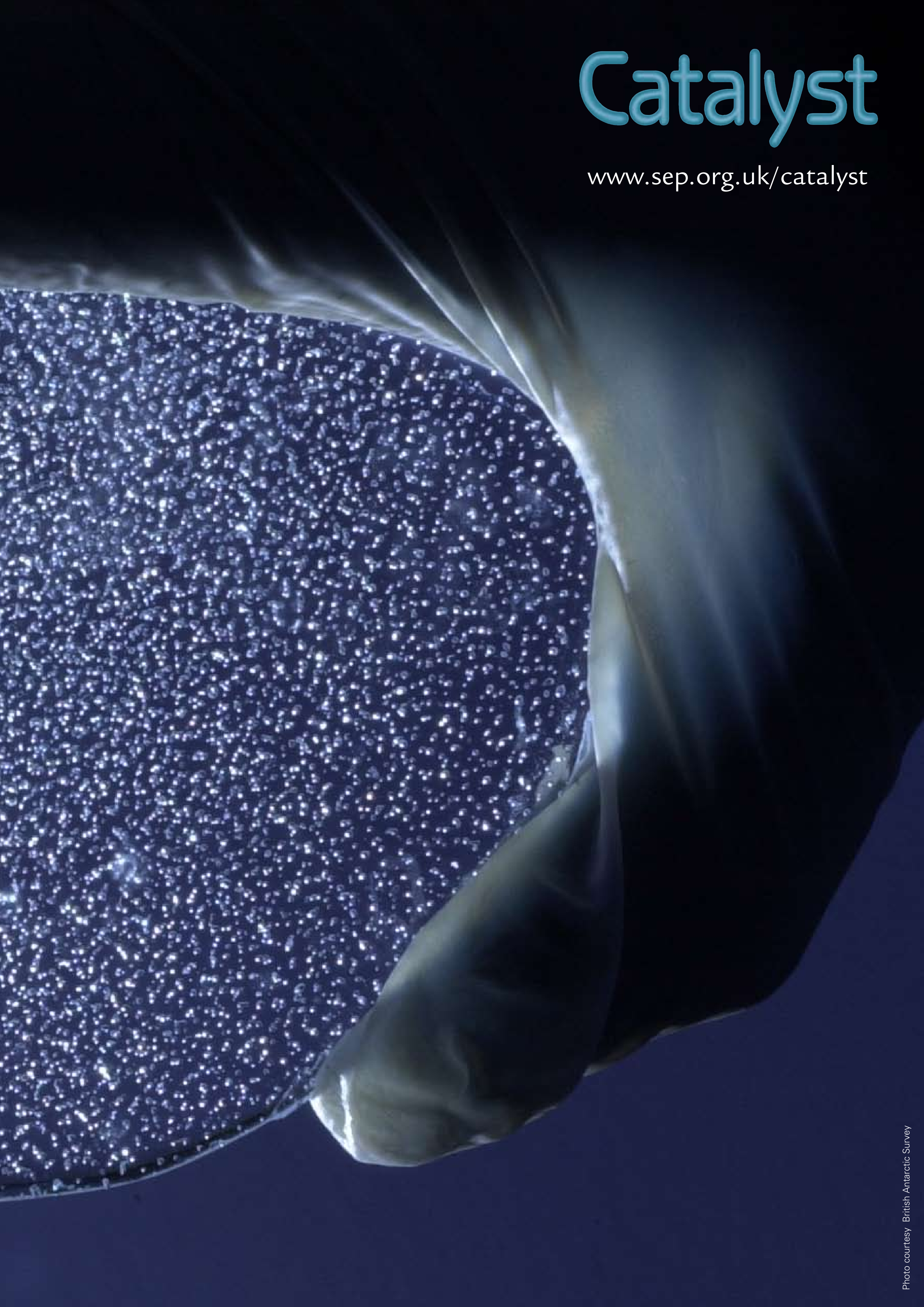


Photo courtesy British Antarctic Survey

Analysing air bubbles in ice

If you think of the ice as a container, then the air in the bubbles can be treated just like a sample of modern air collected in a canister. It just has to be extracted from the bubbles. This is done by placing the ice in a vacuum chamber and first removing all the modern air from the chamber. Then the ice can be cut into tiny pieces to release the air from the bubbles, and the chemical content of the air: nitrogen, oxygen, carbon dioxide and so on, can be measured by instrumental methods such as mass spectrometry and infrared spectroscopy. In fact, bubbles like the ones shown here are present only in the upper few hundred metres of an ice sheet. Below that the pressure actually causes them to dissolve into the ice as crystals called air hydrates (which have cages of water molecules surrounding each molecule of the gas). Fortunately, once the core has been drilled, the air can still be retrieved from air hydrates by the same methods.

The clean room at the British Antarctic Survey's headquarters in Cambridge where ice is analysed. The room needs to be completely clean to prevent modern impurities from contaminating the ice.

Results

The CO_2 content of the atmosphere has been measured routinely only since the 1950s. Almost everything else we know about its history comes from ice cores. From them we know that the concentration remained between 180 and 300 parts per million by volume (ppmv, ie the fraction of the volume of the air which is CO_2) for the entire 650 000 years until 1800 AD. Since the early 19th century, the concentration has increased, from 280 ppmv to its value this year (2008) of 383 ppmv, and is rising by 2 ppmv per year. The concentration of the next most important greenhouse gas, methane, has doubled in the same period.

Drilling ice cores in Antarctica

Obtaining ice samples like the one in the picture requires a huge effort, often involving scientists and engineers from several nations. The ice in the picture came from an Antarctic ice cap called Berkner Island, and was drilled by a joint UK and French team. The ice was 950 m thick at this site. Sand was found at the bottom of the hole, suggesting that the ice sheet was built on dunes of wind-blown sand. The oldest ice core so far retrieved from Antarctica was obtained by a 10-nation European team called EPICA (European Project for Ice Coring in Antarctica), and reaches back 800 000 years.

Dr Eric Wolff is one of the British Antarctic Survey's senior chemists. Read more about his Life in Science on page 4.

Look here!

For information about the British Antarctic Survey and the work which they do see, **www.bas.ac.uk**

Removing an ice core at the Berkner Island site.

All photos on pages 4-5 and 9-12 courtesy of British Antarctic Survey unless otherwise stated

Careers in ecology

From biodiversity to climate change

Some habitats need protection from simple human effects, like these badly trampled sand dunes.

Why do we need to understand how a food chain works? Why does biodiversity matter? How do we know that climate change is happening?

Ecology is the branch of biology that looks at how organisms, plants and animals, depend on each other and their surroundings. It's about life and living things. It also looks at how humans impact the world we live in.

Ecologists in demand

There are many careers in ecology and its related fields. In fact business is booming with the demand for skilled ecologists at an all time high.

But what does a job in ecology look like? A job in ecology today is very different to the job of an ecologist 100 years ago. Once upon a time ecology meant a job looking after the environment, perhaps as a countryside ranger or a warden, protecting, managing and monitoring a habitat and the plants and animals within it, and educating the public about it. People did the work because they loved working outdoors and had a passion for the natural world; others campaigned and lobbied governments to protect plants, animals and their habitats, working with such organisations as WWF and the RSPB.

Ecologists told us which animals were rare and needed to be protected, which habitats needed special consideration. They did not expect to get paid a good salary.

However over the last few years legislation and policies related to the environment such as biodiversity, protecting species and their habitats, sustainable development and monitoring climate change have meant there are more opportunities than ever to find employment.

There's a shortage of skilled ecologists and like all careers where there's a shortage of skilled workers, salaries are increasing.

Where there's smoke … The cooling towers on the left (top) are fairly harmless - they are just giving out water vapour. The chimney (bottom), at a sugar refinery gives out water vapour but also products of combustion including carbon dioxide and gases such as sulphur dioxide which cause acid rain.

TV programmes such as Springwatch show a great deal about the work of an ecologist employed by the many Non-Governmental Organisations (NGOs) such as the Woodland Trust; they may gather information on when the first swift arrives in the UK each spring, or when oak leaves start to turn red and gold in autumn. Analysing this data is the work of ecologists who can report on how the seasons are changing and how our climate is being affected. Such ecologists find themselves at Westminster advising the government. Communication skills are essential

Even an environmentally-friendly development such as the erection of wind turbines must go through an environmental impact assessment, a job which heavily involves trained ecologists.

The photo shows ecologist/botanist Hannah Graves with the rarity Fox Sedge *(Carex vulpina)*. In Britain this species is now classified as 'vulnerable'. It receives general protection under the Wildlife and Countryside Act 1981.

Hannah's first job was with her local County Wildlife Trust. She studied six botany modules at the University of Birmingham, learning to identify hundreds of plant species. These qualifications developed her recording and reporting skills, and allowed her to teach volunteers.

Now Hannah works for British Waterways, surveying plant life in the canals of south east England.

Clearing up

People are messy though and an essential group of ecologists are those involved in waste management, environmental management and pollution prevention and control. They develop the strategies not just to dispose of our waste safely but also how to regenerate damaged land.

An ecologist uses a Surber sampler to assess the quality of water. The sample contains mainly mayfly larvae, showing that the water is of quite good quality.

Ecological consultant

In ecological consultancy, one of the biggest growth areas in ecology, ecologists will conduct field surveys, mapping the distribution of organisms and monitoring sites. This work may be carried out as part of an **impact assessment**. Impact assessments must be carried out for all industrial, building or transport schemes in order to determine the impact a proposed development might have on a habitat, local water reserves and the surrounding environment. The information the ecologist gathers in this process in considered when permission is given for work to go ahead. It can be difficult work, but when two groups of people are arguing about whether or not a new road should be built, the assessment of the ecologist can help determine if a habitat is too important to be destroyed by a road.

Skills and qualifications

Ecologists are very skilled people; they usually have a driving licence, and have gained voluntary experience in identifying plants and animals or sampling different habitats. Most have a first degree and many have gone on to obtain higher degrees.

They are committed people with a fascination for plants and animals. They love fieldwork and are able to enthuse others to protect the natural world. They understand the need to protect the natural world alongside allowing human society to develop in a sustainable way. When they need to they can provide the scientific evidence about the ways in which humans affect the world around them.

__Karen Devine__ is Education Officer of the British Ecological Society

Why worry about plants?


Common spotted orchid and bee orchid

Status	Orchid examples
Extinct – no longer present	Summer Ladies-Tresses
Critically Endangered	Lady's slipper orchid
Endangered	Fen orchid
Vulnerable	Military orchid
Nationally Rare – occurs in 15 or fewer 10 km squares	Small-flowered tongue orchid
Nationally Scarce – occurs in 16-100 10 km squares	Man orchid

Table 1 Some rare plants are rarer than others.

Some ecologists work with endangered plant species. But should we really care if an individual species disappears from these islands? Jill Sutcliffe, a scientist who has worked for several different environmental organisations, explains:

'In this country, there are some 1700 different flowering plants – from those harbingers of spring the bluebell to the large and prickly gorse bush. Britain contains sites which have lots of bluebells on them due to the wet Atlantic coast climate which occurs here. However, when you cross the English Channel –while there are some bluebell woods in France and Germany – these are far less prevalent. The result is that Britain has an international responsibility for the bluebell.

It's easy to think that a plant you don't often see is uncommon but that may only be true near your home or in your county. So how do we find out how rare a plant is?

The first step is for lots of people to go out and spot plants and then send their records into the Botanical Society of the British Isles. A map is drawn up for each species showing in which 10 km by 10 km squares the plant is found. Then we can assess its status. The World Conservation Union developed a set of criteria to assess the degree to which a species is threatened – see Table 1, which includes examples of British orchid species.'

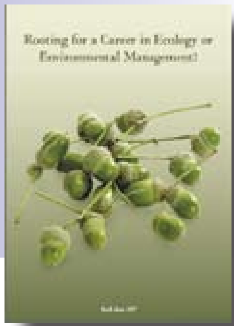

The common spotted orchid (left) occurs across most of the British Isles; the lady orchid has a much more limited distribution.

'Monitoring plants – visiting them and making a note about their presence or absence – also provides important information. It helps to check up on whether the plant is still there, and whether the type of management being used is working or not. It can show, for example, whether water courses are becoming choked by pesky species because the water chemistry has changed and become polluted.

Changes in plant populations can also warn us of the effects of climate change. Many plants are rare because the environment has changed, leaving previously common species isolated in areas of suitable habitat. This means that the arctic-alpine plants, those specially adapted to growing in cold areas usually in upland areas which have been left over from the last Ice Age, face a challenge from climate change. These are the species which could well lose out and be forced off the list of plants which grow in these islands – plants like yellow marsh saxifrage. The converse is also true. Those plants like the ground pine, which prefer a Mediterranean climate of warmth and little rain, may flourish and expand.'

Look here!

The British Ecological Society produces a booklet 'Rooting for a Career in Ecology and Environmental Management' which is available to download from the website, **www.britishecologicalsociety.org**



Employers of ecologists

Forestry, mining and energy companies

Water companies and civil engineers

Governmental bodies such as Natural England and Scottish Natural Heritage

Government-funded research institutes

Local authorities and National Parks

Museums and botanical gardens

David Catling

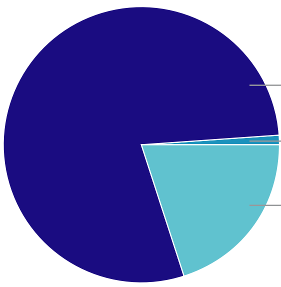
Earth's early atmosphere

The image above shows the Moon rising beyond the blue haze of the Earth's atmosphere. The Earth is the only planet in the solar system which can support life. In this article, David Catling of Bristol University describes how the composition of the atmosphere has changed through its history, and the link between atmospheric composition and life.

Key words
Earth's atmosphere
oxidation
reduction

When I was a secondary school pupil, my main impressions about chemistry were those of the industrial processes, particularly the Haber process to make ammonia and the manufacture of fragrant esters. But my perspective broadened. In the 1980s, the chemistry of the atmosphere and its link to life became prominent through two topical environmental issues: the ozone hole over Antarctica and global warming. It was around this time that my interest in the chemical composition of the Earth's atmosphere took hold. I found myself wondering why the Earth's atmosphere has the bulk chemical composition that we find around us. To put the question another way, how did the atmosphere evolve?

1000 million = 1 billion = 10^9



The composition of the Earth's atmosphere today – but it hasn't always been like this.

The oxygen story

On the modern Earth, living organisms regulate every key constituent of the air with the exception of the inert gas, argon. By far the most unusual constituent is oxygen (O_2), which is not found in abundance in the atmosphere of any other planet. Until around 2.4 billion years ago, the Earth's atmosphere had negligible oxygen and, without oxygen to respire, the large life forms that seem so familiar to us, such as multicellular plants and animals, could not exist. Indeed, there are no fossils visible to the naked eye in rocks from before 2.5 billion years ago, an aeon known as the Archaean. Instead, all you can find are the tiny microscopic fossils of single-celled microbes which make up stromatolites, laminated mineral mounds left behind by microbial communities.

David Catling

Giant stromatolites in South Africa. These formed about 2500 million years ago, in a group of rocks known as the Lyttleton Formation. Note the person's dangling legs at the top of the picture for scale. This enormous mound of laminated minerals was deposited by a slimy community of microbes (and possibly algae) that lived in the tidal zone on an ancient coastline.

ESA/NASA

Box 1 Sulfur and its ions

Sulfur has the atomic symbol S. It can form several ions. The simplest is sulfide, S^{2-}. This can be oxidised to form sulfate, SO_4^{2-}.

Crystals of the mineral stibnite, a form of antimony sulfide.

Charles D. Winters/SPL

The chemical history of Earth's atmosphere is largely the story of oxygen. Ozone (O_3) derives from oxygen and so when the atmosphere had little oxygen there was no stratospheric ozone layer. By looking at the chemistry of old rocks, scientists have established that oxygen levels increased dramatically twice during Earth history. The first rise of oxygen, called the Great Oxidation Event (GOE), was around 2400 million years ago, while a second rise of oxygen happened about 580 million years ago.

After the GOE, the Earth literally changed colour, like an indicator experiment in a test tube. Before the GOE, continental surfaces were the grey or black colour of volcanic rocks, such as basaltic lavas and granites. Afterwards, oxygen that was dissolved in rainwater reacted with iron minerals in the rocks on the Earth's surface to produce reddish-coloured iron oxides, somewhat like the way that your bicycle rusts.

The chemistry of seawater also changed. Today, sulfate is an abundant anion in seawater at a concentration of around 29 millimoles per dm^3. But before the GOE, the analysis of sulfur compounds in ancient marine sediments shows that sulfate concentrations were over a hundred times lower than today's level. Rivers ultimately supply sulfate to the ocean by washing sulfate off the land where it is produced by the oxidation of sulfides in rocks by oxygenated rainwater. Similarly, prior to the GOE, a chemical analysis of ancient soils shows that iron was leached out of soils in its soluble ferrous form ($Fe^{2+}_{(aq)}$) by rainwater. But following the GOE, iron didn't go anywhere; the iron was oxidized to insoluble ferric (Fe^{3+}) oxides, such as haematite (Fe_2O_3), by the small amounts of O_2 dissolved in the rain.

In the absence of oxygen, reducing gases such as methane (CH_4) would have reached very high concentrations compared to today. Today, methane exists at a level of 1.7 parts per million by volume (1.7 ppmv) but in the oxygen-free Archean atmosphere, it probably would have attained a level of several hundred ppmv. Volcanoes and seafloor volcanic vents produce some methane but by far the most important source is biology. Microbes in muds on the seafloor and in lakes decompose organic matter and continually produce methane. Today, nearly all seafloor methane is oxidised by bacteria that use downward-diffusing sulfate or oxygen as oxidants before the methane even gets out of the mud. But in the absence of oxygen or sulfate, such methane would have escaped out to the atmosphere in abundance. There, methane would have been subject to photochemical reactions that produced some other heavier hydrocarbon gases such as ethane (C_2H_6).

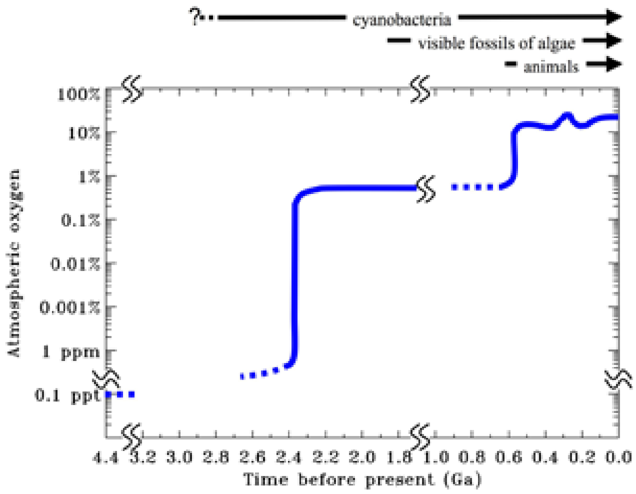
Atmospheric methane and its hydrocarbon derivatives in the early atmosphere would have been powerful greenhouse gases. Indeed, it is widely thought that methane and associated hydrocarbon gases likely account for how the Earth remained warm and habitable despite the fact that the Sun was less luminous by about 25-30% some 4 billion years ago. If it were not for ancient methane, the world's seas could have frozen over permanently. In fact, it perhaps comes as no surprise that signs of major glaciation are found in rocks ages 2450-2220 million years, at a time when oxygen rose and methane should have dropped through oxidation. Glaciers even extended into tropical regions at this time. Eventually, the establishment of an ozone layer prevented the Sun's powerful ultraviolet rays from reaching the underlying atmosphere, which would have slowed the photochemical destruction of methane and allowed methane levels to rise slightly again, permitting the Earth to warm up.

The Archean period was from 3.5 to 2.5 billion years ago.

A photochemical reaction is a reaction which is started by light.

Producing oxygen

Oxygen comes from a type of photosynthesis whereby bacteria or plants extract hydrogen from water and use it to reduce carbon dioxide to make organic matter; oxygen is released as waste. A vast number of photosynthetic bacteria, called cyanobacteria, live in today's oceans. Long before plants appeared, it was the ancient ancestors of cyanobacteria that first produced the oxygen that flooded Earth's atmosphere. Indeed, specific organic compounds that once made up the cell walls of ancient cyanobacteria have been found in black, carbon-rich sediments that were deposited on the seafloor 2750 million years ago. These sedimentary rocks predate the first rise of oxygen in the Earth's atmosphere.



The blue line shows estimated amounts of atmospheric oxygen over time in Ga (Giga anna = 1000 million years) based on a combination of geological evidence and models. Before life existed, at 4.4 Ga, theory predicts that oxygen concentration was less than 1 part per trillion. At 2.4 Ga, geological evidence shows that oxygen levels rose from less than 1 part per million, up to 0.3-0.6%. Shortly after 0.58 Ga, oxygen levels supported animals. The history of some forms of life is shown above the graph.

To explain the delay of oxygenation, it is theorized that the oxygen was initially used up during the oxidation of chemicals coming out of the solid Earth, such as hydrogen released from geothermal and volcanic regions. Also the oxygen would have been mopped up in oxidizing iron that was dissolved in largely oxygen free seawater. Effectively, the Earth underwent a global redox reaction until the production of oxygen exceeded the production of chemicals that consumed oxygen. At this tipping point, oxygen was able to flood the atmosphere.

After the GOE, the Earth's atmosphere and climate appear to have been relatively stable for over a billion years. Some scientists have even dubbed this period of time "the boring billion". Oxygen levels remained limited to a few percent of present levels and biological evolution was slow, being restricted to forms no more exotic than algae or tiny fungi. Then, around 580 million years ago, oxygen levels rose a second time up to 15% or more of present concentrations. We infer that this happened because sulfate levels in the ocean once again increased, this time from around 2-4 millimoles per dm^3 to levels that were perhaps close to modern. The idea is that higher amounts of atmospheric oxygen supported greater oxidation of sulfides on land and a bigger flow, via rivers, of sulfate to the oceans.

The recent history of the atmosphere has been discovered from air trapped in Antarctic ice – see the article on pages 9-12.

Box 2 Observing the atmosphere

Orbiting spacecraft are used to monitor the Earth's surface and atmosphere. This picture, taken by the European Envisat spacecraft, shows the coast of Western Europe. A large 'bloom' of phytoplankton can be seen off the coast of Spain. These microscopic algae absorb atmospheric carbon dioxide and release oxygen.

High concentrations of oxygen are necessary for animal respiration. We find that around 575 million years ago, the first animals appear in the fossil record during a time known as the Ediacaran period (630-542 million years ago) and then a profusion of animals occur around 542 million years ago at the beginning of the Cambrian period. From this time forward, oxygen levels have probably varied between extremes of 10% and 30%. Thanks to high oxygen and the unique chemistry of our atmosphere, the world has remained suitable for animals. Ultimately, then, we owe our own existence to atmospheric evolution.

__David Catling__ began his career by studying atmospheric physics and is now an Astrobiologist. He spent 6 years working for NASA (the US National Aeronautics and Space Administration) in California and is currently an affiliate professor at the University of Washington in the USA and a professor in the Department of Earth Sciences at the University of Bristol. His main research interests include how the evolution of planets' surfaces and atmospheres are related and he is also involved in the exploration of Mars.

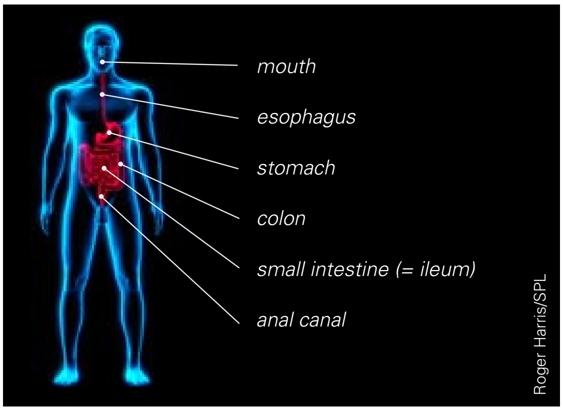
Bob Rastall


looby/Bigstockphoto.com

Probiotics, prebiotics
Manipulating bacteria in the gut for health

Key words
digestion
bacteria
ecosystem
probiotics
prebiotics

The human gut plays host to an enormous number of microorganisms, mainly bacteria. What role do they play, and can we change our diet to encourage beneficial organisms?



Roger Harris/SPL

Figure 1 *The human gut*

Bacteria in the gut

Let's take a journey down the gut (Figure 1), looking at the **microorganisms** present. The numbers in the stomach are very low, at around 10^3 per millilitre due to the gastric acid. The small intestine contains around 10^4 – 10^8 per ml. The colon, however, has a huge microbial population – around 10^{12} per ml. Indeed, if you were to count up all of the living cells in an average adult, 95% of them would be colonic bacteria! There are at least 500 different species present in the colon and they produce very many different biochemicals. It is not surprising then that the colon is increasingly being recognised as a major metabolic organ that can have a significant impact on human health.

Bacteria, good and bad

The bacteria in the colon form a complex, but self-regulating, ecosystem. They use food residues that have escaped digestion in the small intestine for energy and nutrition and produce a range of metabolic end products. We do not understand all of the activities of the bacteria in the colon, but we can broadly divide them into two categories (see Figure 2).

Some organisms are harmful: they produce a range of toxins and cancer-promoting chemicals.

Others are more benign and produce chemicals which act as fuel for the cells lining the gut and also antimicrobial compounds that can inhibit pathogens.

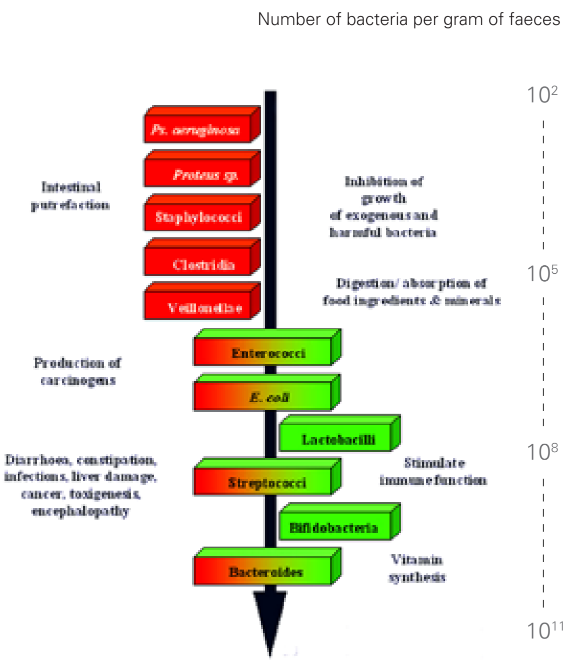


Figure 2 *The balance of harmful and beneficial bacteria in the human gut.*

Acquiring bacteria

At birth we acquire our gut flora from either our mother's birth canal or from the environment, depending on delivery method. The population develops as we get older and by adulthood is stable. These organisms form a complex, balanced 'ecosystem' and it is likely that we each have our own characteristic set of bacteria. The balance of the ecosystem does, however, respond to diet and we can manipulate the colonic ecosystem by means of food ingredients.

Dietary manipulation – probiotics, prebiotics and synbiotics

As we learn more about the bacteria in the colon and what these organisms are doing, the idea of deliberately changing the type and numbers present to improve health is supported. There are two ways that this can be attempted, the use of probiotics or prebiotics. **Probiotics** are live bacterial ingredients or supplements designed to multiply in the colon and have an impact on health.

Figure 3 *A colour-enhanced electron micrograph of probiotic bacteria in yoghurt: Streptococcus thermophilus (yellow beads) and Lactobacillus bulgaricus (red rods).*

There is a long history of use of probiotics; indeed the concept was first outlined by Elie Metchnikoff over 100 years ago. Metchnikoff noticed that Bulgarians tended to live long and healthy lives and he put this down to their drinking milk fermented with bacteria. These bacteria produced lactic acid and were what we now call *Lactobacillus*, used in making yoghurt (Figure 3), cheese and other fermented foods.

There are nowadays a wide range of probiotic products in the supermarket. These are mainly dairy products such as yoghurts and the increasingly familiar 'small shot' bottles of fermented milk products. There are also a range of healthcare supplements available in pharmacies and health shops. These products mostly contain live cultures of bacteria such as species of *Lactobacillus* and *Bifidobacterium* and many of these commercial probiotics have been selected to survive the industrial chilling process, the acid in the stomach and the journey through the intestinal tract. Most of the probiotic products on the market claim to boost immunity and 'wellbeing'. These claims are rather vague as, at the present time, it is not permitted to make a specific health claim for any kind of food. This is likely to change to some degree in the future and probiotics are being very actively researched for a variety of health benefits.

Box 1 An artificial gut

Researchers at Reading University have built a model human gut. This contains real bacteria and is used to test the effects of prebiotics.

A researcher samples fluid from the artificial gut. The fluid will be tested to discover the chemical products of bacteria in the gut.

A technician counts colonies of bacteria grown in the model gut.

A new approach

At Reading University, we are working on the 'prebiotic approach' (see Box 1). A **prebiotic** is a carbohydrate that is not digestible by humans. Instead, it passes through to the colon where it is fermented by desirable bacteria. The target bacterial groups are the same genera that have been developed into probiotics, namely Lactobacilli and Bifidobacteria. Prebiotics have many advantages; principally the fact that they are not alive means that they can be processed into a much wider range of foods than can the fragile probiotics. The disadvantage is that the bacteria already present in the colon may not necessarily have the health benefits of the probiotics.

Prebiotic	Source
Inulin	Chicory
Fructo-oligosaccharides (FOS)	Chicory; manufactured from sucrose
Galacto-oligosaccharides (GOS)	Manufactured from lactose
Lactulose	Manufactured from lactose

Table 1 *Some prebiotic carbohydrates*

Several different carbohydrates have been found to possess prebiotic properties (Table 1). The main players at the moment are the fructose-based carbohydrates inulin and fructo-oligosaccharides (FOS). There are many scientific studies on these ingredients that have shown a positive effect and they are the most common type of prebiotic found in foods. Less common, but showing commercial growth and receiving a lot of interest from scientists, are the galacto-oligosaccharides (GOS). These are made from lactose, a by-product of cheese-making which many people find it hard to digest.

Prebiotics are being incorporated into all kinds of foods including bread, biscuits, breakfast cereals, yoghurts, milk drinks, infant formulae and sports supplements. GOS are mainly used in infant formulae or as consumer healthcare products.

Research at Reading and elsewhere is currently attempting to understand the basis of the prebiotic effect in the hope that we can one day design improved prebiotics with specific health benefits. We are also looking at other carbohydrates from plants and bacterial cultures that have beneficial properties in the gut and from these we hope to develop new ingredients.

A logical extension to the concept of prebiotics and probiotics is to combine the two. The result is a synbiotic and this is a very active area for research at the moment. The idea is that by combining a probiotic with a prebiotic that it can metabolise, we can improve the activity and persistence of the probiotic when it reaches the gut.

Commercial developments

We are rapidly discovering more and more about the vast array of bacteria that live in our guts. As we learn more about their impact on health and disease (see Box 2), we will be able to identify specific changes we might be able to bring about in order to optimise human health. We are also developing the new food ingredients needed to bring about the changes and we will see much more commercial development in this area in the years to come.

Bob Rastall *is Professor of Food Technology in the Department of Food Biosciences at the University of Reading.*

Box 2 Gut bacteria and health

Probiotics and prebiotics are currently being studied to see if they contribute to certain diseases.

Irritable bowel syndrome (IBS): This affects around 20% of individuals in Western Europe and the USA. It is often linked to stress and causes periods of constipation, diarrhoea or alternating periods of both. Although the exact causes are unclear, the yeast *Candida albicans* has been associated with the condition. Research is under way to find probiotics with good anti-*Candida* activity which might help to alleviate the symptoms.

Ulcerative colitis (UC): This inflammatory disease affects predominantly young individuals on a Western diet. Again, the exact cause is unclear but there is strong evidence that there is a role for the gut bacteria – experimental animals without gut bacteria cannot develop the disease. Some lines of research have pointed to colonisation by sulfate-reducing bacteria. These bacteria adhere very strongly to the gut wall and reduce dietary sulphur compounds to H_2S – a very potent toxin. Probiotics and prebiotics may prove useful in inhibiting sulphate reducers in the gut.

Colon cancer: Colon cancer is the second most common form of cancer and certain gut bacteria can produce a range of carcinogens and tumour-promoting substances. Research in animals with probiotics has shown that they can reduce the concentration of such substances and that this provides protection against cancer. Recent trials have been carried out in humans with synbiotics with encouraging results. Levels of cancer-promoting substances were reduced and tumour development retarded.

Antibiotic-associated diarrhoea (AAD): Administration of broad-spectrum antibiotics often causes a major imbalance in the gut bacterial ecosystem. This can mean that bacteria such as *Clostridium difficile* can multiply, although this is normally suppressed by the more desirable members of the gut flora. There is consequently much interest at the moment in probiotics that can inhibit this organism which may be of benefit in recovery from AAD.

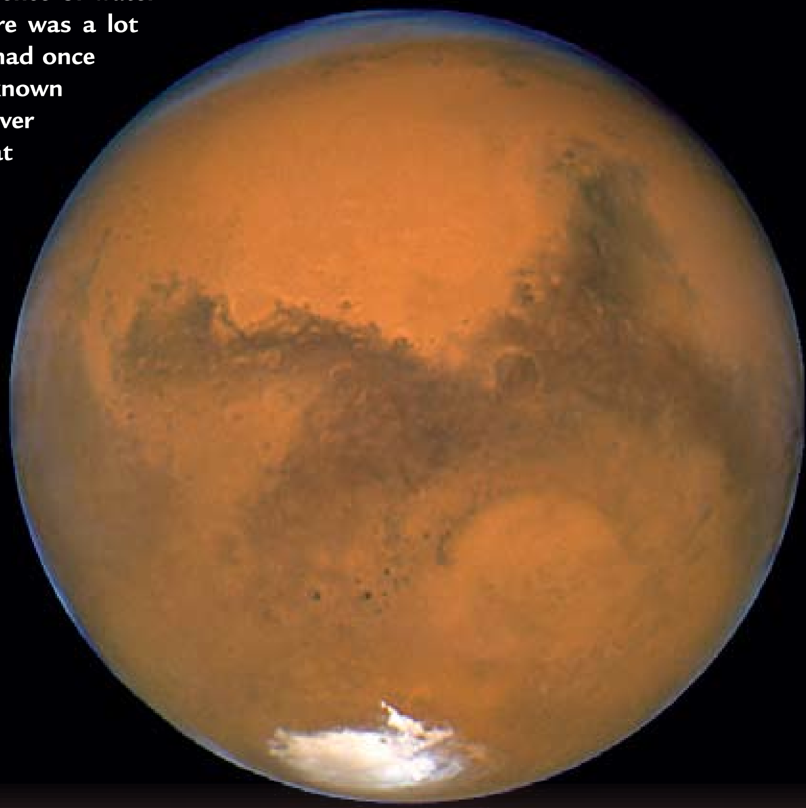
Autism: Although autistic spectrum disorders (ASD) are not actually caused by the bacteria in the gut, they may still play a role through the generation of toxins. Bacteria such as *Clostridium* species, common toxin producers, have been found to be elevated in children with ASD relative to other children. Probiotics have been isolated that have inhibitory effects against clostridia and they may prove useful in management of symptoms in children with ASD.

Obesity: Recently there have been some very preliminary data published showing that the gut bacterial profiles of obese individuals may be different to those of non-obese people. So far the picture is very unclear and much more research is needed before the potential of probiotics or prebiotics in obesity management is clear.

Is Mars dead?

Clouds over Mars
Mars photographed by the Hubble Space Telescope (a telescope which orbits the Earth) in 2003. The blue-ish white areas at the top and on the left hand side are water ice clouds.

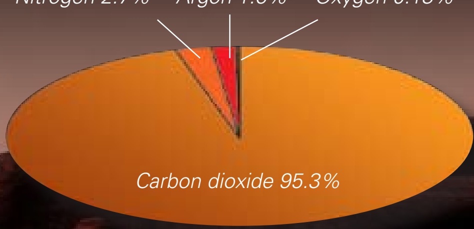
New data suggests that it is very unlikely that life ever existed on Mars. When the presence of water was confirmed a few years ago, there was a lot of speculation that at least simple life forms had once lived there as water is essential for every known living thing. The latest data gathered by Rover vehicles on the planet's surface suggests that the water was far too salty to support any life and that life on Mars would have been very challenging for even the toughest organisms at any time during the past 4 billion years.



NASA, J. Bell (Cornell U.) and M. Wolff (SSI)

Ice on Mars

Water ice in a crater on Mars. The ice forms a thin crust on the sand dunes of the crater floor. In the polar regions of Mars, water ice can exist all year round. There is no liquid water on the surface of Mars, however, as the atmospheric pressure is too low. Instead, the water sublimes – it turns straight from a solid to a gas and back again. The crater shown is about 35 km in diameter.



Martian atmosphere

Mars' atmosphere is thin; its pressure is about 1% of Earth's atmosphere. Only a tiny fraction is oxygen, suggesting that life is unlikely.

Visitor from Earth

The Opportunity rover is one of two identical rovers sent to Mars in 2003. It can travel up to 100 metres in each Martian day (24 hours 37 minutes). One of the main aims of the mission is to look for water. It also analyses rocks and soils to find out what they were made of.

NASA

NASA/JPL/Malin Space Science Systems

A watery past

This image was taken by the Mars Global Surveyor orbiting satellite in March 2001. It shows gullies on Mars, with meandering channels and fan-shaped aprons of debris located downslope. The gullies are thought to have been formed by erosion, both from a fluid (such as water) running downslope, and by slumping and landsliding processes driven by the force of gravity.