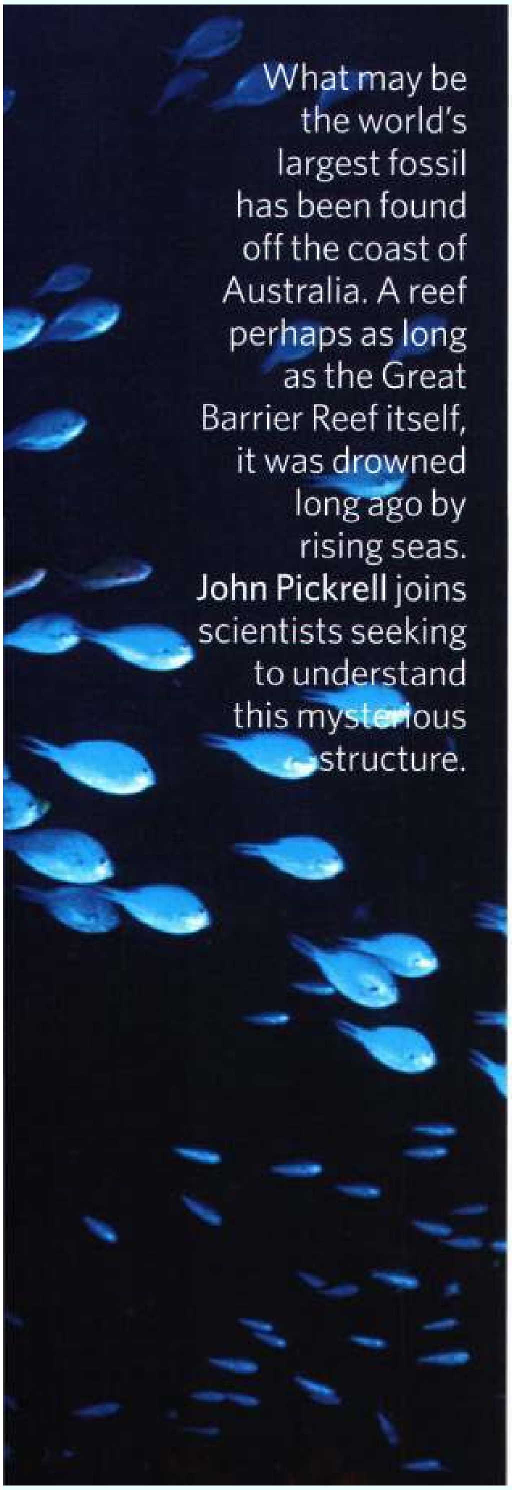
MEDIA MONITORS
INCISIVE INSIGHT

Cosmos
Saturday 1/11/2008
Page: 52
Section: General News
Region: national
Type: Magazines Science / Technology
Size: 4,063.87 sq.cms.
Published: Bi-monthly

THE DROWNED REEF



What may be the world's largest fossil has been found off the coast of Australia. A reef perhaps as long as the Great Barrier Reef itself, it was drowned long ago by rising seas. **John Pickrell** joins scientists seeking to understand this mysterious structure.

I'M SITTING IN FRONT OF A TIME MACHINE. We're deep in the bowels of a survey ship, 50 km off the coast of Cairns. It's mid-afternoon and the room hums with the quiet whirr of a bank of busy computers and the distant clanking of the engine room.

"The machine is just giving us an update of what the present situation is," says Robin Beaman, my tour guide to the Palaeolithic past of this part of Australia. "It's not something you can leave and forget, it's a very complicated machine and it needs watching and tweaking occasionally." He taps away at the computer, calibrating it. There's a ping, and an array of data and scribbly lines dance across the screen. It doesn't mean much to me. But, somewhere beneath the ship, pulses of sound energy have been unleashed and they're bringing back a grainy picture of the past.

Beaman takes me to another screen that renders the stream of data into something I can understand. He shows me an aerial view of an ancient river bed. A waterway meanders between limestone hills. "In fact, this may even have been a waterfall at some stage," he muses, concentrating hard and pointing at one part of the image. "It almost has waterfall-like features, with the rivulets coming through here ... [and] on either side of the river channel is the drowned reef."

It's not a time machine in the strictest sense, but this multi-beam or 'swath' echosounder is, for the first time, giving us a vivid picture of an ancient coastline which met its demise long ago. It's a high-tech sonar mapping device that simultaneously sends out 135 individual pulses of sound. This carpet of sound bounces off the seafloor, as far as two kilometres beneath us in some places, and brings back the first detailed, three-dimensional (3-D) topographical maps of the ocean bottom around Australia's Great Barrier Reef.

Twenty thousand years ago, with much of our planet's water locked up in Ice Age glaciers, sea levels were much lower than they are today. So even though we're 50 km out from the modern coast of Queensland, we're floating above an ancient shoreline from a time when this part of Australia looked very different: "During the last Ice Age, the Great Barrier Reef as we know it was high and dry. It was a marshy mangrove plain and Aborigines would have been roaming across the landscape hunting and fishing," says Beaman, a marine geophysicist with the Cairns campus of James Cook University (JCU). "That's not to say these coral reefs didn't exist; but they existed as limestone hills covered with eucalypt forest."

On the seaward side of this ancient shoreline, though, is the scientist's real quarry. It's an ancient reef that runs in deeper waters, all along the edge of the continental shelf. Beyond that, the seafloor drops away to the deep abyss; but this narrow strip, an average of 40 to 70 m deep and a few hundred metres wide, was once teeming with a plethora of hard and soft corals and brightly coloured reef fish. Then, over hundreds of years, sea levels rose so rapidly that the reef was unable to grow in height fast enough to keep up. It 'drowned', and today languishes in deeper waters, a more thinly populated shadow of the ecosystem it once was.

Remarkably, the experts are only just beginning to understand the true extent of this structure, which they suspect was the major part of the Great Barrier Reef for 60 to 85 per cent of its 500,000-year history. Unlike today's living reef, which is a patchwork of nearly 3,000 smaller reefs stretched over 2,300 km, the drowned reefs are "truly the Great Barrier Reef because they are nearly unbroken for more than 700 or 800 km," says Beaman. »

Ref: 43152664

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Today, the Great Barrier Reef is made up of thousands of smaller reefs, but the ancient reef may have been much less fragmented.

"During the last Ice Age, the Great Barrier Reef was a marshy mangrove plain and Aborigines would have been roaming across the landscape hunting and fishing."

"As the sea level rose after the last Ice Age [ending 19,000 years ago] the very first part of the Great Barrier Reef was growing on the edge of the continental shelf – it was the first part of the continental shelf to actually have water coming up onto it," he explains. "The thing is, it didn't continue. That's the big question: why didn't it continue?"

With each discovery new questions arise, and finding the answers could help predict what will happen as climate change threatens to bring catastrophic sea level rises this century.

ONLY THE DAY BEFORE, I'd joined Beaman and a small team of scientists on the RV *Southern Surveyor*, an ocean science vessel run by Australia's national science agency, the CSIRO.

It's late July and the scientists are starting at Cairns (where I board the boat), sailing for two and a half weeks (via Port Douglas, from where I depart two days later) and ending up at Gladstone – hundreds of kilometres down the coast. They'll be weaving their way around reefs as they go, largely collecting water samples for a study of how increasing atmospheric carbon is making the oceans more acidic, but also imaging large portions of the seafloor.

To create a detailed 3-D map, the boat goes backwards and forwards across a given section of the ocean, in a process described wryly as "mowing the lawn". The strips – which are anywhere between a few hundred metres and three kilometres wide depending on the depth of the seafloor – are then stitched together by a computer and plotted onto existing maps using GPS coordinates.

The reason we know so little about the reef – existing and extinct – is that the seafloor around Australia is about the most poorly mapped of any developed country – partly due to its enormous coastline and small population, but also because of a dearth of government-funded marine survey vessels. The crew describe the scale of the problem to me by noting that Belgium, a country with 66.5 km of coastline, has more government-funded marine science vessels than Australia, which has a coastline 387 times longer, at 25,760 km. In fact, Australia has just one dedicated vessel for its own coastline, and I'm aboard it (though another research ship, the RV *Aurora Australis*, is Australia's Antarctic flagship).

"For most of the U.S. and U.K. coast, the seafloor is very well mapped. Australia is really lagging behind," says Beaman, a youthful-looking 44-year-old who has short dark hair and an infectious enthusiasm for his work. "Here we are off the coast of the Great Barrier Reef, and there are areas that we know virtually nothing about." The other reason the region is so poorly mapped is that it's a dangerous place. Reefs are dotted about everywhere and can rear up suddenly out of shallow water. Boats typically stick to an easily navigable shipping channel, which hugs the coastline.

Without the help of detailed maps, or any idea of the extent of the structure, one marine scientist did make valiant attempts to understand

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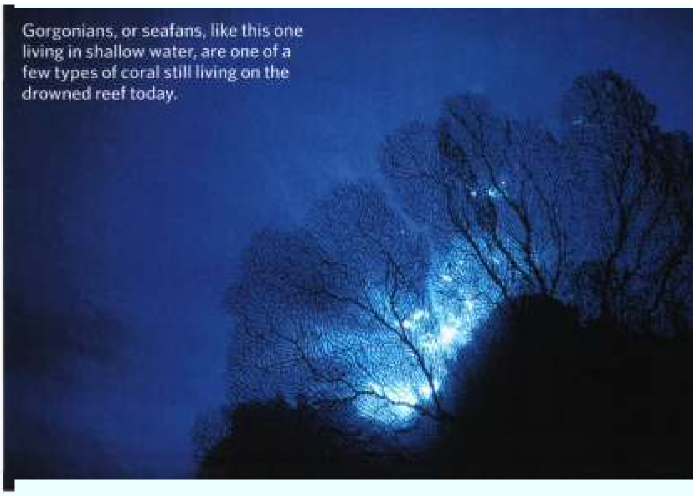
Robin Beaman (far left) talks to John Pickrell aboard the RV *Southern Surveyor*.

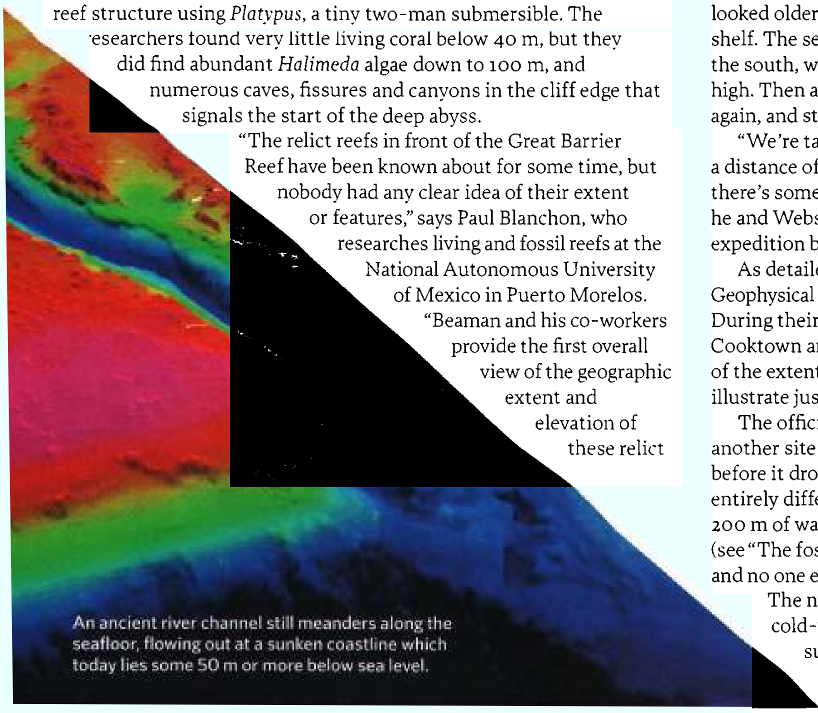


Gorgonians, or seafans, like this one living in shallow water, are one of a few types of coral still living on the drowned reef today.

parts of the drowned reef between the 1960s and 1980s. David Hopley, now retired, is an adjunct professor at JCU and the authority on the geology of the Great Barrier Reef. He's been amazed to finally discover just how extensive the drowned reefs are. "The amount of technology available now is nothing like what we had in the 1980s," Hopley told me by phone from his home in Townsville. "What Jody Webster [Beaman's co-worker on the project at JCU] and his team have been able to achieve is on a different scale to what we were able to do."

Despite the limitations, in October 1984, Hopley worked with University of Sydney researchers to explore one part of the fossil reef structure using *Platypus*, a tiny two-man submersible. The researchers found very little living coral below 40 m, but they did find abundant *Halimeda* algae down to 100 m, and numerous caves, fissures and canyons in the cliff edge that signals the start of the deep abyss.

"The relict reefs in front of the Great Barrier Reef have been known about for some time, but nobody had any clear idea of their extent or features," says Paul Blanchon, who researches living and fossil reefs at the National Autonomous University of Mexico in Puerto Morelos. "Beaman and his co-workers provide the first overall view of the geographic extent and elevation of these relict reefs, and it implies that they were just as well developed as the present Great Barrier Reef, and possibly just as extensive."



An ancient river channel still meanders along the seafloor, flowing out at a sunken coastline which today lies some 50 m or more below sea level.

THE FIRST CLUES to the full extent of the drowned reef came around two years ago when Beaman and Jody Webster, who is a lecturer in marine geoscience at JCU's Townsville campus, pored over maps made by the Royal Australian Navy. Though rudimentary, and collected for navigation, they were the best available for the region.

They quickly spotted curious parallel ridges along the edge of the continental shelf near Cairns. These mysterious structures looked older and smoother than the living reefs further up the shelf. The second piece of evidence came from Flora Passage, to the south, where the ridges appeared again, 200 m wide and 20 m high. Then at a third site, also near Cairns, they found the ridges again, and strange pinnacles, at depths of 50 to 60 metres.

"We're talking about geological features that are similar over a distance of 80 km – now that's not a coincidence [we thought], there's something real there," says Beaman. And that's the evidence he and Webster used to get funding for a *Southern Surveyor* expedition between September and October 2007.

As detailed in a preliminary paper, published in the American Geophysical Union journal *EOS* in June 2008, it was a spectacular success. During their voyage – which covered nearly 1,500 km between Cooktown and Mackay – they not only succeed in plotting much more of the extent of the drowned reef, but also made major discoveries that illustrate just how little we really know about the region.

The official Australian map for the seafloor around Noggin Pass, another site near Cairns, shows a relatively smooth continental shelf, before it drops off to the deep abyss. But the sonar maps revealed an entirely different story: 20 or more submarine canyons that start in 200 m of water and violently plunge to depths of up to 1,200 m (see "The fossil barrier reef", p56). "These are vast escarpments, and no one even knew they existed," says Beaman.

The next big surprise was the discovery of deep-sea, cold-water corals. Not far from the bottom of some of the submarine canyons, the research team found eight bumps on the seafloor, each several kilometres long, 200 m wide and 100 m high. At these depths, conditions are vastly

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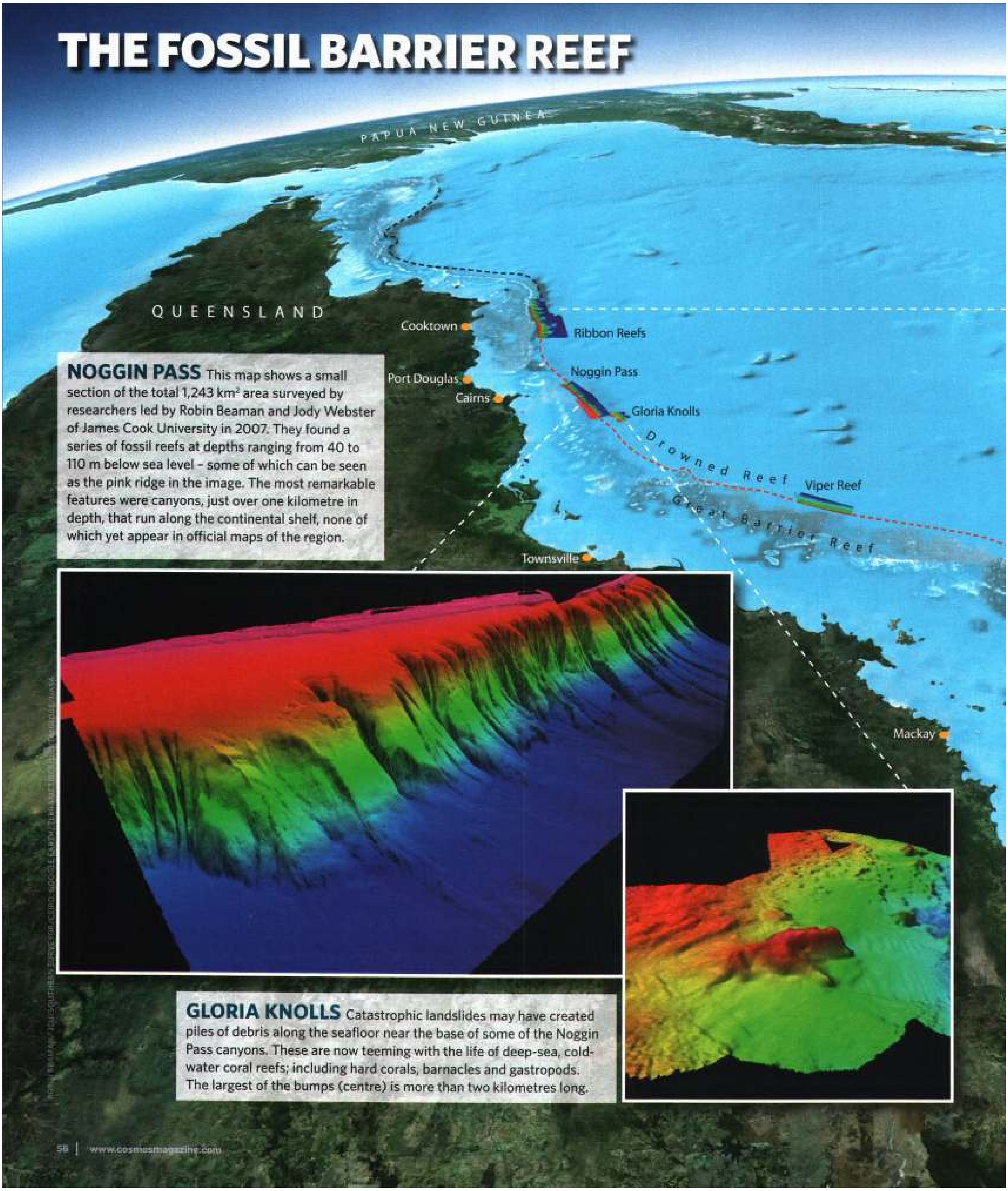

THE FOSSIL BARRIER REEF

NOGGIN PASS This map shows a small section of the total 1,243 km² area surveyed by researchers led by Robin Beaman and Jody Webster of James Cook University in 2007. They found a series of fossil reefs at depths ranging from 40 to 110 m below sea level – some of which can be seen as the pink ridge in the image. The most remarkable features were canyons, just over one kilometre in depth, that run along the continental shelf, none of which yet appear in official maps of the region.

GLORIA KNOLLS Catastrophic landslides may have created piles of debris along the seafloor near the base of some of the Noggin Pass canyons. These are now teeming with the life of deep-sea, cold-water coral reefs; including hard corals, barnacles and gastropods. The largest of the bumps (centre) is more than two kilometres long.

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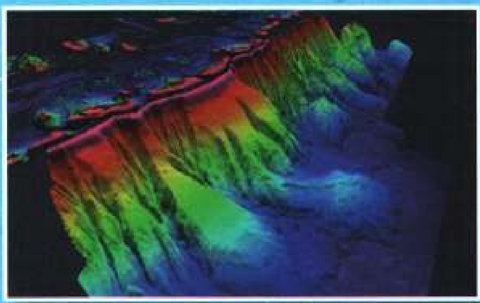
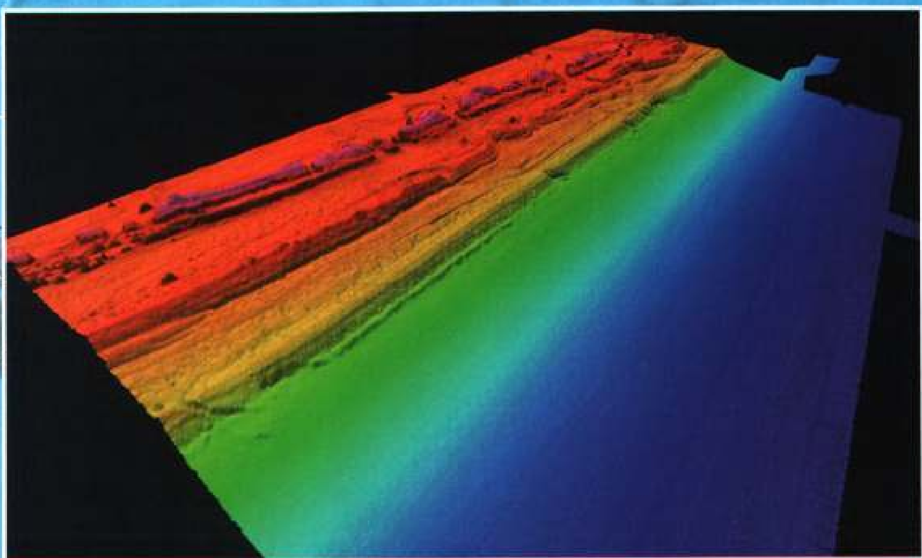
ILLUSTRATION *Andrew Davies*

Australia's Great Barrier Reef is made up of 3,000 smaller reefs scattered along 2,300 km of the Queensland coast. But running on the seawards side, for 900 km or more, is a fossil reef, drowned when sea levels rose rapidly many thousands of years ago. Researchers are now using a sonar technique to create detailed maps of the seafloor that will reveal the full extent of the structure. It's hoped that studying the reefs will provide new information about ancient sea levels and help us protect today's living reef from climate change. The maps below, created using an echosounder, indicate relative depths of the seafloor, with red denoting the shallowest and violet the deepest parts. The dotted black line shows the edge of the continental shelf, while the red part indicates the known extent of the fossil reef.



RIBBON REEFS This map shows a 20-odd-kilometre-wide swath of the continental shelf punctuated by deep submarine canyons and ravines that lead down several kilometres into the depths of the Queensland Trough. The fossil reef, at around 50 m below sea level, can be seen as pink bumps along the top of the shelf's edge. It was at one of these reefs that the only manned submersible to examine the fossil reefs was taken down in 1984.



HYDROGRAPHERS PASSAGE This image shows a survey site around 40 km in length. The drowned reef can be seen very clearly as the series of pink and red ridges, mostly between 40 and 70 m below sea level, that run right across the top of the image. No submarine canyons were found at this site and the continental shelf drops off smoothly into the abyss of the Queensland Trough.

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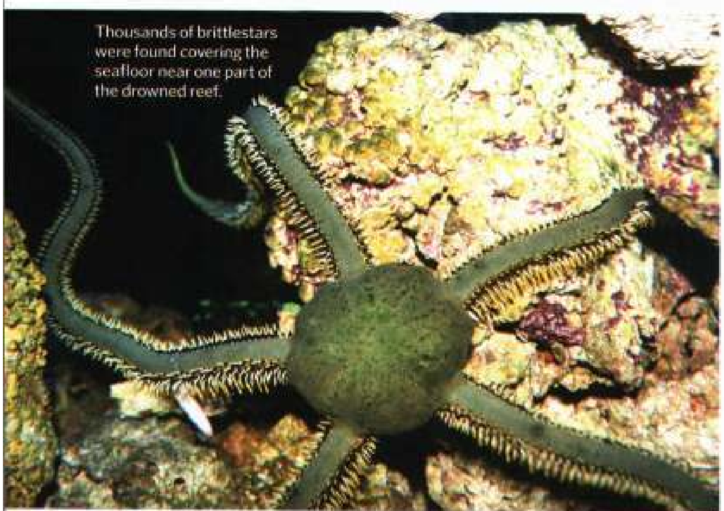
different to those of the tepid tropical waters at the surface: little light penetrates and the water is a fairly constant 4° C. Yet life still persists here and a rock dredge (using a sampling device lowered from the boat on a cable) revealed that the bumps were deep-sea coral reefs, and returned living gorgonian and dead scleractinian corals as well as snails worms and shell plates of what appear to be giant barnacles.

A deep-sea reef near Macquarie Ridge, southeast of New Zealand; experts think species found on sunken reefs off Queensland are similar to those already known from New Zealand.



Thousands of brittlestars were found covering the seafloor near one part of the drowned reef.

Preliminary analysis suggests the species are similar to those known from seamounts off southern New Zealand. "The fact that they were so close to the Great Barrier Reef was a huge surprise, we never thought they would exist," says Beaman. His guess is that more exist all along the continental shelf edge, wherever there are canyons, but it's still early days and only further research will tell.

Up on the edge of the continental shelf, where the canyons originate, the drowned reef is found at Noggin Pass too. The 2007 expedition also mapped the titanic fossil for hundreds of kilometres along the coast at the Ribbon Reefs, 60 km from Cooktown, Viper Reef off the coast of Townsville and a region known as Hydrographers Pass, 200 km out from Mackay. These disparate sites proved just how far-reaching the structure is (it's currently thought to extend 900 km, though the scientists have yet to confirm its northern and southern limits).

Further work with a camera-mounted, remotely-operated submersible revealed life such as algae, soft corals, gorgonians and brittle stars living on the surface of the drowned reef, but none of the variety of life and living hard corals that characterise the shallower reefs today.

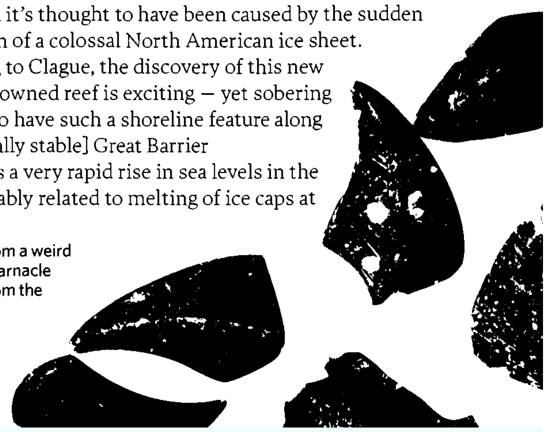
CORAL REEFS CAN cope with some sea level change. Hard corals can lay down sediment and grow vertically as sea levels rise – or reefs can creep sideways up slopes to retain an optimal depth. In this way they capture enough sunlight to support the photosynthetic algae on which they rely.

We are currently in an 'interglacial' period. The last glacial maximum ended 19,000 years ago, but during the grip of that Ice Age, sea levels were up to 120 m lower than today. As the planet warmed up, the ice melted and sea levels gradually rose.

Occasionally, though, something happens that causes a more catastrophic pace of sea level rise. Then, coral reefs are unable to keep up and the lack of nourishing sunlight 'drowns' them. Over the last 15 years or so, as technologies have improved, scientists have begun to discover drowned reefs in many parts of the world, from the Caribbean to Tahiti. Studying them is helping to build a picture of how sea levels may rise with climate change over the next several centuries.

Webster has worked with David Clague of the Monterey Bay Aquarium Research Institute (MBARI) in California, USA, to understand one of the best-known drowned reefs, off the coast of Hawaii. Now located at a depth of 150 m, and slowly sinking, this reef was drowned when sea levels rapidly rose 14,700 years ago, radiometric dating has shown. Scientists have labelled this event 'meltwater pulse 1A', and it's thought to have been caused by the sudden disintegration of a colossal North American ice sheet.

According to Clague, the discovery of this new Australian drowned reef is exciting – yet sobering – science. "To have such a shoreline feature along the [geologically stable] Great Barrier Reef...implies a very rapid rise in sea levels in the past, presumably related to melting of ice caps at



Shell plates from a weird type of giant barnacle dredged up from the deep-sea reef.

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the end of the glacial period," he says. "These events are thought to have been triggered by catastrophic release of impounded meltwater from the receding glaciers on North America."

Though Beaman and Webster's team has not yet completed radiometric dating work on coral remains sampled from the fossil barrier reef, Beaman agrees that it was likely drowned by a meltwater pulse 10,000 to 20,000 years ago. "We were getting tens of metres of sea level change over a period of 1,000 years, and for the Aborigines using this landscape it must have been quite frightening," he says. "Every year the shoreline retreated further inland, by several hundred metres, so it meant they had to keep moving camp."

If such a pulse occurred today, it could threaten low-lying cities such as Sydney, London and New York – and a number of alarming recent studies say that the break-up, or rapid melting, of the ice sheets is much more of a risk than we realise. In 2002, a 3,259 km^2 piece of the Antarctic Ice Sheet – roughly the size of the U.S. state of Rhode Island – snapped off. Since it was already floating, it didn't have a major effect on sea level, but it made experts pause to ponder what would happen if a similar 500-billion-tonne mass of ice was dislodged from the Antarctic continent itself.

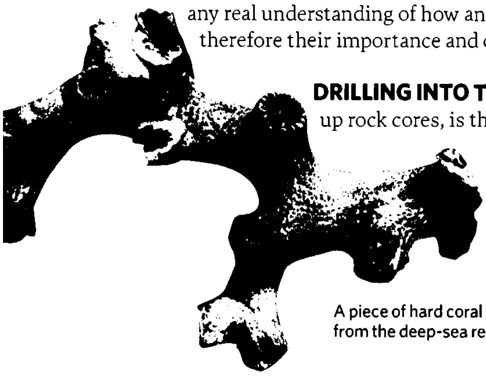
Blanchon, of the National Autonomous University of Mexico, says that although drowned reefs have been known of for some decades, their significance has only recently been appreciated. Prior to the mid-1990s, most reef scientists "were in denial", he says; though they knew reefs could grow vertically and accumulate rapidly, they found it hard to contemplate that sea level could rise fast enough to outpace the reefs, because established theory said ice sheets melted steadily.

But all that changed when swaths of sediment from ice sheets were discovered on the floor of the North Atlantic Ocean. "These were deposited by an armada of icebergs that were released when ice streams started to rapidly drain the interior of the North American Laurentide Ice Sheet," says Blanchon. "As the ice sheet collapsed – spewing bergs out into the Atlantic – sea levels started to rise dramatically. When it was all over, sea levels had jumped between 11 m and 16 m in less than 400 years, leaving a legacy of drowned reefs, lagoons and shorelines around the planet."

There's a good chance the newly discovered fossil reef can answer numerous questions about sea level change as the last Ice Age ended. This particular period of sea level change is one that we know little about, "but it can tell us a hell of a lot about how sea levels will respond in the future under different global climate scenarios," says Beaman.

Unfortunately, though, with research on the drowned barrier reef at such an early stage, it's impossible to tell when the reefs started to grow, or when they died, says Blanchon. And the "lack of data precludes any real understanding of how and why these reefs died and therefore their importance and climatic context".

DRILLING INTO THE fossil reef, and bringing up rock cores, is the only way we can get answers to these questions, and that's exactly what the scientists plan to do next. Tentatively scheduled for September 2009, the world's biggest marine geology project, the Integrated Ocean Drilling Program (IODP), will be coming to Australia.



A piece of hard coral brought up from the deep-sea reef.

A rock core is a long tube, 10 cm in diameter and tens of metres in length, and looks something like a monster stick of chalk. Back in the lab, scientists can cut it down the middle and study the layers of coral laid down over millennia. From this, says Beaman, they hope to glean all kinds of information, from the species of coral present and how these relate to modern species, to the chemical composition of the Palaeolithic seawater. They will also complete detailed radiometric dating. By testing at different levels down the core, they can get a perfect timeline of climatological and other events, just as you can with an ice core.

Will this tell us what life was like on the ancient reef? In terms of species of coral, we've probably not seen a whole lot of extinction or evolution during the last 20,000 years, says John Pandolfi, a palaeoecologist of coral reef systems at the University of Queensland in Brisbane. So the fossilised corals we find in the rock cores are likely to be similar species to those on the living reef, he predicts – but in different abundances and compositions.

"The abrupt and significant environmental changes that accompanied deglacial sea level rise have barely been investigated," said Gilbert Camoin, a researcher with France's National Centre for Scientific Research (CNRS) in Aix-en-Provence, and principal scientist for the proposed IODP Great Barrier Reef expedition. "In particular, there are few studies that tackle the environmental changes recorded by changes in reef communities." The rock cores, Camoin hopes, will help provide some answers about shifting reef communities.

Aside from answering bigger questions about global climate, says Camoin, studying the composition of ancient coral communities may help us protect the living reef, which is threatened by warming waters, bleaching and pollution today, and rising sea levels in the future.

Pandolfi agrees that the ancient reef, which was crammed onto a narrow strip at the edge of the continental shelf during its life, could be a good analogue of how today's reef will react as warming waters force it into tighter patches of habitat.

We have good evidence that reefs are resilient, and were able to re-establish themselves at shallower locations in previous interglacial periods, says MBARI's Clague. But he warns that today's set of circumstances are unique, and there may be limits to what the fossils can tell us: "The present may be very different [because the] global climate is already as warm as during any previous [interglacial] period in the last several million years, yet the trends say it is still going to get warmer and the oceans more acidic. This means the past, recorded in drowned coral reefs, may not be a very good predictor of the world we are now entering."

Whatever the practical results that come of the IODP work may be – and of which there are likely to be many – for some of the scientists involved it might just be the exploration of a whole new Australian frontier that has them hooked. "We spend a lot of time focussing on the shallower reefs in the World Heritage Area, but to me it's the bits you can't see that are truly fascinating," says Beaman.

"It's a landscape that is incredibly complex and has all kinds of marine life that we didn't even know existed," he muses, as we sit in front of his time machine in the depths of the survey ship. "Yet, this is just 60 km from Cairns, one of the tourism capitals of Australia. It just shows how little we still know about our own backyard."

JOHN PICKRELL *is deputy editor of* Cosmos *and editor of* Cosmos Online. *While at the Great Barrier Reef he swam with a turtle and saw a giant clam big enough to swallow a child.*