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Making materials matter
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History written in wood

It's all there as long as you can read the rings

For a better understanding of the future of our water supply in Canberra we should look at our trees. More specifically, we should look at the climate record they have written into their rings. Well, that's the approach being taken by Matthew Brookhouse, a PhD student in the Fenner School of Environment and Society.

Mr Brookhouse is a dendrochronologist – he studies tree rings to gain insights on the past. The annual, radial growth of a tree (seen in the cross section of the trunk as a ring of growth) is sensitive to changes in the tree's growing environment. If you know which trees to sample and how to interpret the growth rings, it's possible to reconstruct a picture of the past. In so doing you're better placed to plan for the future.

Reconstructing river flows

"I use tree rings to reconstruct climate and river flow history in Australia," explains Mr Brookhouse. "The research that I'm working on now is for south eastern Australia and uses tree ring material from the Australian alps to reconstruct rivers flows in our local river systems.

"It may be possible to do similar work throughout the whole country using different tree species but at this point we're focussing on alpine species, specifically the snow gum (Eucalyptus pauciflora), because these hold the greatest promise. That's because dendrochronology relies upon strong seasonal contrasts because those contrasts are what are necessary for trees to lay down clear tree rings. These contrasts are most pronounced in the alpine area, where we have a very strong temperature difference between winter and summer.

"Also, when you get close to a plant's climate distribution, it's climate tolerance, it becomes very sensitive to variations in climate. Snow gums form the upper limit of the tree line in Australia. If you get to that limit then the growth of snow gum each year is very much controlled by climate variation, meaning that when the climate is unfavourable it hardly grows at all but when it' very favourable it grows exceedingly well."

Reading Aussie rings

Most people will have heard something about reading tree rings, even if the term 'dendrochronology' is new. And that's because the field of dendrochronology is very well developed overseas and has a rich history. Indeed, in America there are dense networks of tree ring chronologies, where multiple data sets of tree ring widths have been stitched together into one series of measurements. These networks of chronologies extend right across the continent and they're used to reconstruct drought patterns and build drought maps. They do very similar things in northern Europe, Canada and Alaska for temperature. But it simply hasn't happened in Australia. And it's not because our history of western science is shorter or our dendrochronologists are slower. It's because our trees are trickier, in terms of being interpreted.

"In Australia we have almost no history of dendrochronology and the reason relates to our climate and our flora," comments Mr Brookhouse. "Our climate varies little from

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Matthew Brookhouse (above) holds a cross section of a tree trunk showing its rings. If you know what to look for, the rings contain a rich load of historical environmental information. And that even applies to dead trees. The old and dying snow gums (pictured below) hold a wealth of information that can inform us about river flows going back centuries.

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season to season over much of the continent. And the Australian flora has adapted to this situation of unreliable rainfall by developing a physiology that allows plants to grow any time adequate moisture is available. This means the regular, clear tree rings that you'll find in many northern hemisphere tree species simply don't occur in Australian species

"In terms of dendrochronology, Australia is a tough place to make it work. But it's also a great place to be working because not much of it has been done. Overseas you'd only be adding an increment to an increment in terms of the sum knowledge, but over here there's still a book to be written.

"It's a wonderful place to be a young researcher – to be involved in an evolving field, and one that has so much to offer in terms of understanding our environmental past and future. You have opportunities to contribute to important issues such as reconstructing river flows for a river system that supplies a huge quantity of water for hydro power, irrigation and human consumption."

Rings in context

Part of the challenge of dendrochronology in Australia is understanding what it is the trees are telling you in the Australian context. And, unfortunately, lessons learnt in the northern hemisphere often don't apply in the 'land down under'.

"It might be surprising to many people but in dry years in Canberra snow gums actually grow better than in wetter years," says Mr Brookhouse. "That's because snow gums are most affected by the temperature, and temperature is negatively related to precipitation in this region. So, if you have a lot of precipitation, particularly as snow, you have low temperatures, and snow gum growth is decreased.

"One factor that is also important to snow gums is snow. If you have more snow on the ground, and it remains for a long period into spring, then the snow gum can't really start growing until that snow has melted and the soil temperature has begun to warm. So, if you have a lot of snow in winter then you have less snow gum growth the following season, despite the fact that there is more water for them to use they just don't use it. And you can see this in the trees rings.

"From the widths of the tree ring we can see where snow gums have been affected by climate variation, and we can correlate those variations in tree ring widths to known variations in climate variables (from our weather records). We can then exploit this and reconstruct climate variations and snow fall variations and, from this, river flow variations much further into the past. In effect, we're using tree rings to reconstruct the past."

Signal to noise

Reading the climate signal in tree rings is a powerful way of understanding the past but there's a lot of other information encoded there as well. Some of that information further colours our understanding of the past environment, some of it just gets in the way.

"Bushfires and insect attack can certainly complicate the interpretation of tree ring data if you're interested in climate," laments Mr Brookhouse. "And there are many other factors to consider as well. So, take for example the width of an annual ring. That width is not only affected by climate. As a tree grows in size, the tree rings become narrower because the tree has to put its growth onto a much larger diameter stem.

"Other factors like fire also play an important role. Fire removes the canopy of a tree and this negatively impacts on its growth. If you're interested in climate, these things can become noise, if you like, and this obscures the climate signal; but it also gives you the opportunity to study those things. If you decide that the signal you're interested in is not so much climate but fire then you can focus on fire and its impacts on the ecosystem.

"Or you can study insect attack. Over a certain period you might identify that a certain area received repeated insect attack, and that might also be related to climate variability. We really don't have a very good understanding of what drives fluctuations in natural insect populations and those populations at times can kill complete stands. So, having some understanding of how climate might affect things is very important if we want to understand the complex matrix of the factors that might change with increasing temperature and changing rainfall patterns over time."

Beyond the ring measurement

And there's more to a ring than just how thick or thin it is.

"We can section the samples and send the timber from individual rings off for a range of analyses," explains Mr Brookhouse. "These provide additional information on the growing environment of the tree at any particular time. For example, isotopic analysis comparing carbon 12 with carbon 13 gives you another indication of drought stress. In drought conditions the lighter isotope of carbon is favoured by the metabolic process, thus increasing the C12/C13 ratio in the wood rings.

"Tree ring samples are also measured for density as there's a strong relationship between wood density and temperature. The colder it is, the slower the growth and the denser the wood.

"There's also an analysis where we use the size of the water conducting vessels in the timber and the number of them in each ring as an alternative measure for moisture availability in drought seasons.

"So, it's not just a straight measurement of ring width, there are a whole suite of other measurements that can be used afterwards. As with dendrochronology in Australia in general, there is so much we still have to learn with these additional analyses because they are very rarely done in Australia, whereas they are much more common overseas.

Read from the rings, not into the rings

There's a lot more to tree rings than simply saying it was a good season or a poor season. You can tell temperature, amount of rain, and the presence of many other things that were in play at different times. However, as Matthew Brookhouse warns, we need to understand the information in terms of what the tree is sensitive to, not in terms of what specific information you're wanting it to tell.

"Snow gums are sensitive to snow," he says by way of example. "Yes, temperature and the amount of rain play a role in parts of the landscape, but where we find a really important climate signal it's snow that's really important.

"In many gum forests temperature is very important; but, year to year, what they are really sensitive to are variations in relative humidity and that's really what drives growth. Yes, there are definitely climate signals in them but we need to be responsive to what the tree is actually responsive to.

"This appreciation is so important and it's why I've managed to make progress recently. In the past people have attempted to do tree ring studies on eucalypts and extract climate signals. They've gone to pre determined sample sites, and they've brought with them a prior idea of what the climate signal is that they're looking for. Then they've tested for that and found nothing.

"This approach doesn't really work because you're imposing your own idea of what the tree ring record has in it and that's not the way it works at all. You have to allow the trees to tell you what they're sensitive to and keep a fairly open mind about what can actually affect tree growth – and take a lot of samples."

Samples that count

Though Mr Brookhouse is still an early career researcher he's already clocked up thousands of tree cores in his PhD and from prior work as a forester in Victoria. In his next study he'll be taking around 40 samples from snow gums in the Brindabella Ranges to reconstruct river flows in the Murrumbidgee River going back hundreds of years. The research is made possible with money from a Young Scientist of the Year Award from the Commonwealth Department of Agriculture, Fisheries and Forestry (which he was awarded in September). Given the difficulty of extracting

How to read the rings

Most people will have seen tree rings when a large tree is cut down but how does a dendrochronologist obtain their tree ring data? By cutting a swathe through the forest with a chain saw?

Matthew Brookhouse samples another snow gum. "We remove cores that are 5-6mm wide," he says. "And we go in around half a metre."

"Actually, the field component of dendrochronology is quiet and relatively non destructive," comments Mr Brookhouse. "We take a core out of the tree using a hand-powered increment borer. The borer itself is about a 15 mm in diameter, and it removes a core that is about 5-6 mm wide. The corer is about 40-50cm long. Of course, this can cause problems because you can't extract a full sample from a big tree with a radius in excess of 50cm. However, you can't make a really long corer and put it into a very hard tree because the forces generated by turning the corer would snap it.

"The holes we create are usually left open. The rationale is it's better for the tree's health to leave it open than to seal it off. By sealing it off you create a perfect incubation space inside the tree for fungal spores. A healthy tree will normally fill the hole in the following year.

"We then take the core we've extracted and glue it in a channel cut into a piece of pine. Once dry we then sandpaper it down. We start with a rough paper and progress through to fine grades, finishing with wet and dry sandpaper and sanding underwater to flush away the wood dust. We sand down to a very fine finish that's easy to look at and measure in regards to tree ring boundaries. We stay away from staining it as it can make interpretation more difficult.

"We then put the sample on a flat bed scanner and record an image. With the assistance of image recognition software we then take measurements. In this way you have a permanent sample record and you can then use your sample for other analysis."

The cores are glued onto another piece of wood and then sanded down till they're mirror smooth and easily 'read'.

information from tree rings, is 40 samples enough to obtain the necessary data to tell a good story?

"I'm very confident that I can reconstruct a river flow history based on 40 samples," says Mr Brookhouse. "Knowing what to look for is what my PhD study is all about.

"My PhD was originally going to be about visiting the Brindabellas, collecting samples and from those samples reconstructing river flow histories. However, at the start of my research I sat down to work out a sampling strategy for achieving this and I realised that we knew too little about what eucalypts were sensitive too, how that sensitivity would change in different parts of the landscape, how many trees we would need, and what species were the right species. There were so many questions at that point in time that if it had worked it would have been more luck than good management, and if it hadn't we wouldn't have known why – it could have been due to any one of ten different reasons and we wouldn't have been able to say where the problem was.

"In a sense then, my PhD has been writing an instruction manual on how you can actually carry out this type of study. And now, having done the appropriate preliminary studies, I can go up into the Brindabellas, strategically sample trees and build a dendrochronology that's four to five hundreds years long. From this I'll be able to reconstruct river flows for that period.

"And I'm confident in saying that because one of the elements of my PhD actually tests this. I have tree ring data sets from a number of different elevations in the Brindabella ranges and I actually tested the climate sensitivity along the elevation gradient. And, having demonstrated that, I also have a sample set from the Kosciusko plateau and I do the same thing for that and demonstrate that yes, the signal is the same at the top of the Brindabellas as it is at Kosciusko. Both tree ring data sets correlate with river flow.

"Now, all we need to do is go and get the sample materials, and build the longer chronologies. Of course, there are a few complications. As the trees get older their crowns start to senesce and this slows growth down dramatically. Eventually the tree rings are so close together that they no longer carry a climate signal. We need to sample a group of younger trees and older trees so that we can build an adequate record, and also look for dead trees in the landscape so we can even extend the record further."

Other parts of Australia

In this instance Matthew Brookhouse is relying on the sensitivity of the snow gums to snow. However, in other parts of the Australian landscape the challenge is find other tree species to measure.

"One genus of tree that is very sensitive to soil moisture is Callitris, native cypress pine," says Mr Brookhouse. "And those trees grow throughout the continent, from tropical areas right down to here around Canberra. Unfortunately, they're an incredibly difficult genus of trees to work with in terms of dendrochronology because they form numerous false rings which are almost impossible to pick apart from true annual rings. They arise because the trees are so sensitive to soil moisture. If there's any change in soil moisture throughout the season then they'll respond – growing and not growing sometimes forming multiple rings in one season. There are ways around this, there are some sampling tricks you can employ, but it's a big challenge."

However, given the insights that dendrochronology can generate about how our landscapes function, maybe that's one challenge worth taking on.

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Reading sponges and diatoms

Generating insights on silicon and seasons in the deep ocean

In an approach similar to a dendrochronologist reconstructing the past with tree rings, Dr Michael Ellwood from the Department of Earth and Marine Sciences (DEMS) is generating fresh insights on past ocean environments by reading the elemental composition of sponges and diatoms.

Now, at first glance that might seem a bit strange because there's not much in common between sponges and diatoms. Diatoms are microscopic, unicellular plants floating in the surface layers of the ocean, while sponges are macroscopic, multi-cellular animals that live attached to the ocean floor. However, the supporting skeletons of both organisms are made out of silica, and it's this feature that makes them so interesting to Dr Ellwood.

"The interest in siliceous organisms like diatoms is that they take silicon up from the surrounding water, and they store it in their little glass shells," explains Dr Ellwood. "Then these glass shells are left when they die, and they settle down to the bottom of the ocean where they are preserved in the sediment. The same happens with sponge spicules after the sponge dies. The sediment builds up layer upon layer over time, and each layer carries in it these siliceous skeletons.

Sediment cores

"Oceanographers take cores of these sediments, and we pick out the siliceous component from each sediment horizon in the core, be it diatom shells or sponge spicules. From these samples we can determine what the conditions were like in the past in terms of the chemistry of the ocean in which these organisms were growing.

"The individual horizons in the cores have all been dated independently. This is done by other researchers and involves people picking out other plankton, like foraminifera, and analyzing them for their oxygen isotopes and the carbon 14 ratios in their calcite shells. From this we know exactly what the age of each sediment horizon is.

"We're working on sediment cores that have been mainly collected from around Antarctica. These waters are rich in diatoms. We isolate the diatoms in each sediment horizon using sieves and physical separation. The diatoms we're after are 10-40 microns in diameter. To carry out an analysis we need around ten milligrams of diatom shells. The elemental analysis of the diatoms involves digestion and then running it on the inductively coupled plasma mass spectrometer.

Dr Michael Ellwood holds up a dried specimen of the deep sea sponge Corallistes undulatus *that he discovered possessed growth rings. (The specimen was collected by Michelle Kelly.)*

"We analyse them for silicon, germanium and trace elements like zinc. And we're doing silicon isotopes as well, using the RSES multi collector ICP-MS. These isotopes will help tell us the relative growth rates of the diatoms and the germanium will tell us how much silicon was in the water. The other trace elements provide us other information on what other nutrients were present in the water column.

Reading the surface signal

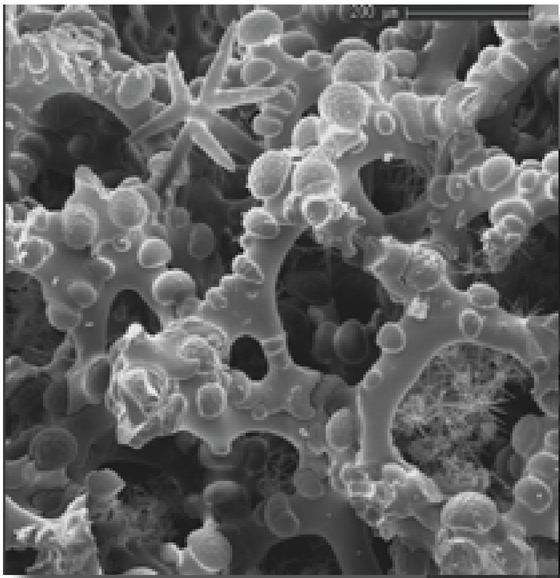
"Because the diatoms lived in the surface ocean they give us a surface ocean signal. In terms of silicon, you can't just measure the amount of silicon by itself because you don't know how much is taken up over what time frame, so you need an independent element and that's why we measure germanium.

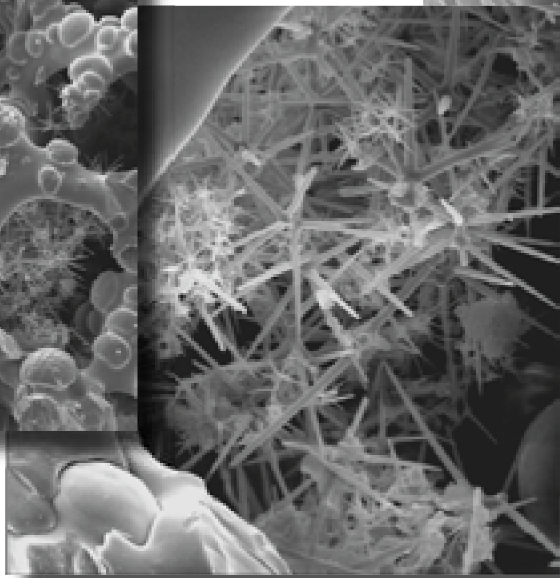
"Germanium is just below silicon on the periodic table so it has very similar chemistry to silicon. And because these organisms require silicon to grow we think we can use the germanium and silicon in their shells to see what the silicon levels were in the ocean in the past. We know the germanium/silicon ratio of the water and we know the amount of germanium incorporated in the shells is dependent on the amount of silicon in the water, so if you know those two constraints you can work out the amount of the silicon in the water at the time the diatoms were alive."

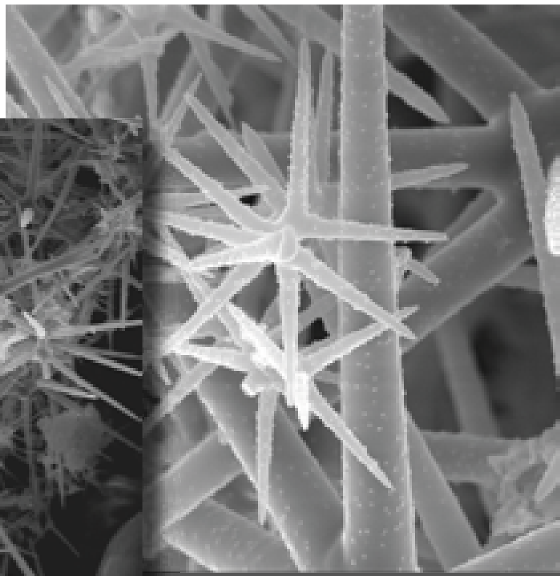
And why is there an interest in silicon levels of the ocean?

"Silicon is pretty important," says Dr Ellwood. "Diatoms account for about 40% of primary production in the ocean and they require silicon to make their shells. So, if you take away silicon you reduce diatom productivity which also reduces overall productivity.

A light micrograph of diatom shells extracted from a sediment horizon.







Three scanning electron micrographs of the stunning silica skeletons of a sponge. Analysis of the elements in these spicules is allowing scientists to reconstruct the past environment. (SEM images: M Ellwood/ S Eggins)

Silicon in the big picture

"The bigger story that we're investigating is that we want to know what the silicon levels in the ocean were so we can work out how much diatom production there was in the past. Diatom growth is important because they take up a significant amount of carbon dioxide out of the atmosphere which plays an important role in climate. In the past carbon dioxide levels in the atmosphere were lower, and some people believe that diatom production was higher. However, to fuel that production you need more silicon in the water to allow them to build their shells.

"While many researchers have looked at silicon levels in the surface ocean, no-one has examined what's been happening in the deeper ocean. That's one of the reasons we're using two independent organisms: diatoms for the surface record and sponges for the deeper levels."

Sponge rings

Prior to coming to ANU, Dr Ellwood was based at the National Institute of Water and Atmospheric Research (NIWA) in New Zealand. With colleagues Dr Michelle Kelly from the National Centre for Aquatic Biodiversity and Biosecurity, NIWA in Auckland, and Dr Bertrand Richer de Forges from the Connaissance des Faunces et Flores Marines in New Caledonia, Dr Ellwood was involved in analysing large sponges from the deep ocean, over 500 metres deep in the South Pacific. And this is where another parallel with dendrochronology arises because they discovered what looked like annual growth rings in the sponges – something that had never been described before.

"We were looking at large deep sea sponges," says Dr Ellwood. "Sponges live by filtering the water for particles of food and absorbing silicon from the surrounding ocean. Now, for these deep sea sponges we had no idea of how old the sponges were or how they form spicules; for example, did spicules grow via an annual deposition or over some other time period? We studied the cross section of the sponge closely and observed light and dark bands of growth. We counted about 140 to 150 bands.

"Then we made quite an exciting discovery because, using other techniques we found that the sponges were 160 years old, meaning the bands might well represent some form of annual growth. Maybe this is evidence of seasons at the bottom of the sea.

Cycles of the deep

"What's causing the cycle? We don't know. It could be the reflection of a seasonal cycle following on from seasonal cycle of growth of phytoplankton at the ocean surface which provides carbon which, in turn, enables more silica to be put down. Or, it might be changes in deep sea current, we still have more work to do."

The research on diatoms and sponges is continuing. Dr Ellwood believes that their results so far point to the possibility that these siliceous organisms could be used for more research into the history of the oceans and the climate above.

Dr Ellwood is a joint appointment between DEMS and RSES, an example of a greater integration between teaching and research in earth sciences occurring across the ANU College of Science.

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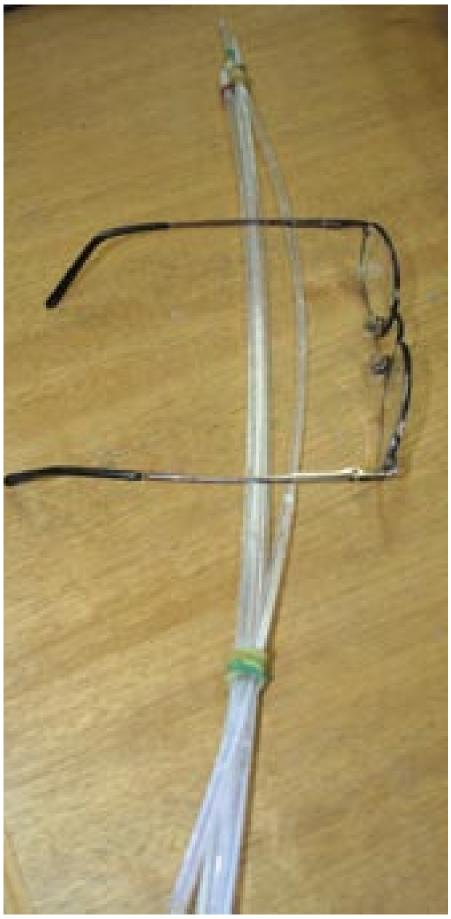

Bioglass: Not all sponge spicules are microscopic. The sample above looks like a set of bendy knitting needles. In fact, each 'needle' is an individual sponge spicule. What's more, Michael Ellwood has revealed that the cross section of each spicule reveals over 400 individual growth rings, though it's not known for certain that these represent annual growth rings. Also of interest, these 'glass' rods exhibit much greater flexibility than human-made glass rods suggesting another example of Nature's incredible materials engineering. But that's a topic for another story. (Sponges were collected by Bertrand Richer de Forges)

Building bridges to Saudi Arabia

Rector of the King Fahd University of Petroleum and Minerals, Dr Khalid Al-Sultan, welcomes Dr Zbigniew Stachurski. On the right (in dark suit) is Dr Mazen Kahled, Interim Director of the Centre of Excellence in Nanotechnology.

Earlier this year the King Fahd University of Petroleum and Minerals (KFUPM) in Saudi Arabia established a Centre of Excellence in Nanotechnology. Dr Mazen Khaled, the Centre's Interim Director, toured many countries collecting information on how the Centre might operate. In May, he visited ANU, and was shown around by CSEM. As a result of this interaction, CSEM's Director Dr Zbigniew Stachurski was invited to visit the KFUPM and present an overview of research in nanoscience and technology at the ANU at the Centre's inaugural Nanotechnology Workshop.

The Workshop was held at the KFUPM on 9th and 10th of September, and involved a group of around 100 people, including guests from other universities as well as from the King Abdulahaziz City for Science and Technology (KACST) from Riyadh.

"It was a fascinating excursion for me," says Dr Stachurski. "As you might imagine, Saudi Arabia is a very different world from Australia with day time temperatures reaching around 45º Celsius and a value systems based on orthodox Muslim culture. However, for all the difference, they too aspire to be strong in nanotechnology, and this workshop brought together a glittering array of researchers from all over the world.

"Presenters included Professor Munir Nayfeh from Illinois University on how to make silicon nano particles with interesting properties of photoluminescence. Dr Stephen Grey from the University of Victoria described how several research groups in Australia have joined together to attract funding for work on water desalination. Dr Feng Si-Shen from the National University of Singapore spoke on research towards the application of nanoparticles in biomaterials and drug delivery. And Mr Tim Haper from the London based company Cientifica discussed how to foster links between researchers, research organisations and venture capital."

An Arabian feast was served up as the workshop dinner.

Dr Stachurski outlined several nanotechnology projects underway at ANU. These included the growth of nanowires (Jagadish's group); the fabrication of nanotubes (Ying Chen's group); the application of CT scanning to materials research (Mark Knackstedt's group); the application of nanoscience particles in corrosion protection (Skyrabin, Koplick and Stachurski); and nanocrystallisation in bulk metallic glasses(Wang, Jackson, FitzGerald, Stachurski).

"I think the Saudi's were very impressed by the level of nanotechnology research at ANU," comments Dr Stachurski. "And I hope that this visit may catalyse greater interaction between our institutions in the future. This year Saudi Arabia will send abroad approximately 3000 students with full scholarships to study for higher degrees. Following, my presentations at both KFUPM and KACST I expect many of these students to apply for studies at ANU.

Dr Stachurski's trip was fully paid for by the KFUPM.

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