Fossilised giant clams
give high fidelity climate records

Ancient giant clams dug from Papua New Guinea's tropical rainforests have provided Australian paleoclimatologists with a unique and detailed record of climate 400 000 years ago. The new lead promises to help answer some of today's central climate change questions. **Wendy Pyper** reports.

Bridget Ayling's field colleague Jol Desmarchelier, with local guides, uncovers one of five fossilised giant clams that were collected from the expedition to the Huon Peninsula. The clams can grow up to one metre long and 15–20 cm thick at their hinge, and weigh up to 100 kg. Bridget Ayling/ANU

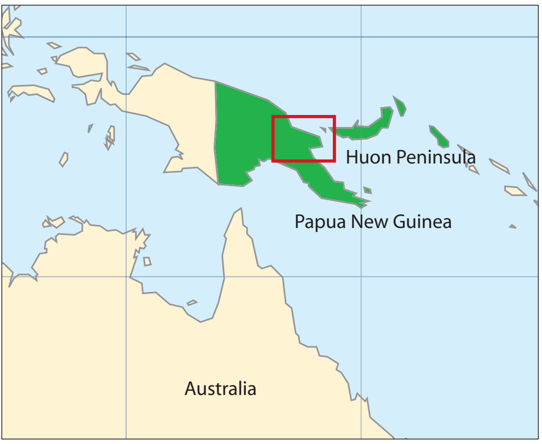
Three years ago, Australian National University PhD student Bridget Ayling despaired that her research project had stalled. In order to reconstruct the climate of past interglacial periods, she had visited Henderson Island, in the far south-eastern Pacific Ocean, to collect 330 000- and 630 000-year-old fossil corals for climate studies. But only a few of her samples were found to be useful.

Describing the painstaking work involved in getting good paleoclimate data for research, she explains why.

'Living corals have a porous skeleton composed of aragonite – a form of calcium carbonate – that is laid down in growth bands, much like tree rings, and which contains chemical signatures that vary depending on the temperature, water composition, rainfall and intensity of sunlight,' she says.

'This information can be used to build a picture of past climate. But when corals die, their skeletons gradually recrystallise and change chemical composition, rendering them unusable for climate studies. You can find well-preserved corals older than 120 000 years in some exceptional locations, such as Henderson Island, but otherwise they are extremely rare.'

Looking for alternative fossil climate records, Ayling and her PhD supervisors, Professors John Chappell and Malcolm McCulloch, revisited an older idea of using giant clams (*Tridacna gigas*). Work conducted by one of Chappell's students 25 years previously had shown that giant clams could potentially provide detailed climate information from



hundreds of thousands of years past.

At the time, the technology needed to unlock this information was in its infancy. However, recent technological advances in Professor McCulloch's laboratory at the ANU's Research School of Earth Sciences held promise.

With renewed hope, Ayling set off for the heavily forested slopes of Huon Peninsula in Papua New Guinea (PNG). Here, fossilised giant clams, which lived during a 40 000-year-long interglacial period known as Marine Isotope Stage 11 (MIS 11), can be found in ancient reef beds uplifted by geological processes to some 1200 metres above sea level. Ayling's new brief was to collect clams from MIS 11, which occurred between approximately 420 000 and 380 000 years ago, and attempt to obtain several snapshots of seasonal climate, recorded during the clams' 40–60 year lifespan.

MIS 11 is an important interglacial period for climate researchers because the Earth's orbit around the sun was relatively circular – as it is today. This means that the seasonal distribution of solar radiation across the globe in winter and summer was also very similar to today.

'For this reason, MIS 11 is believed to be a good analogue for the present interglacial period and, with a duration of 40 000 years, it was also unusually long,' Ayling says.

'More recent interglacials were only 10 000 to 20 000 years long and we're already 10 000 years into the current one. So the first question we are interested in is: is the next ice age imminent, or do we have another 30 000 years to go? The second question, and the big question in terms of climate change, is: what will rapidly increasing greenhouse gas concentrations do to our climate? Where's the threshold above which we alter things and after which we will enter a new climate state?'

Understanding the climate of MIS 11 will help paleoclimatologists answer these questions by providing a baseline with which they can compare pre-industrial era climate and the changes wrought more recently by rapidly increasing greenhouse gases. Real climate data from MIS 11 will also enable climate modellers to test and validate their models, improving their ability to reconstruct past climate and predict future climate.

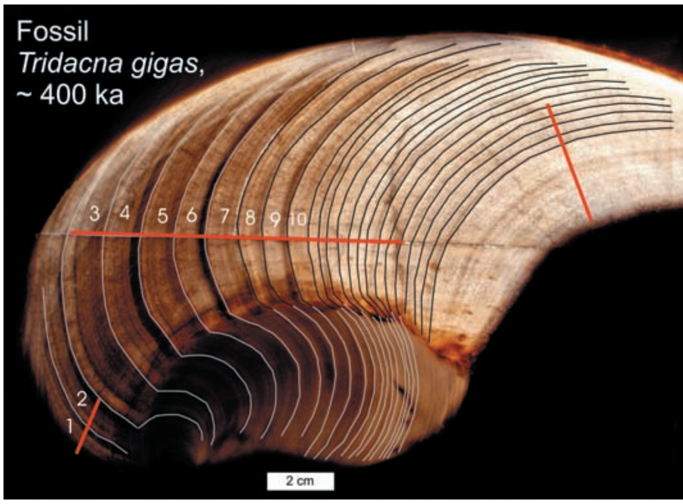
So in March 2004 Ayling and a colleague, Jol Desmarchelier, found themselves slogging up the slippery slopes of ancient reef terraces on PNG's Huon Peninsula, following two fitter and better acclimatised local guides they had enlisted to help.

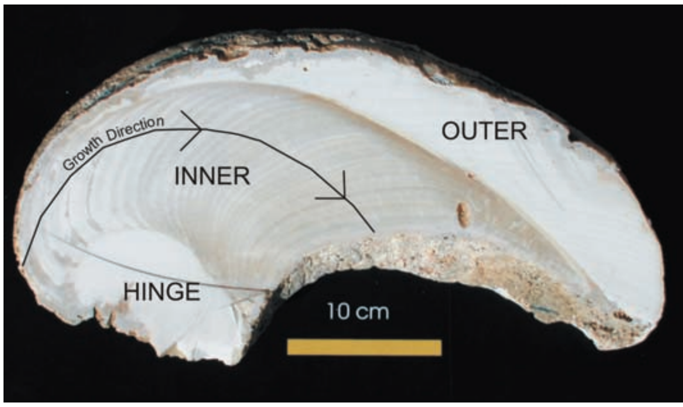
'We knew we needed to climb to about 1200 m elevation to find clams of the right age, but we didn't know where to look. We tried to explain to our guides what we wanted to find, but neither of us spoke much Niu Gini Pidgin, so it was difficult,' Ayling recalls.

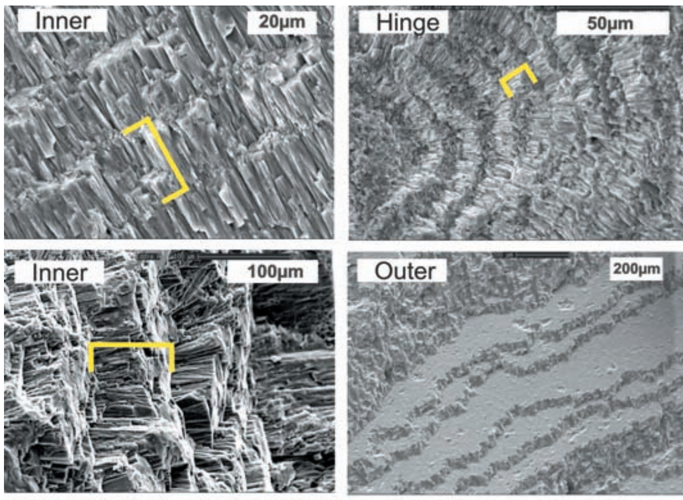
'They took us up a very rough track. It was hot and humid and we had trouble getting a foothold at times, but the guides made it look easy, walking over limestone and fossil coral in their bare feet. The forest was so thick around us that I didn't expect to find anything, but we did. We were very pleased and paid our guides well for their trouble.'

Excited by their find, but less enthusiastic about a return journey the next day, the pair decided to spend the night at a village further down the mountain. Sharing water crackers, a few cucumbers and some corn for dinner, Ayling and Desmarchelier roughed it under mosquito nets in the village guesthouse. Word of the pair's intentions and their generosity obviously spread during the night – Ayling was presented with a dozen giant clams, dug from villagers' gardens, the next morning.

'We were happy because we had so many clams,' Ayling says, 'but we were also a bit concerned because we didn't know where they'd come from. We needed to get a GPS location for each clam, as they could have come from different interglacial reef terraces, so we got the guides to take us back to the sites where the clams had been collected.'







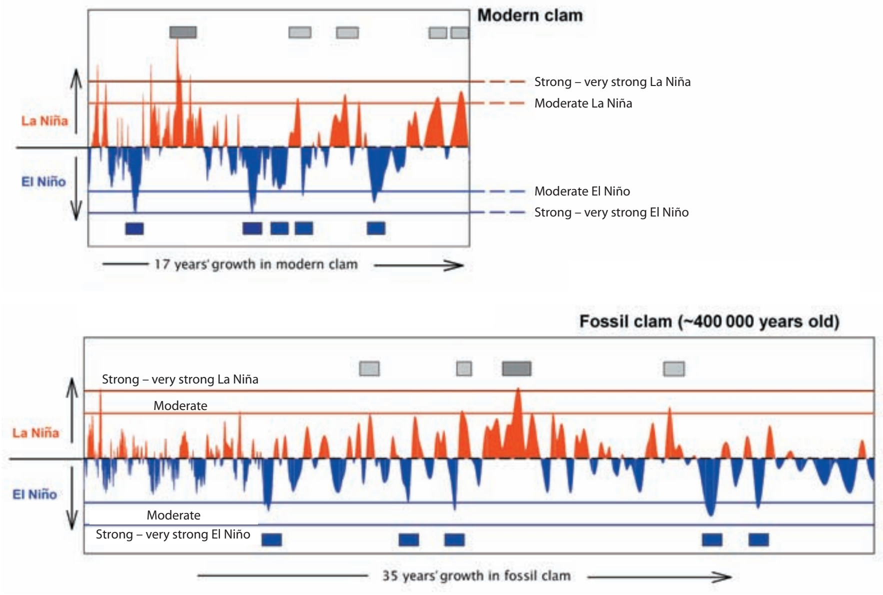
* Yellow bracket represents 1 day of shell growth

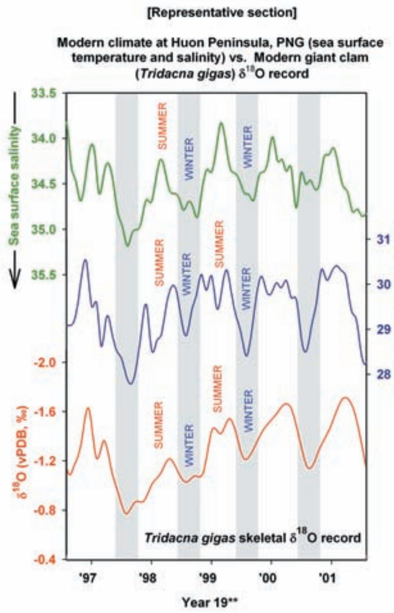
Top: A transmitted light picture of the fossil clam. The red line indicates the transect along which the chemical composition of the clam shell was measured. The numbers represent the age of the clam (in years) at various times during its life of between 40 and 60 years.

Middle: Large growth rings in the giant clam (*Tridacna gigas*) allow researchers to obtain detailed records of seasonal climate.

Bottom: Close-up views of the giant clam skeleton obtained using a scanning electron microscope. Daily growth bands of aragonite crystals can be seen in the hinge, inner and outer zones of the clam shell. Bridget Ayling/ANU

Weather records from clam growth





Left: El Niño and La Niña events recorded by the oxygen isotopes in a 17-year-old modern clam compared with El Niño and La Niña events recorded by a 35-year-old fossil clam that lived approximately 400 000 years ago. Threshold limits for moderate and strong/very strong El Niño or La Niña events are marked. Grey boxes above each record indicate La Niña events (where the event threshold is exceeded for more than a few months), and blue boxes below each record indicate El Niño events. Reconstruction of the relative seasonal climate from the fossil clam record indicates that El Niño and La Niña events were about half as frequent some 400 000 years ago than they are today. ANU

Right: The graph shows variations in sea surface salinity and sea surface temperature at Huon Peninsula, Papua New Guinea, from ship observations and satellite data between 1997 and 2001, and changes in the ratio of oxygen isotopes in a modern clam shell. The good correlation between changes in salinity, temperature and the clam oxygen isotopes shows that the clam shell acts as a useful climate archive. Such analyses are usually performed using modern material from the relevant geographic location, before fossil material is collected and analysed.[1] ANU

1 Salinity and temperature data sourced from http://iridl.ldeo.columbia.edu/SOURCES/.CARTON-GIESE/.SODA/.v1p4p2/

Ayling took GPS locations for five of the clams. The next priority was to get the clams – weighing some 40 kg each – down to base camp.

'The locals tied ten of the clams up with vines and hung them from a branch and the two guides carried them down across their shoulders,' Ayling says.

'We didn't want all the clams, but we couldn't communicate this to our guides, so we had to take them all.'

Back in the lab, Ayling began analysing one of her clams for its seasonal climate record. Her focus was on the central part of the clam, which grows to a thickness of 10–15 cm. Clams grow rapidly in the first ten years of an approximately 40–60 year life, and each annual growth ring can be 1–2 cm thick. But by about the age of 35, one year's growth ring may only be 2 mm thick.

Using laser ablation (a technique that vaporises solid materials into their chemical elements) and mass spectrometry (to identify and quantify these chemical elements), Ayling analysed 0.25 mm slices of shell for their chemical composition – predominantly their oxygen isotopes and trace elements including calcium, magnesium and barium. As these chemical signatures are closely linked to climate they can act as proxy records of climate. The ratio of the two oxygen isotopes – ^{18}O and ^{16}O – in the shell, for example, is determined by sea surface temperature and the oxygen isotopes present in seawater, which are affected by rainfall and evaporation, at the time the given portion of shell was formed. Different isotope ratios provide information on how warm the sea surface was and whether rainfall was high or low.

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In PNG, climate is strongly affected by the El Niño-Southern Oscillation (ENSO), a large-scale interaction between the ocean and atmosphere that affects rainfall, sea surface temperature and ocean productivity around the world in different ways.

'The Southern Oscillation is the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin, and this is linked to major temperature fluctuations in the surface waters of the tropical eastern Pacific Ocean, which regulate El Niño and La Niña events,' Ayling says.

'In Australia, El Niño is often associated with warmer temperatures and drought, while La Niña brings cooler temperatures and flooding rains. Since 1970, we have been in a state of increased ENSO activity. We don't know if this is the result of increasing greenhouse gases or a natural

Papua New Guinea's Huon Peninsula features a series of reef beds uplifted by geological processes to some 1200 metres above sea level. The upper terraces are now heavily forested, while lower terraces are covered in kunai grass. Bridget Ayling/ANU

A view back to the coast from the jungled field site. Bridget Ayling/ANU

Crowbars are used to remove a giant clam from its fossil bed in the rainforest. Bridget Ayling/ANU

climate fluctuation, but it's something the fossil record should give us some insight on.'

Remarkably, Ayling was able to tease out 35 years of seasonal climate detail – variability in rainfall and sea surface temperature in summer and winter – from her ancient clam. This information indicated that El Niño events were about half as frequent 400 000 years ago than they are today – an important finding.

'However, we only have one record, so we need to analyse more clams to be confident that this result is representative of MIS 11,' Ayling cautions.

'What I have shown is that clams are an excellent climate archive, perhaps even better than corals, which will allow us to build up a picture of this important interglacial period.'

Her PhD supervisor Professor John Chappell agrees.

'The exciting thing about Bridget's work is that she's shown it's possible to investigate these ancient times; that there are well-preserved seasonal signals in the clams. While a 35-year reconstructed climate record is not statistically sufficient to characterise the frequency of El Niño events, we have more material we can work with to improve the robustness of our conclusions and the data we can provide climate modellers.'

● **Wendy Pyper**

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