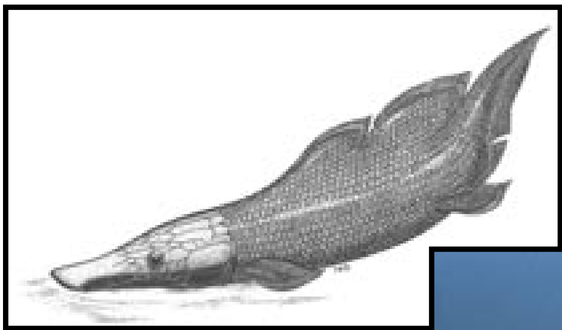
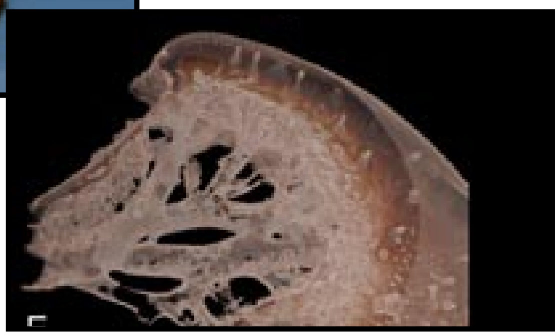
CSEM's
# Materials Monthly
April 2006 Making materials matter

# Old brains, new data

**X-ray computed tomography has proven to be a big winner in understanding the structure and function of many materials. Now it's being used to decipher a particularly exotic material - fossil bones that are hundreds of millions of years old.**



*Opening new windows on our evolutionary past:* Griphognathus whitei *(above and right) was a species of lungfish that lived 375 million years ago. X-ray CT scans are now revealing fantastic new detail (far right) about the internal structure of the skulls of these and other lungfish - detail that has never before been available and which holds the potential to unlock the evolutionary development of the vertebrate brain.*



The physical chemist set up his lap top before the small group of palaeontologists and said "I think you'll all be interested in this. I just scanned it last night so no-one's seen it yet."

He opened a file and there on the screen was what looked like a lump of brown stone.

"Okay, that's a fossilised ear bone of one the earliest known whales in the fossil record," the young scientist explained. "It's about the size of a walnut and the bone is incredibly dense.

"This is what we discover when we scan it using the CT."

He starts the animation and the lump of brown rock dissolves away to reveal an intricate array of circular tubes and canals at the centre of the bone – the inner workings of an extinct whale's ear. It's available in exquisite three dimensional detail and can be viewed from any direction.

Around the room there are gasps of amazement and awe at both the beauty and the detail of the structure on the screen. They're just as impressed by the power of the technique that has delivered them this new information for the truth is, as they are quick to acknowledge, prior to the X-ray CT technology being available there was no easy way that such detailed structural information could have been extracted from a fossil such as the whale ear bone.

### Materials science meets paleontology

The scene just described took place last month in a tea room in the Department of Earth and Marine Sciences (EMS). The palaeontologists present were Professor Ken Campbell, Dr Dick Barwick and Dr Gavin Young, three of the country's leading experts on Devonian fish. They are all currently Visiting Fellows at EMS.

The physical chemist was Dr Tim Senden and the CT he referred to was the X-ray Computed Tomography facility run by the Department of Applied Maths (Research School of Physical Sciences and Engineering). The CT uses X-rays to image slices of a sample and then a computer to stitch these slices together to build a 3D model of its structure. (see box on the CT Lab).

"Our X-ray CT is one of the finest around," says Dr Senden, a Research Fellow at Applied Math. He played a key role in developing the facility. "When it comes to mapping the fine structure of complex materials over length scales of microns to millimetres there are few other facilities anywhere that can match our capacity.

"The facility has been used to characterise a diverse range of structures and materials. For example, it's been applied in a wide ranging investigation on the nature of oil-bearing rock. Many of the rocks we've examined have contained a number of fossils but up until recently the focus has never been on providing information on

**continued on next page**

## Inside this MM



**Volume VII, Issue III**

*Materials Monthly* is produced by the ANU Centre for Science and Engineering of Materials

ANU
THE AUSTRALIAN NATIONAL UNIVERSITY

## Old bones, new data

(continued from previous page)

the fine scale structure of those fossils. However, that all changed several months ago when Dick Barwick approached our group to see if we might be able to help map out the internal structure of several lung fish fossils they had been working on."

Now, when it comes to fossil lung fish ANU is blessed both in having world experts on the topic and one of the richest sources of fossils near by.

### Old bones

Some 400 million years ago, in a time known as the Devonian Period, the area west of Canberra was a shallow tropical sea with coral reefs, large bony predatory fish and shell-crushing lungfish. Evidence of this time can still be found at Wee Jasper in the form of fossilised lungfish, some of the best preserved fossils of their kind found anywhere. What's more, the conditions of their fossilisation has meant that

*The beautifully preserved skull of the lungfish* Chirodipterus australis *with X-ray CT detail of the structure of its snout.*
*(Fossil image above & on page 1 courtesy of Dick Barwick.)*

the fossils can be extracted from the surrounding rock with their fine details still intact.

"The bones are embedded in limestone," says Professor Ken Campbell, a world expert on the evolution of lung fish. "Bone is apatite, calcium phosphate, and the OH molecule is usually replaced by fluorine, so you get fluorapatite as the common preservation. That dissolves in acetic acid but only very, very slowly.

"We found by practical experience that by putting these things in acetic acid you could take away all the limestone and the fossil would be preserved. This is possible only if you etch it for two days, wash it for three days to get rid of any salts that had been deposited, dry it out, put it under a microscope and, using a highly penetrative plastic on the end of a camel hair brush, cover up all the exposed bone. By doing this over about four months you can get a specimen clear of the limestone matrix."

Over many years of collecting at Wee Jasper and other locations around Australia* and the world, Professor Campbell and his colleagues have put together one of the most important collections of Devonian lung fish ever assembled. (*The two examples pictured in this story - *Griphognathus* and *Chirodipterus* - both come from Gogo in the Kimberleys, WA. It's another famous fossil lung fish site in Australia. These fossils are slightly younger than the Wee Jasper fossils.)

The palaeontologists have spent countless hours patiently unlocking these fossils from their rocky prisons and, in the process, uncovered many of the secrets of their evolutionary development. This collection now resides in a fire-proof strong room at EMS where its specimens are available to researchers seeking to unravel their evolutionary development.

"The acetic acid goes right down all the tubes connecting to the exterior of the lung fish," says Professor Campbell. "You can see the nerves coming out of the brain and the position of the jugular vein as it comes in, you can see the notochord and the brain – the degree of anatomical detail which became available with this technique opened up our understanding of these early vertebrates."

Which all serves to further our understanding on the evolution of the vertebrate brain.

### Old brains

"The vertebrate head has developed over some 500 million years of evolution," says Dr Gavin Young. "Of all the complex structures biology has provided, the evolution of the vertebrate brain and its sensory organs is perhaps the most enigmatic. The fossil record occasionally provides us with a chance to trace this evolution but the finer detail of the internal structures of these fossils are fiendishly difficult to unravel. We have the specimens, now it's a matter of finding ways of understanding their internal detail.

"We were aware of X-ray scanning techniques being applied to the study of fossils overseas, indeed the X-ray CT facility at the University of Texas at Austin is world renowned in this field. So Dick Barwick made a few enquiries."

"Despite our keen interest in exploring the potential of X-ray CT we were unhappy about sending irreplacable fragile skulls overseas to Texas," says Dr Dick Barwick. "So, I made some enquiries locally to find out if similar technologies might be available and discovered, much to our surprise, that the Department of Applied Maths had its own X-ray CT facility.

"We were put in contact with Dr Tim Senden from Applied Maths who has now assisted us with a number of investigations on a range of fossils. The detail we are uncovering is simply astounding and it seems that not only do we have a local CT facility, but it's operating at the cutting edge of what's possible in this field."

### New data

"Our CT facility has been designed, built and operated by an impressive group of engineers and physicists," says Dr Senden. "It was built with state of the art components and we have access to the best computing processing power around through the ANU Supercomputer Facility. Indeed, one of our colleagues Dr Ajay Limaye in the Vizlab at the Supercomputer Facility has just released a freeware version of a brilliant visualisation program called Drishti to assist in working with the data collected by the CT.

"Apart from the hardware, the stand out feature of this facility is the strong group of computational physicists behind it. This strength

*Dr Gavin Young (left) and Professor Ken Campbell examine priceless lungfish fossils in the EMS Fossil Strong Room.*

makes it so much more than a visualization tool. The strength of the group lies in building physical understanding from the 3D framework that the CT provides. This research is principally supported by the petroleum industry, but many other areas of science benefit directly.

"When you put all these factors together you have a unique capacity, one that is proving very valuable to the palaeontologists. In combining their knowledge and treasure trove of unique specimens with our X-ray CT I feel we're making a substantial contribution to their field."

"The new data we're generating will radically change views on the evolutionary relationships of the major groups of jawed vertebrates," says Dr Young. "It's an exciting time to be involved in this work."

And the enthusiasm is not just being felt by the palaeontologists.

"This is some of the most exciting work I've been involved with," says Dr Senden. "To see how intuitive these gentlemen are with these fossils, and to witness the thrill they get when we reveal new detail in these treasures is tremendously rewarding. It's also opening my mind to new scales of time and space, scales in which life on Earth has evolved complexities from which we have all sprung."

And it seems that the seeds of interest that have been planted through this collaboration are yielding some interesting fruit. Dr Senden is now working with some of Australia's other top palaeontologists on a range of fossils including the earliest known animals in the form of the Edicaran fauna and the world's earliest mammals.

**More info: Tim.Senden@anu.edu.au on the X-ray CT and GYoung@ems.anu.edu.au on the palaeontology.**

## The X-ray CT Facility

The X-ray Computed Tomography facility probes the structure of materials by taking a number of X-ray images of an object from a variety of angles. Computers then stitch the images together to build a 3D model of the structure. It's the same process as medical CAT (Computerised Axial Tomography) scans taken in hospitals to image the body although in CAT scans the patient stays in the same position and the X-ray scanner moves around the body; in the CT lab the X-ray scanner stays stationary and the object is rotated.

The X-ray CT at Applied Maths is one of the few facilities in the world that can measure over three scales of magnitude simultaneously - from microns to millimetres. Further, the facility was purpose designed to be as flexible as possible allowing a wide variety of samples to be analysed over a broad range of time scales.

During the scan the sample rotates within a fixed X-ray microscope. The X-ray camera then records 2D radiographic information over a variety of rotation angles. Computer manipulations of the data allows the construction of a three dimensional image of the sample's structure.

While X-ray tomography has been around for many years, the CT lab put together by Applied Maths has many unique attributes which give it incredible power and flexibility. The micro-focus X-ray source can produce a wide range of X-rays (30-225 kV) suitable for scanning soft biological materials through to hard materials like stone or metal.

The X-ray detector is an extremely sensitive 16-bit, scintillator-coupled 2048x2048 pixel CCD camera mounted on a linear rail allowing it be moved back and forth from the sample and X-ray source. Moving the camera gives a range of magnifications from 3x through to 100x. The sample is mounted on a precision rotation stage, and the entire apparatus sits on custom-built vibration isolators (allowing the sample, X-ray source and detector to be rock steady over long time periods). The facility is contained in a lead-lined room with safety interlocks.

Because the CCD camera is so sensitive, and the apparatus is so stable, the X-ray source can be used at low power for extended periods of days to weeks meaning structural changes can readily be monitored over time. Because the apparatus is simple and open (ie, not encased in restrictive lead shielding, the lead is in the surrounding walls) elaborate experimental rigs can be accommodated.

The X-ray CT is being used to characterise and model a wide range of materials including soils, sedimentary rocks, minerals, wood, bone, polymer composites, foams, catalysts, coatings, gels, concretes and ceramics. The results of this materials science will include the development of improved biomaterials, achieving higher yields of oil extraction from rocks, and designing better paper for printing.

The astounding success of the X-ray CT facility has led to enormous interest in expanding the work. Consequently, Applied Maths is about to build another three CT facilities. One is for the department itself, the second is for research collaborators at the University of NSW and the third is for a petroleum company. The new systems will be four times as fast with three times the resolution (<1micron) as the original facility.

*The X-ray CT facility at Applied Maths - one of the few facilities in the world that can measure over three scales of magnitude simultaneously - from microns to millimetres. (Photo by Tim Wetherell)*

# Reading the Sun in the Moon

What's the chemical make up of the Sun and the proto-planetary soup that gave birth to our solar system? These are burning questions in astrophysics and the earth sciences, and part of the answer is believed to lie in samples of soil collected from the Moon by Neil Armstrong back in 1969.

Why would you look to the Moon when you're trying to understand the composition of the Sun?

"We can't get samples directly from the Sun," explains Dr Trevor Ireland from the Research School of Earth Sciences. "However we can infer its composition by looking at lunar samples, which are believed to reflect its composition. This is because lunar soil contains oxygen isotopes 'implanted' by solar winds carrying elements blown out from the Sun."

To date, the isotopic composition of the Sun has been inferred for some elements from lunar samples, but not for oxygen because of its high abundance in lunar minerals. However, a new analysis using the Sensitive High-Resolution Ion Microprobe (also known as the SHRIMP) has been able to get an accurate measurement of the solar oxygen isotopes in iron metal grains. The metal grains have very low intrinsic oxygen and so the solar wind implant dominates the signal from these grains.

*Dr Trevor Ireland holds a meteorite. Dr Ireland has long been fascinated by the chemical composition of the early solar system. Using the SHRIMP to decipher the isotopic composition and age of meteorites, lunar soil and solar wind it's possible to build a model of how the Solar System and our planet formed.*

In particular, researchers hoped to find evidence for either of the two reigning theories about the Sun's composition. According to one theory, the Sun has a similar oxygen composition to the planets and meteorities. The other theory suggests it has enriched levels of the isotope oxygen-16.

However, rather than producing a result that supported one of the theories, their analysis came up with something neither of them predicted – it has lower levels of oxygen-16 than expected (and the oxygen signal is dissimilar to bodies like the Earth and meteorites).

"We found that the oxygen isotope levels did not agree with either a planetary composition or the oxygen-16 rich composition," says Dr Ireland.

"The oxygen isotopes are telling us that the mix of components in the Sun is different to that in the planets, particularly in regard to the amount of dust versus gas that comprises the Sun versus the planets."

"This was a completely unexpected result for us," says Dr Ireland. "Our Sun is not the Sun that we thought it was.

"The finding also suggests the Sun somehow ended up with a different composition from the cloud of dust and gas that preceded it."

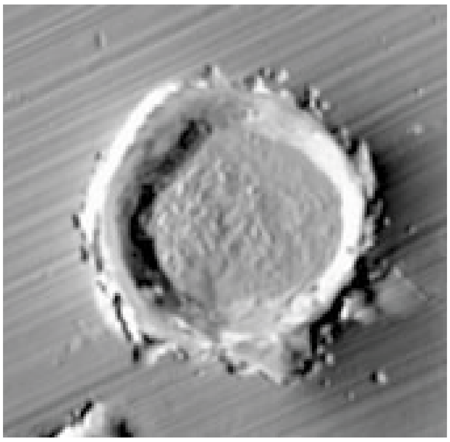
The results, which were recently published in *Nature*, come at an interesting time for studies on the composition of the Sun. Between 2001 and 2004 a NASA space probe called Genesis has been collecting samples of solar wind. The probe crashed down to Earth in 2004 but

**continued on next page**

## The Moon & the SHRIMP

As an interesting aside, the lunar samples that have been so successfully analysed by the SHRIMP for oxygen isotopes are directly connected to the very reason the SHRIMP was originally developed by RSES. When Apollo 11 returned from the Moon with a crate load of lunar samples the first big question of science that was addressed was how old they (and the Moon) were. The Geochronology Lab at RSES was one of a handful of labs around the world chosen to analyse the samples. Professor Bill Compston led the ANU team and they came up with an answer of 3.8 billion years, an answer that has subsequently been shown to be very accurate. However, the painfully slow and intricate wet chemistry that they needed to perform to come up with this answer was the trigger that caused Professer Compston to search for a better way of measuring isotopic ratios. His search led to the creation of the SHRIMP. For the full story on what the SHRIMP is and how it came to be, see the April 2005 issue of Materials Monthly.

*Dr Ireland with the SHRIMP prototype (or SHRIMP 1). It was developed following the original analysis of the Moon samples back in 1969.*



*A scanning electron micrograph of one of the iron metal grains analysed from the lunar soil sample.*

*An artist's conception of the Genesis probe with solar wind collectors deployed. (Courtesy of JPL/LMA)*

it's precious cargo of solar particles was retrieved. Those samples are now being sorted and catalogued and will soon be available for analysis.

"In many ways, our measurements on the lunar samples were our first attempt at scoping the experimental difficulties we might have in measuring the Genesis samples," says Dr Ireland. "As it turns out, the analysis we have undertaken using the SHRIMP has proved to be very successful.

"The real question our finding raises is why this solar composition appears unrelated to the composition of the planets, the largest rocky bodies in the solar system, or to refractory inclusions from meteorites which have been regarded as solar condensates. Further study of samples from the Genesis mission may have the answers."

MM

**More info: Trevor.Ireland@anu.edu.au**

# Leading seismologist appointed Director

Earlier this month the ANU Vice-Chancellor Professor Ian Chubb announced that Professor Brian Kennett has been appointed as the new Director of the Research School of Earth Sciences (RSES). He will take up the position in September.

Professor Kennett is currently Professor of Seismology at RSES. He joined ANU in 1984 as Professorial Fellow at RSES, and was Interim Director of the School in 1993, and Chair of the Board of Advanced Studies and Pro-Vice-Chancellor from 1994-1997. From 1999-2003 he was President of the International Association of Physics of the Earth and Planetary Interiors.

Professor Kennett's leadership in his field has won him numerous awards, including the Adams Prize of the University of Cambridge (1983), the Jaeger Medal of the Australian Academy of Sciences (2005) and the Murchison Medal of the Geological Society of London (2006). He was made a Fellow of the American Geophysical Union in 1987, a Fellow of the Australian Academy of Sciences in 1994 and a Fellow of the Royal Society, London in 2005.

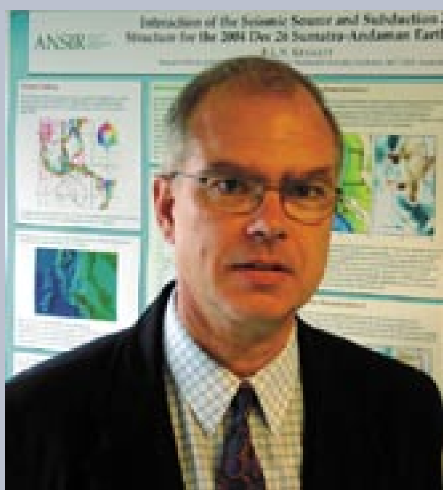
"Professor Kennett is one of Australia's most eminent earth scientists. He has long made an outstanding contribution to the Research School of Earth Sciences and the ANU," Professor Chubb said.

"His new role will enable him to inspire some of the best earth scientists in the world and lead a research school that is of international standing and national importance.

"Researchers of Professor Kennett's calibre are the source of the School's strength, and are responsible for its position as one of the top ten university geoscience programs in the world."

Professor Kennett responded:

"The Research School of Earth Sciences is a great Australia asset, with strength in many areas of the earth sciences. My aim will be to enhance interactions between disciplines to provide a multi-faceted view of the Earth and its interior."




*Professor Brian Kennett*

# Drishti = insight

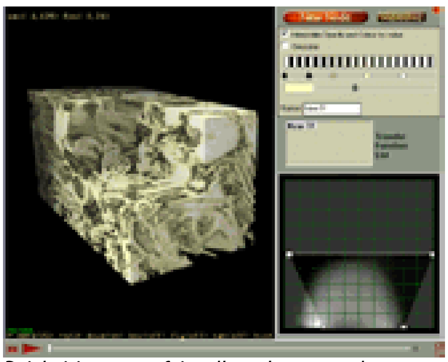
## Breathing life into volumetric data

When an object has been scanned using X-ray CT or MRI, information is collected on the three dimensional structure of that object. However, before that structure can be meaningfully visualised and analysed that information, which exists in the form of volumetric data, needs to be transformed into images that can be manipulated in a number of ways. For example, it might be that you want to examine the structure from different angles, or zoom in on one segment of the structure, or you might want to only see the void spaces rather than the solid material.

Software programs that transform volumetric data into images that can be manipulated in these ways are known as volume renderers, and the ANU Supercomputer Facility has just released one of the world's best. What's more, it's free.

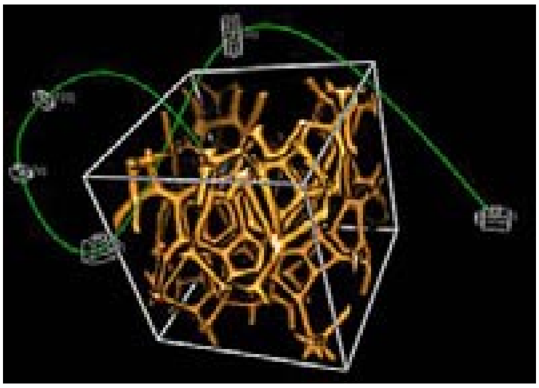
The program is known as Drishti, which is Sanskrit for 'insight', and has been developed by Dr Ajay Limaye, a visualization programmer working in the Facility's Vizlab*. He's been developing Drishti for the last couple of years with the aim of allowing the user who generated the data to easily carry out their own image manipulations. He's now developed it to a point where he's prepared to release the code as freeware.

"There are several programs out there that render volumetric data into usable images," says Dr Limaye. "But Drishti has many advantages in the area of animation. With Drishti users can manipulate, revolve and even travel around and through the image that has been created.



*Drishti is a user-friendly volume renderer that allows researchers to probe their data in variety of novel ways.*

"Very few volume rendering progams allow users to rotate volume as a simple animation and fewer still give the facility to choreograph your own camera moves. Drishti goes way beyond what's currently available, it provides facility to animate transfer functions, animate volumetric time series, animate sub-volumes and much more."



*Where do you want to go today? With Drishti the user can travel around, in and through their volume data at the touch of a button.*

Dr Tim Senden from the Department of Applied Maths (see main story) is a big fan of Drishti. He believes it's going to become 'a CT industry standard'.

Drishti should work on any NVIDIA card from FX 5200 and above.

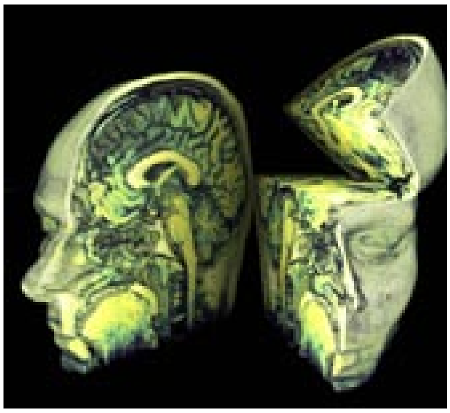
For more information on Drishti check out http://sf.anu.edu.au/~acl900/Drishti/ For a good example of the power of the program click on the 'movies' link and view some examples of animations produced using Drishti. The fly through of the lizard's skull, as one example, will take your breath away.

*Dr Ajay Limaye has developed a volume rendering program called Drishti that many believe will become the industry standard.*

**More info: Ajay.Limaye@anu.edu.au**

***VizLab at the ANU Supercomputer Facility was established in May 1990 to assist researchers and post-graduate students interpret the data generated by computer simulations, remote sensors and experiments through the application of modern computer graphics techniques. The laboratory is located on the 4th floor of the Leonard Huxley Building.**

**More info: http://anusf.anu.edu.au/Vizlab**



*Open wide, come inside - with Drishti it's easy to segment your image in any number of ways.*


# Contacting CSEM

### Director
**Dr Zbigniew Stachurski**
Phone: (02) 6125 5681
Email: Zbigniew.Stachurski@anu.edu.au

### Editor, *Materials Monthly*
**David Salt**
Phone: (02) 6125 3525
Email: David.Salt@anu.edu.au

### CSEM Office
CSEM
Department of Engineering
Bld #32, ANU ACT 0200

***Materials Monthly*** comes out 10 times a year (February to November). We welcome your feedback and contributions. Please send them to David Salt, Editor, ***Materials Monthly***, care of CSEM.

Please let us know if you wish to be added to our electronic or postal mailing lists.

Electronic copies of ***Materials Monthly***, useful links and additional information about CSEM can be found at our website:
www.anu.edu.au/CSEM