COMMISSIONER: Good morning. We'll reconvene. Topic 3, geology and hydrogeology. Today and tomorrow the commission's public session focuses on the topics of geology and hydrogeology. Before counsel assisting provides a context statement for today I need to state that this will not be the last time the commission will address these topics and, indeed, the topic of climate change and energy policy. Today we'll provide background and some of the specifics necessary to address the terms of reference with respect to geology and hydrogeology.

We will return to these topics in later sessions when we address the potential to expand exploration and mining activities, the relationship of those issues to the risks associated with past mining practices and then again when we deal with the issue of waste storage and disposal. The same applies to the issues of climate change and energy policy. We expect to address these topics again later this year as we examine the potential for electricity generation from nuclear power plants. These topics also inform the rationale for the discussion next week on low-emission technologies and their development.

The link between the future form and the structure of the National Electricity Market, as discussed last Friday, also re-emerges in later discussions concerning low-emission technologies. As the commission will, it's important that all these issues are considered in combination with and in light of all of the material, including submissions, that have been received by the commission. Mr Jacobi.

MR JACOBI: Thank you, Commissioner. The commission is tasked by its terms of reference with considering the potential for the future exploration and extraction of radioactive minerals. Over today and tomorrow the commission will be hearing evidence relating to the geology and hydrogeology of South Australia which will feed into the commission's analysis as to the feasibility of further exploration and mining in this state. While what is known about the geological formation and mineralisation of South Australia might seem to be easily stated, the questions posed by the terms of reference ask where South Australia's future deposits might lie and what they might contain. It asks, in short, what the long-term might look like.

That requires an understanding not only of what's being done and is known but, critically, what is not presently well understood about South Australia's mineral geology. Today it is critical for the commission to hear from those with expertise in this mineralisation and what they reasonably anticipate the potential to be based on the science and the techniques now available. The question also invites an analysis of the range of activities that might be pursued to develop a long-term strategy, bearing in mind the costs of exploration.

Aside from mineralisation, an understanding of geology in South Australia, particularly it's geophysical and seismological characteristics, is critical to an assessment of the feasibility of proposals for industrial activities, including the storage and disposal of radioactive and nuclear waste. A detailed understanding of those characteristics is a necessary underpinning of the design and management of facilities engineered for those purposes.

Further, critical to those activities is an understanding of the groundwater systems in the state. That is relevant to the commission for two reasons. Most significantly, that is so because groundwater resources must be conserved and managed because they are important to domestic commercial and industrial activities. The availability of those resources for future mining activities and the sharing of those resources with other activities requires their careful management. An understanding of those systems is also required to ensure that activities and designed and carried out so that their potential impact on the environment and those resources is minimised.

Hydrogeology has a further particular significance to the in-situ method of uranium mining licensed to be carried out in South Australia which extracts uranium from secondary deposits found in aquifers. The potential for the expansion of that method of extraction requires the commission to consider that technique and the risks and opportunities it presents.

The commission calls at its first public session Prof David Giles from the University of Adelaide. David Giles is the Program 3 leader of the Deep Exploration Technologies Cooperative Research Centre where he carries out research into improving utility data collected by drilling programs. Prof Giles has worked extensively in the area of exploration geoscience and is widely published on geological formations in both Australia and overseas. The commission calls Prof David Giles.

COMMISSIONER: Professor, welcome. I think you've got some slides to walk us through the issues.

PROF GILES: I do.

COMMISSIONER: So why don't you start.

PROF GILES: Sure. What I've done here, just by way of background, is I've put together slides of almost the whole state of South Australia. As we go through them you'll see these grey slides are a compilation of aeromagnetic data. The aeromagnetic data shows a distribution of magnetite almost exclusively. They're really put up there to give you a sense of the shape of the geology. What I've done is, in a fairly crude way I've outlined some key areas of geology as they relate to uranium mineralisation and exploration.

The first one here shows in the large red outlined area on the left the Gawler Craton and in the smaller area on the right the Curnamona Craton. These are the fundamental building blocks of the geology of South Australia. So these were built a long time ago. They're in the Neoarchean and Paleoproterozoic, so from about two and a half billion to about one and a half billion years ago. It was during that time that the fundamental uranium-rich nature of the South Australian crust was established.

So what I've highlighted there in yellow blobs is the known uranium resources and they'll appear on subsequent diagrams again and again. They're roughly scaled for size. You can see the largest blob there in the middle of the Olympic Domain is Olympic Dam. We'll go through and we'll talk about each of those deposits, broadly why it's there and its significance for exploration as we step through these slides. So just one more thing there, Kevin. On the eastern side, the right-hand side of the diagram of the Gawler Craton, is the area known as the Olympic Domain where our key basement host of mineral deposits are found. Really important thing there where I've put a big question mark at the top of that is we know the distribution of that very well in the southern and central zones and we don't at all in the northern. It's a big, open question of where that goes in South Australian geology.

MR JACOBI: Perhaps if we could proceed to first address the yellow areas and perhaps we can do that by the next slide to understand the relationship between those areas and currently known and historically exploited deposits.

PROF GILES: This image now, this is now showing the uranium channel from airborne radiometrics. So this is a direct measure of uranium concentration in the top 30 centimetres or so of material on the earth's surface. Red is hot, blue is cold. You can see straightaway that there are particular patterns here. Those patterns are a combination of that two and a half billion years worth of geology that we're going to step through to try and show you how uranium has been redistributed and, in some cases, concentrated to make deposits over time.

I'll just draw your attention to the dotted line roughly down the middle of the state there through Oodnadatta and Coober Pedy and down towards Port Lincoln. Everything to the east of that line is something that is known in the geological community as the South Australian heat flow anomaly. That represents a zone where the temperature as you go down through the earth's crust increases more rapidly than elsewhere. It's very important and you'll come across this again when you look at geothermal energy in the state. That's obviously very important for geothermal. The fundamental reason for that is that the crust in that eastern part of the state is enriched with respect to uranium; also other heat-producing elements like potassium and thorium but uranium is really important.

Within that zone, you can see that I've outlined five areas there in solid red which represent zones where basement rocks are exposed at the surface that are part of the Gawler Craton and the Curnamona Craton, those fundamental building blocks. You'll see that those zones are hot in general with respect to the radiometrics.

About 1.6 billion years ago there was a thermal and magmatic event in South Australia of global significance which resulted in massively voluminous volcanics of the type of composition that you would see roughly in New Zealand now and granites related to those. So the most pronounced surface expression of those is a thing called the Gawler Range volcanics, which is highlighted there as the stippled area of high uranium roughly in the centre of that zone. That thermal and magmatic event transferred a huge amount of uranium into the upper crust of South Australia mostly through magmatic processes, which are one way to enrich uranium.

We don't know exactly why all of that happened, but we know the outcomes of that where a whole series of volcanic and intrusive rocks that are unusually enriched in uranium. That is the fundamental reason for the uranium prospectivity of the State through multiple cycles of reworking of the uranium. From then, from 1.6 billion years ago, it's still going on today.

MR JACOBI: Can I just pause?

PROF GILES: Yes.

MR JACOBI: Just in terms of the interpretation of the map itself, there's an area at the top right which I think corresponds with the Eromanga Basin. Is that an area where there's no radiometric mapping? Is that the reason for its - - -

PROF GILES: Yes. So in this compilation, that area was either not covered or wasn't covered to sufficient detail to be put in with the stitch.

MR JACOBI: And in addition, I think the chart refers to "uranium rich basement". I'm just wondering whether you could just offer a simplified explanation of what you mean by "basement rock".

PROF GILES: Yes, okay. So geology works a lot on superposition of events, working from youngest back to oldest. Sedimentary rocks that are deposited recently tend to lie flat near the surface of the earth, and as you go back older and older, deeper and deeper, you tend to get to older rocks. "Basement" is a tricky term because it can mean different things to different people, but in general terms, it means the underlying crystalline crustal rock upon which younger sediments have been deposited. So specifically in this context the basement refers to those materials that were formed in that period between about 2.5 and 1.5 billion years ago. They're mostly well crystalline, solidified rocks and they comprise those kernels of the Gawler Craton and the Curnamona Craton that are the fundamental building blocks of the State.

MR JACOBI: And why is basement significant, or is why the basement rock significant to the prospectivity of uranium?

PROF GILES: Because that first round of uranium enrichment that set up the fundamental prospectivity from then on, that happened during that period of time. So it's contained within those granites, those volcanic rocks that were formed at that time.

MR JACOBI: I think that might lead us into the next graph and might lead us back to where I was going before, which is the linkage between the areas that you identified as prospective from the radiometric mapping to existing or previously exploited areas.

PROF GILES: Yes. In fact, if whoever is controlling the slides, if you could just back one off again and then we'll come forward as Chad suggested. You'll notice there that the larger deposits in the area around Andamooka, that's Olympic Dam and Woomera, they're in an area that's not particularly hot with respect to the radiometric map. Remember that the radiometrics there is only picking up the very surface rocks. A really important point about South Australia is uranium endowment, that had come up again and again over the next couple of hours, is that most of it is obscured, it's buried, and so that zone is not particularly hot with respect to uranium because it's covered by younger sediments.

The basement there is concealed and Olympic Dam, beneath about 300 metres of cover, that’s not uranium rich and as you go south it actually gets a little bit deeper, so the next biggest circle to the south there is Carrapateena and that's under 600 metres or so of concealing cover. So if we just move forward to the next slide then. I guess what this does is highlight there - you know, I just put up some of the names of those deposits - it really highlights that the two zones where the prospectivity comes to the fore is Olympic Dam of the eastern Gawler Craton and the exposed rocks in the Olary block as you head out towards Broken Hill.

So just to come back to that original uranium enrichment, which I said happened about 1.6 billion years ago, that event not only moved the material into the upper crust within magmatic rocks. There was a huge amount of heat that was fluxed into the upper crust with that event which drove large hydrothermal systems. Hydrothermal means just hot water circulating usually in the upper crust, and the remarkable thing about uranium is just how amenable it is to mobilisation in hot, particularly oxidised rocks. So not only did that event move the material into the upper crust, it also stripped a bunch of the uranium out of those original rich rocks, moved it in hydrothermal fluids and deposited it in these mineral deposits, you know, in really vast quantities. The focus of that is that little strip, absolutely that little strip along the western side of Lake Torrens and stretching down towards Whyalla.

MR JACOBI: Can we just focus on the Olympic Dam deposit for just a moment before we, I think, come to address a number of the others, and that is I'm just interested in understanding is it regarded as significant mineral geological terms, and if so, why?

PROF GILES: Yes, it is. It's often referred to by explorers and geologists as one of the world's great mineral deposits. The fundamental reason for that is its sheer size. You know, we're pretty easily impressed by big things. The most recent resource announcements from Olympic Dam during the ODX period were about 10 billion tonnes of ore. That is an outrageously large volume of mineralised rock. It makes it the largest single accumulation of uranium anywhere on the planet known. It also happens to be, I think, currently ranked the fourth in terms of copper and maybe around that number in terms of gold as well. It's an extraordinary accumulation of metal.

That comes about because of the scale of the system it sits within, but not just that. It also comes about because of the extremely efficient focusing mechanisms of that hydrothermal system which allowed a large volume of fluid to be focused in a small area where the uranium and the copper and gold have been deposited.

MR JACOBI: Before we come to address that particular method or the method by which it formed, which I understand is significant for reason we'll come to, to come back to that deposit, you've addressed its size. I'm just interested to understand whether it can also be attributed to the question of any concentration of the minerals within that deposit itself.

PROF GILES: Yes. Not particularly high grade. As often happens with very large tonnage deposits, the grade tends to be lower. I think the all-up resource at Olympic Dam has a grade of about 250 parts per million, something around that. The high-grade zones can be higher obviously. There are deposit types that we'll talk about a little bit later that get up to percent values of uranium. You know, so a percent is 10,000 parts per million. So that's a big difference in grade.

But the economics of a mine depends not just on grade and not just on size but how efficient it is to get the material out, what other credits come with it. So

Olympic Dam makes its money based on copper. The world's largest uranium deposit but it's still considered somewhat a by-product of the copper. So it's a terrific thing to have for the company that's mining it but would it be economic – I don't know. I haven't done the sums. Would it economic on its own? I don't know.

MR JACOBI: To come back to this question of – I'm just interested to understand the primary – you referred to the thermal flows and the heat flow anomaly and the focusing event. I'm just wondering whether you could walk the commission through, at least in broad terms, the primary mechanisms by which that particular deposit formed.

PROF GILES: I will, and it's relevant to all of those deposits in that belt – Prominent Hill, Olympic Dam, Carrapateena and some of the smaller ones. So if we just move on to the next slide. This is very schematic and it will always be the case. This was put together by Geoscience Australia a few years ago now based on some models that are still relevant to this deposit. Just getting you a little bit in the headspace of this diagram, it's supposed to be a cross-section through the earth. So the surface layer is the green material at the top. As we go down the page we're getting deeper. You'll see that the pink rock there with little crosses on it is a granite. The white and green rocks on the top are volcanic rocks, the Gawler Range volcanics which we talked about before which are the surface expression of this large magmatic event. The purple rocks there with little squiggles on them, that's the older basement rock. It was intruded by the granite which is itself an expression of this magmatic event and had the volcanics come out through the top.

So what this diagram is trying to convey is the fluids within this system and how they migrated through this very upper part of the crust. Just up at the very top there you'll see that there's a little divot in the surface which looks a little bit like a volcanic cone. That's exactly what it's supposed to look like in this diagram. One of the favoured models and one that I particularly like for this deposit is that it formed in that very near surface volcanic environment. The yellow in that diagram is intended to represent the Olympic Dam Breccia Complex which hosts the ore.

Picture a surface environment very much like Yellowstone National Park, if you've ever been there, fumeroles, little volcanic centres around the place, very high heat flow, no trees, no grass. Back at that time the world would be a very muddy kind of environment with bubbling mud pools and what have you, an environment where masses of amount of heat are being transferred to the upper crust in this volcanic and magmatic system. Immediately below that yellow is a black line which is intended to represent a fundamental crustal structure, a fault line, a break in the earth's crust which is permeable, which allows fluids to flow through it, as are all of the black lines on that diagram.

What happens in the upper five kilometres or so of the earth's crust which is heavily faulted in these high-temperature areas is that fluid is extremely mobile. It's as mobile as it is in a lake, arguably. So if you heat it from the bottom or put a point source of heat on it you will drive, effectively, convection within that system. You'll drive upwelling zones of hot fluids. At the same time, when something comes up sometimes else as to go down to replace it. So you can picture the upper crustal container of fluids here as a highly mobile fluid system with fluid coming down some areas and being expelled in other areas.

Now, that fluid is connected to the surface and is oxidised. It has tremendous power to strip uranium out of the rocks that it interacts with. So there's a whole bunch of downgoing arrows there which are intended to represent fluids that are moving down through the crustal pile that are getting heated, that have come from the surface so they're oxidised. A key point that you'll hear again and again today is uranium in its oxidised form, uranium(6+), is very mobile. Uranium in its reduced form is far less so, uranium(4+), and it will tend to deposit as uranium ore mineral.

So we've got sources of fluid here. We've got fluid that's coming from the deep magmatic system. Those are the red lines. Tend to be more reduced, so not carrying as much oxygen. You've got uranium-rich fluids that are interactive. All of those pink rocks there, fundamental magmatic enrichment in uranium. Mix them with those oxidised fluids and strip the uranium out, pump them up a fault and mix them with a reduced fluid and you've got something very interesting with respect to uranium mineralisation. As it happens, this system was so efficient that it was also extremely good at gathering copper and gold and it just so happens that the reactions that dropped the uranium out within that volume also were able to drop out the copper and the gold.

MR JACOBI: I'm just going to ask you about the polymetallic nature of the deposits. I just want to understand whether that's characteristic of systems that have developed in this particular fashion. That is, is it typical that one finds uranium produced by these particular primary mechanisms in combination with copper, gold, silver and other metals?

PROF GILES: It's common without being a one-to-one relationship. So the situation that I've just explained is the preferred model of many of how this deposit formed. It's my preferred model. It's not a hundred per cent proven but there's a lot of evidence to say that it was the mixing of these two fluids, a surface-derived fluid and a deep fluid, which was really important for the formation of the deposit. One of the lines of evidence for that is that there are copper and gold rich deposits within the same belt that don't have the same tenor of uranium within them that seemed to be more reduced. They're more reflective of that red fluid coming up the pipe before it had a chance, necessarily, to interact with those uranium-rich surface fluids. So, yes, if you go to Prominent Hill, Olympic Dam, Carrapateena and Hillside, other deposits in this belt, the amount of uranium in the deposit varies.

MR JACOBI: Perhaps we might be able to come back to the previous slide. I think you identified that – we've just addressed the primary mechanism by which Olympic Dam formed. Are the other deposits that are shown there, are they also formed by a similar mechanism?

PROF GILES: Very similar, yes. Not all exactly the same. There's some good evidence at Olympic Dam that you are actually quite near that volcanic event, for example. Some of the other deposits might have been formed a little bit deeper but very similar, similar. One of the things that's really quite characteristic is the ore textures for these brands of the deposit. So these are often Prominent Hill, Olympic Dam, Carrapateena are an end member which people would call a hematite breccia deposit. Breccia just means - is a jargon word for broken rock.

So these are areas of rock where the hydrothermal system has been almost explosive in its nature and has managed to completely fracture and retexture the entire rock mass. There are other types of deposit in here. Hillside is one, not shown on there, not particularly high in uranium. There's some smaller deposits such as Emmie Bluff that are unlikely to be mined, more copper and gold rich where it's more of a replacement style where you haven't had that explosive fluid mixing interaction.

MR JACOBI: Based on the primary mechanism that you've just described, is there a reason for thinking that there would be other deposits within the area that you described that are currently not located?

PROF GILES: Yes, absolutely. If we move onto this diagram, when you have a very large mineral system they tend to organise themselves in quite a characteristic way, and we see this in all - in all of the very large mineral caps in the world there's a scaling relationship that exists which says very simply that if you have a big system that you'll tend to get some very large deposits, which often get found early in the exploration cycle because they're large and they're therefore easy to find, but what you get is a lot of babies around it, and there's a rule of thumb which we can't prove in this terrain because we just don’t have enough data, but where we have enough data in well-exposed terrains this rule of thumb works pretty well, and that is this: it's demonstrated by the green line there, which is called a Zipf curve.

What we've down the bottom there is - the numbers along the X axis on that diagram are just a rank of the deposit from first, in this case Olympic Dam, showing copper in blue and the by-products, which includes the uranium, in red. The next deposits as they move across include Prominent Hill and Carrapateena and what have you. So they're just shown in rank from largest on the left to smallest on the right. Now, the Zipf curve says that that mother and family relationship is that the second rank deposit will tend to be about half the size, the third rank deposit will tend to be about a third of the size, the fourth about a quarter of the size. Remarkably, shown again and again it's a power law relationship and the exponent on that power law very commonly produces this curve, quite remarkable.

The reason I love showing this diagram is it shows the potential missing inventory within that zone. The potential for missing is everything below that green line and we haven't come close to scratching the surface of this area. So we're talking about a belt which is 600 kilometres long, 150 kilometres wide, and we've got a big daddy sitting in there and just a few little ones hanging around the edges. Huge potential missing inventory.

MR JACOBI: To come back to what you described as the Zipf curve. That describes a probability analysis. I'm just interested to understand the evidence that supports elsewhere in the world the existence of such a power law relationship and the extent to which that's been demonstrated by an actual fit to more examples.

PROF GILES: Yes. There are some terrific examples. The distribution of porphyry copper deposits in the Andes, and indeed globally, fits a curve like this remarkably well, deposits of similar scale in terms of tonnage and grade. There was an absolutely fascinating study done in the Western Australian goldfields just a few years ago which showed how the discovery of goldmines in that belt over a period of time populated a Zipf curve. So what they did was they said, "Starting in 1970, let's look at our single largest deposit in the eastern goldfields of Western Australia," which was Kalgoorlie golden mile, which is on the left of that diagram. "Now, let's calibrate our Zipf curve based on that," just using this incredibly simple, just really dumb thing of saying the second one will be half the size, the third one will be a third of the size.

They drew the curve and they looked at the missing inventory in 1970. So this was a retrospective thing that they did, everything that was known. Then as things were found at various stages through the exploration cycle in Western Australia they populated that curve. You know what? As things were found they gradually - the skyscraper started to build and just filled in the curve, almost now completely filled in, which tells you that's a very mature exploration terrain, a few little bits and pieces are missing, but the key way to use it, you know, the shape of that curve might be slightly different. It might be slightly higher, might be slightly slower. We don't know that until we find everything in this belt.

What it does is it tells you the potential scale without giving a number. A number doesn't come out of the back saying that there is still, you know, five million tonnes of uranium that ought to be found out there. What it says is that this is the scale, this is the order of magnitude of the opportunity that that's there, and we'll only know that by efficiently exploring within.

MR JACOBI: Am I right to understand that the natural mechanisms lend themselves to this sort of probabilistic analysis in the sense that you would expect a distribution?

PROF GILES: Yes. It does lend itself to this because it's a - the distribution of ore deposits and the incredibly complex interacting mechanisms that produce them tend to produce fractal distributions of the deposits themselves and of the structures and rocks that host them, and the absolute characteristic of fractal systems are population distributions that have at their highest end, their high-grade cut-offs, this type of power law relationship, absolutely characteristic. So you predict this type of behaviour. It happens empirically. The key thing is fitting the curve to the terrain, and I guess that's why I don’t feel that I'm putting my neck on the block at all by putting up a curve of this style, and the reason is when we've done it in other terrains that's the curve that comes up empirically.

MR JACOBI: That leads, I think, to the next question, which is the areas of South Australia about which little is known which are thought to potentially be within the belt you described, and I think the next slide might take us there. You've marked that area called the Pandurra Formation. Can you explain what that is and what its significance is?

PROF GILES: So once we have the basement rocks established, the rest of the geological history of South Australia - my geological colleagues would hate me for saying this - is essentially a superposition of sedimentary basins on top of the basement which didn't move that much. Okay? So just think of the basement being established with those rich rocks and we're going to put sedimentary basins on top of that. Absolutely the first one of those is this sequence called the Pandurra Formation, which was deposited - we don't know exactly when, sometime between about 1590 million years ago and about 1200 million years ago, a big range, deposited directly on top of that uranium-rich basement with a very large component of the sedimentary material that makes up the Pandurra Formation derived directly from that uranium-rich basement.

So the basement is sitting here with eroded material off the basement into a hole which had roughly that shape. We don't know exactly the boundaries because the boundaries have been eroded off. Now, that material importantly not only derived from that uranium-rich material sitting on top of that uranium-rich material deposited in rivers and lakes, so interacting with the oxygenated atmosphere or the atmosphere that was becoming oxygenated, and so those deposits are red or orange in colour because they're full iron oxide.

MR JACOBI: Now, the radiometrics show that area as being blue or relatively cold.

PROF GILES: Yes.

MR JACOBI: I'm just wondering whether you can explain the reason for the radiometrics in the area being essentially cold.

PROF GILES: Yes. So that - - -

MR JACOBI: (With regards to it)? being prospective.

PROF GILES: Yes. That group, the Pandurra Formation, very poorly exposed. So it's mostly covered by rocks, by some of those cover sequences with very little uranium in them. So the importance of the Pandurra Formation, it represents a series of rocks that are relatively coarse grained that should have been permeable, at least at some stage during their deposition and after. We're interested in that because we want oxidised fluids to be able to flow through them. The fluids that would have flowed through them would have been buffered by the rocks there. So they would have been oxidised, they would have had the potential to carry uranium. We're sitting in a zone, as we've already established, with bucket loads of uranium that's available.

So most geologists who work in this area would consider the prospectivity of the Pandurra Formation by analogy with a very well known uranium producing area of Canada known as the Athabasca Basin. This is an area with a very similar sedimentary sequence, oxidised, coarse-grained, very silica-rich material sitting over uranium-rich bedrock in Canada.

MR JACOBI: Before we go on with the Athabasca Basin in Canada, there's a note at the bottom of the slide that refers to that Pandurra Formation being barely tested. I'm just wondering whether you can explain the extent to which that has been drawn.

PROF GILES: Look, there are quite a few drill holes in that area and quite a few if you look at it at the scale of the state, but almost none if you look at it at the scale of the type of deposit that you would find in there. So the types of deposits that are known as unconformity-type deposits have a very small footprint. There are – Laura, you might have to help me out here. I think there are only about 27 drill holes in that entire area that actually go through the

Pandurra Formation and into the basement rocks and it's at that interface between the cover rocks and the basement where the deposits are likely to form. So what that means is we have very sparse information about what's happening at that interface or within that unit with which to try and reconstruct how fluid was moving around it during that period of time.

MR JACOBI: You described the particular characteristic as being unconformity.

PROF GILES: Yes.

MR JACOBI: Am I right in understanding that that means that it's necessary to drill more closely than you might otherwise?

PROF GILES: Yes. That might be a good time to move to the next slide. It's a very generic slide put up there to show the types of geological relationships that are common in these deposits from Canada. The little black blobs there are the deposits. The yellow through to red kind of pancake material on the top, that's the Athabasca Basin sediments. So those are oxidised sediments comparable to the ones in the Pandurra Formation. The material on about a 45-degree angle below that are older basement rocks. You can see again geologists are fond of putting thick black lines where there are structural discontinuities or faults in the rock. Those are the zones where you tend to get focused fluid flow.

So a couple of different models here. One of the absolute key aspects to it – notice in the central grey line there, there's one of those black faults and it says Graphitic metapelite. Graphite is carbon without any oxygen or hydrogen or anything attached to it. It's a reduced form of carbon. That is a fault shear zone through rocks that are reduced and fluids flowing up there will be reduced. They have the capacity, if they interact with oxidised fluids bearing uranium, to cause the precipitation of that uranium. That, in its essence, is the model of this type of deposit. So you have oxidised material carrying uranium in solution in the basin that interacts by hook or by crook with reduced material in the basement.

So the reaction happens right at the contact. That's why they're called unconformity. Unconformity is a geological word that means that you have a time period between the deposition of those rocks that are on an angle in the basement. They were rotated and eroded off – that's the unconformity – and the new rocks were placed on top. So what they've done there is they've – just see above those black blobs there the fault zones continue into the sediments and there's areas where it says Dissolution, silicified. They're some very cryptic geochemical and mineralogical signatures of these deposits within the sediments above them. But all the action in terms of grade happens at the bottom and they're really small high grades, so up to per cent values the highest grade uranium deposits around but really small. That alteration footprint is just above them.

So if you have 27 drill holes in an area – Laura, again, can you help me with the area of the Pandurra Formation? 40,000 square kilometres, 27 drill holes. You've got no chance – those drill holes weren't necessarily drilled to explore for this type of deposit. You would have no chance. You've got zero chance of hitting those just by pure luck. You need a systematic program that seeks to find those particular alteration signatures and tags the basement itself.

COMMISSIONER: How many drill holes would you estimate would be needed to have a reasonable of finding it?

PROF GILES: That is the million-dollar question in these terrains.

COMMISSIONER: Presumably you'd try and improve your intelligence to mark an area.

PROF GILES: Yes. We might come to this later because absolutely fundamental to all of the exploration in these cover terrains – and that is there's a high cost to drilling deep. A mining company that would go into this terrain and try and blanket drill would run out of money extremely quickly. So one of the things which is really coming to the fore in this exploration of uncovered regions is what is the right balance of trying to use your geological smarts to target the holes and to try and push back the cost of the exploration so that we can do the right density of sampling within those zones that we identify.

That is not an easy problem and there's two ways around that. One, reduce the cost of the drilling and sampling. Two, get smarter. But they're related and the reason they're related is that you cannot get smarter in these terrains until you start gathering information. Some of them we've got so little information that we don't even know where to start. The two problems will help themselves out because if we can get cheaper drilling and gather more information, that will also help us target further holes and eventually we'll build up a picture of how to explore more effectively.

MR JACOBI: The million-dollar question might lead us to another question, which is how they were found in the Athabasca Basin.

PROF GILES: I might take one step back from that because I don’t know the detailed exploration history of each of these deposits. If we move onto the next slide I'll tell you something which links to this one. The black outline there, the roughly kind of rectangular-shaped outline, is the outline of the Athabasca basin. What we're looking at here in the pretty reds and blues is a magnetic image. So this is showing fundamentally the distribution of magnetite. Notice that those north-east, south-west trending zones just go straight through the Athabasca Basin. There's no influence on it at all. That's because the Athabasca Basin has no magnetite in it. It's blind. It's transparent, is a better word, with respect to the aeromagnetics. So what we're seeing there is a signature from the underlying basement rocks.

The reason I put this slide in is I wanted to show you that, yes, it's difficult but using some fundamental understanding of the nature of the systems you can cut down the volume in which you would like to explore. So magnetite is an iron oxide. It's not the most oxidised version but it's an iron oxide, and if you interact that with a fluid or rocks that are reduced you will destroy the magnetite.

So the zones of blue there represent the reduced sequences that underlie the Athabasca Basin. The likely source of reduced fluids are done an unconformity and you'll notice that the stars and the dots there are the uranium deposits in that basin. Particularly up on the eastern side there you can see the relationship with what I would call a geological fairway. If you're in that zone you are far more likely to find mineralisation. You still have explore smart within it, but what you've done by focusing in with that zone there is you've cut down your exploration to a twentieth of the original volume and, you know, that's what mineral exploration is about. It's about making decisions at various scales that give you a higher likelihood of focusing in on the mineralisation.

MR JACOBI: Can I just interrupt there?

PROF GILES: Yes.

MR JACOBI: Am I right in understanding that the opportunity is aerial magnetics in South Australia is limited as compared to the position in Saskatchewan?

PROF GILES: No. South Australia has been a world leader in gathering aerial magnetic data and it has an absolutely fantastic aero-magnetic dataset State-wide. If you go back maybe one slide. Just go one more. Sorry, we're going to have jump backwards and forwards. I just want to find the magnetic image, which is a grey one. Yes. That's it. There we go. So that grey image there, on this scale, right, it's not a terrific representation.

The light colours there are magnetite rich and the dark or the blander grey colours are magnetite poor, and you can see that type of this image picks that up remarkably well, remarkably well. The area covered by the Pandurra Formation is not particularly textured in that way. So it's not chalk and cheese like the picture from the Athabasca Basin, but I don't want to create the impression that those datasets don’t exist and wouldn't be useful.

MR JACOBI: I wasn't suggesting, I don’t think, that they don’t exist or that they can't be used. I'm interested in understanding how telling they might be in South Australia.

PROF GILES: Okay. Yes. Not so much beneath the Pandurra Formation. You know, that clear pathway in the aero-magnetics is really quite obvious in Athabasca, are not so much underneath the Pandurra Formation.

MR JACOBI: Bring us back from the Athabasca pictures and bring us back to the slide that follows the radio aerial magnetics.

PROF GILES: Yes.

MR JACOBI: Now, I understand that there's a challenge in terms of locating other deposits of redistributed material and this is what this slide demonstrates.

PROF GILES: Yes. I wanted to put this one on because we can't ignore this very important period in South Australian geological history from about 800 to about 500 million years ago, which is responsible for our most famous rocks in South Australia in the Flinders Ranges, Mount Lofty Ranges. There was a very large sedimentary basin that developed over large parts of Australia during this period of time. It blanketed this huge section of eastern South Australia right over the high-heat producing uranium-rich basement.

The outline there of the red, as you can see, includes the northern Flinders Ranges where you'll see there is quite a lot of yellow to slightly red shades in there. Those are relatively uranium-rich rocks. What that represents is the reworking again of the uranium in this system, but slightly differently. It's mostly physical to try to do a reworking of bits of uranium in sediments into specific sedimentary horizons. So it's more a dispersion rather than a focusing of uranium within those particular horizon.

There are other horizons in there you'll see which are not particular uranium rich at all, and to my knowledge, there's been no uranium mining or serious uranium deposits that have been found within those sedimentary rocks. So their most important role in uranium exploration in South Australia is the blanket that they form over the underlying prospective material. So that's the blanket primarily. At Olympic Dam there's about 300 metres of those sediments. As you go further south in the Olympic Domain they get thicker and commonly, you know, hundreds of metres to up to a kilometre of that material between the surface where we have to explore from and those prospective basement rocks that we want to get to.

MR JACOBI: Moving on from the redistribution that's shown there, I was wondering whether we could address the even younger redistribution in the hydrothermal system that's shown in our next slide.

PROF GILES: It is indeed. So in the northern Flinders Ranges there's an area of exposed basement rock, very uranium-rich basement rock, known as the Mount Painter inlier. This is the area around Arkaroola, and you can see that that's the hottest part of the entire radiometric map of South Australia, highlighted there, very roughly, I should add, by the thick red outline. It's a terrific example here of the mobility of uranium through multiple stages of Earth's history.

So these are some of the hottest basement rocks, so quite a lot of uranium, highly fractionated granites which really concentrated the uranium into them. These rocks were exposed near the Earth's surface during the Palaeozoic period, call that for 450 to 250 million years ago. During a period when they were right at the Earth's surface these rocks were involved in a hydrothermal system very similar to the sort of thing that I outlined to you before, Yellowstone or something that you might see in Rotorua in New Zealand, driven by, once again, the high uranium content in the basement which leads to elevated geothermal gradients, hot fluid bubbling around near the surface of the Earth.

So this system, bubbling mud, oxidised fluid, was able to interact with these very uranium-rich rocks and concentrate uranium in the deposits that are in the Mount Painter inlier. Mount Gee is one of them, and there's a whole series of them up there. If you've ever been on the Ridgetop track at Arkaroola you drive right over the top of them, quite spectacular geology.

MR JACOBI: I understand that there's been further redistribution since the formation of Mount Painter itself and that has shown itself up in terms of secondary deposits, and I think that's shown in our next slide.

PROF GILES: Yes. So we're moving through now. We're getting into the Mesozoic, the period of the dinosaurs, and we really are getting into the stage now of tectonic quiescence, really not much happening in terms of the ups and downs of those basement rocks and you can see that there are sheets of quite thin terrestrial, meaning on the continent, rivers and lakes and what have you, and shallow marine sediments that covered huge areas of South Australia. So what I've tried to show there is - and it's a little confusing because all the boundaries line up - but if you look in the area that I've labelled Eromanga Basin there, there is an area to the northeast there above the red line, a very large area, part of the Great Artesian Basin. It was covered by a shallow continental ocean from the Cretaceous period until the Tertiary. That is some fascinating geology in there. Some of the key things about that is that there are river and beach sand sequences that were deposited in there as the ocean came in and then went out that had coarse quartz-rich material that's permeable. Permeability is absolutely important in these rocks.

All you'll see is that that basin in particular, the Eromanga Basin, and the Frome embayment part of that on the eastern side, the area that that inundated came up to and onlapped the edges of our high-uranium basement, uranium-rich rocks that were exposed at the surface and had these sediments deposited on its margins. Similar things happened in the Murray Basin down to the south-east, although not s many uranium-rich rocks there, the Eucla Basin in the south-west and in the little internal basins there, the Torrens Basin and Pirie Basin.

So the significance of this is in the formation of a different style of uranium deposit which most people would call a sandstone-hosted deposit. Nothing particularly scientific in that very descriptive term. They tend to be hosted in these river sediments or marginal marine sediments, like dune sands, very close to where those sands are adjacent to uranium-rich basement. So the absolute key area there for South Australia over time has been the Frome embayment. If we move onto the next slide you'll see that the deposits that I've highlighted there are all of that style, sandstone hosted. There is also an emerging area down on the eastern side of the Eyre Peninsula with some resources down there, just south of Whyalla.

So these deposits tend to be – they're smaller in terms of their tonnage. They can have quite good grades of uranium and their geometry can be quite challenging in terms of extraction because of the very fine-scale interaction of oxidised surface waters which carry the dissolved uranium and reductants within the basin that causes the deposition of that uranium.

We'll move on. I think my next slide shows a little bit of a distribution of that within the Frome embayment. So this is an image which has gone back to the radiometrics, to uranium channel on the radiometrics just zoomed into that little area of the Frome embayment. So the red dots on there are the uranium deposits. What I really want to point out there is the relationship of those uranium deposits in terms of proximity to the exposed uranium-rich basement, really close, within tens of kilometres of that exposed basement. In the same way as you could identify a mineralisation fairway beneath the Athabasca Basin in relation to those reduced rocks, there's a mineralisation fairway here in relation to proximity to the uranium-rich source rocks.

In really simple terms, oxidised fluids have interacted with the uranium-rich source rocks by being rained on them, they've dissolved the uranium out over time, carried it downhill and the aquifers adjacent to the basins have captured that water and it has moved out into the basin. As soon as that oxidised fluid interacts with material that can reduce it – a classic one might be fossilised vegetable matter within the basement. It could be faults with reduced fluids coming up them, similar to the unconformity uranium model. As soon as it does that it will tend to drop its uranium out. So if you look down in the southern part of the diagram you'll see a bunch of red squiggly outlines. Those are paleochannels. That means that's the old buried river systems. What you can see is the relationship of those deposits at Oban, Honeymoon and Gould Dam within those drainage channels. That says that the groundwater is following those old systems.

The most important area in terms of uranium resources and significant reserves is the area around Beverley, Four Mile West, up there, where the uranium source rocks are really right next door. If you're standing on the deposit you're looking at the source rocks of the northern Flinders Ranges right there within kilometres and those are hosted within a series of aquifers. Those are more classic, what we call a roll-front deposit, which is where the fluid has moved down through an aquifer. Because of the nature of fluid flow within that aquifer it moves faster in the middle and slower at the edges. It's kind of a drag effect. As it interacts with water-reduced rocks out here you have a boundary which is the oxidisation and reduction down here. It has this crescent shape. That's called a roll-front deposit, really quite characteristic.

These are interesting on a number of levels. I find it fascinating that the way that they mine these is through in situ leach, typically, which is that they reverse the depositional process by drilling holes in the ground and using the permeable nature of the aquifer to put oxidising fluids down there to redissolve the uranium and suck it back out, so very little surface disruption. You go out there and it just looks like a plumbers' convention.

MR JACOBI: Can I just pick upon one aspect of what you said, and that is in terms of the distance that you'd expect to find a secondary deposit from a primary deposit is there an expectation that you – you mentioned a couple of kilometres.

PROF GILES: Look, it might be more than that. It might be within tens of kilometres. The uranium tends not to get far, certainly in the examples here in South Australia. The fairway, if you like – if you really wanted to focus your exploration the most likely areas are, I would have though, within 10 kilometres of the exposed basin, maybe a little bit more. It's a well defined zone around the edges of these exposed uranium-rich rocks.

MR JACOBI: I'm just conscious of the time. There are a number of matters that we touched upon, I think right at the start, in terms of barriers to further exploration activity in South Australia. You've identified issues of cost, given issues of cover. Are there any other barriers that you can see to further exploration activity in South Australia?

PROF GILES: Technical barriers, I think that's the easier one for me to address. The technical barrier is absolutely 100 per cent the nature and the thickness of the cover material. One of the really interesting parts of that is that these particular cover materials are also host to the mineralisation. So we might just park that for a moment and look at exploring within the original uranium-rich basement rocks. Really very few of those rocks are exposed at the surface. 10 per cent would be an extremely high number, I would have thought, that are effectively exposed for exploration.

As you can see from the radiometric maps there, the geochemical signature that is expressed in uranium or any other element that might help you find those things is obscured. It has gone. It has been obliterated by that cover. So we can't do much at the surface. If you went out there and took surface geochemical samples, what you would do, if you took enough of them, is you'd effectively recreate that radiometrics map. It wouldn't help you in the Olympic Domain. We can use magnetics and gravity, as I outlined before, and those are really wonderful datasets. They can help you get in a fairway. They can help you define the likely location of those discontinuities in the crust, the major faults and shear zones where fluid is likely to have flowed. They can help you identify broad packages of rock that might be of interest to you.

Those things that you identify there are not mineral deposits, no. The way that exploration has evolved in those cover rocks in South Australia because of those fantastic magnetic and gravity datasets is people have used them to target their actual drill holes and they've done it by this logic. Those big breccia systems, they're called iron oxide, copper, gold deposits for a reason. They have iron oxide associated with them. Iron oxide though is not the ore mineral. So one of the iron oxides, magnetite, is magnetic. So it shows up in those aeromagnetic images.

Both of the iron oxides, magnetite and hematite, are dense. They're more dense than the rocks around them. So they show up in gravity images. Gravity just gives you the distribution of dense rocks in the subsurface. And what we know about these hydrothermal systems is they moved a lot of iron around with them as well as the uranium and the copper and gold, and there is a large footprint of iron hydrothermal alteration, for want of a better word, which has expressed itself in the magnetic and the gravity images.

So what people have done is, they said, "Right. We think we understand that. Now, if we see a magnetic image with a blip in it, and even better, if it's got a coincident blip in the gravity, both of those are telling us that there might be iron oxide there. Let's put a drill hole in it, see what it is. Let's see if it's one of these iron oxide breccia systems." Terrific, except that iron oxide is not all. So you're using two layers of proxy: you know, number 1 proxy is you're saying that that concentration of iron oxides is going to be representative of ore, and it rarely is, mostly it's not; and the other one is that you're magnetic signature and your gravity signature is iron oxide even to start with, and it's not always.

In fact, quite often it's another type of dense rock somehow coinciding with a rock that has magnetite in it and the most common one of those is a bog standard basalt. Basalt is a very common rock, very common to the three cover sequences and basement sequences here. It tends to contain some magnetite and it's dense so that it creates a gravity signature. What this does in the exploration world is it either says that the primary targeting mechanism for making a drill hole is kind of two layers removed from the likelihood of there being an ore deposit there and there is massive potential to be what you would call a false positive in the exploration world.

So that's been the basis of most exploration in the last - well, in all of the exploration under the cover rocks in South Australia actually, and what it's resulted in is a series of essentially isolated one-off drill holes, sometimes quite deep drill holes with a lot of money spent on them, into one of these targets that has either hit iron oxide breccia with no copper or gold in it, has hit basalt or some similar rock that gave a false positive, or hasn't actually explained the anomaly at all because they didn't reach the required depth.

So these isolated holes spread around the State at roughly the density that we talked about with the Pandurra Formation, so, you know, one drill hole per eight, 20 kilometres, you know, as a general spread, have populated that area if you stand back on the scale and say, "It looks like there's a lot of drill holes out there," but in actual fact, the ability of those drill holes to test the mineral potential has been very low. There hasn't been an efficient use of the data from each of those drill holes because they're spatially isolated from each other to build up a picture of the entire mineral system.

If you want to build up a picture of that system without relying on proxies, or just using the proxies to fill in the gaps between known points of data, there is only one solution, and that is you have to stop trying to guess based on very little data and you have to collect more data. You have to fill in the gaps. There's only way to do that and that's to drill holes, and drilling is expensive. In Deep Exploration Technologies CRC, we did an exercise recently where we tried to calculate the actual cost of drilling per metre to companies, the all-up cost of drilling.

In terms of diamond drilling, which is certainly desirable in these sorts of areas, the cost is conservatively $500 a metre, the all-up cost. So if you're a small explorer and you hit one of these targets and drill a 1,000-metre hole, well, there's half a million bucks of your budget gone, and these guys are sitting on small cash reserves. You know, that's really one-shot-in-the-chamber stuff. Drill a hole or two and you're done.

So drilling is expensive. There is a combination that is extremely, I think, strategically important to the State of South Australia in reducing the cost of drilling and the analyses that go with it so that more drill holes can be done, and focusing our exploration in those fairways as we identify them. You know, we have enough knowledge of these systems to have a decent guess at where those fairways are.

COMMISSIONER: There's nothing on the technology horizon other than drilling?

PROF GILES: There's always lots on the technology horizon. There's some terrific stuff happening at surface to try and map out the mineral systems, but in the end, that is always a proxy for a physical characteristic of the rock which doesn't necessarily represent the ore. Uranium has a great signature in the radiometrics if it's in that top 30 centimetres or so, but if it's buried it doesn't. So there's a couple of areas that are proving potentially useful as we move forward as a surface technique. One is magnetotellurics, and you're talking to Graham Heinson next who is a world expert on that particular technique, which turns out to be really useful at mapping out the paleohydrothermal cells, at least that's what we think it's doing. So we think that's going to be a good way of helping to identify the fairways, where the fluids are moved around in the crust.

The other one, which has got very little airplay but could turn out to be quite useful if it was done in a systematic way, is measuring heat flow. So I mentioned this thing called the South Australian heat flow anomaly. It's been built up over time by measuring the temperature within welds within drill holes where you can work out how much heat is flowing out of the crust at any one point. Where there's high heat flow it tends to be a combination of high heat-producing rocks and thermally insulating sediments above them that tend to trap the heat within the crust.

MR JACOBI: So you have to do that through a drill hole?

PROF GILES: Yes, you do. To get a good number you have to do it through a drill hole. I've been involved in a project which is trying to do it in a reconnaissance way by just making small holes in the ground. That technology is not mature but we did that with a very specific thing in mind, which is to say that if you could make a blanket coverage that gave you heat flow it would be a very useful thing. So as a specific exploration tool, because if you have a point source of high uranium, it should create a heat flow anomaly above it which is measurable within those holes above it. So the key thing there, at the moment at least, is if you want to use that technique you've got to make holes in the ground. You've got make more holes in the ground so you can put the probes down there.

Those are the surface techniques. A bit of a plug for what I'm doing at the moment. The absolute key thing, whatever you do with that sort of surface sampling is you still have to take a sample there. You have to take a sample from where it matters from within the mineral system. If you're going to do that you have to drill. That is the whole rationale behind the work that I've been doing for the last five or six years, which is to say let's deal with it at a drilling engineering stage and try and reduce the cost there by about an order of magnitude. So we would like to be able to drill at $50 a metre all up cost, 10 times the holes, you know, within the same program and do all the analysis and testing of those drill holes at the same time as you make the hole in the ground.

MR JACOBI: Have you identified the areas in terms of reducing costs in terms of the inherent parts of the cost of drilling that are prospective in terms of actually being able to achieve those reductions?

PROF GILES: Yes. The key thing is time. So it turns out that a very large proportion of the time drilling is spent screwing drill rods together. I'm not sure if you're familiar with how a drill rig works. You stand at the surface, you drill into the ground a certain distance, which is the length of the pipe, you screw another rod on and you drill down, screw another, drill down, and when you come out you have to unscrew each of the rods. So a large proportion of the time is spent making connections.

A very large saving can be made by not making those connections, and that means drilling with a coiled tube which continuously unrolls, unravels, and goes down the hole. So you're drilling all the time and when you come out you just pull it off one time and roll it up. So that's the technology that we're working on. Quite a few challenges to get that to work in hard rocks but we've found – we talked earlier about the financial modelling. We've done some financial modelling on the cost of that and we believe it's feasible to push the cost down to that $50 a metre kind of mark.

MR JACOBI: I have one further question to ask. The commission has heard about measures of proven reserves and I'm just interested to understand the extent to which proven reserves – the extent to which, when it's proven, they prove the entire reserve. Can you offer any insight into that?

PROF GILES: Yes, I think I can. When mineralisation is being discovered, that doesn't necessarily make it economic mineralisation. So the geology is one thing, the business of making money about a mine is quite another. The distribution of the ore, we've talked about that probabilistic model of the distribution of uranium in the crust following these fractal patterns. Well, it happens like that within the ore body itself. You don't just go – or very rarely, I should say, do you go to a deposit and say all of those black rocks and all of those white rocks are waste and, therefore, we can mine all of those black rocks and make money, and if we make a pile of those white rocks we'll avoid diluting the money that we make. So a much more complex distribution of the ore minerals.

What that means is that you have to sample them in great detail. So lots of drill holes go into defining the resource because you're trying to capture that variability that's within the deposit. You can't entirely capture it until you've mined the whole thing. Even then, because you take bucket loads of things and mix them up, you're not capturing the extent of that variability. So it's that uncertainty that defines the difference between a resource and a reserve and eventually the reconciled material that you've dug out that hopefully if you process in the right way you are able to then find a market and make money out of it.

So when somebody talks about a resource it's usually based on a certain density of drilling and understanding of the deposit. They say, "We understand the variability to a level that says we've got a broad handle on the total amount of tons of material and the variation in grade that's within it," at the very end of an exploration program. A reserve is intended to indicate the material that they can make money out of with some sort of a measure of certainty of the grade that allows them to say, "We'll be able to extract this much ore. In the current market that's worth so much money." Of course, if the price goes down by half, that must affect the reserve. The reserve is the material that you can dig out of the ground and make money out of.

So that should never be a fixed number. What tends to happen in the mining world is that the reserve is defined by having a higher density of drilling and a better understanding of that geological variability, but you can see that something that's economic in the boom with the uranium price of $110 a pound is not necessarily economic in a time when the uranium price is $40 or something like that. It's this complex interaction between a very complex geological system which I hope myself and my colleagues are barely trying to understand and an incredibly complex economic system which I don't have a hope of and I doubt the economists do either. So there's the uncertainty in reserves.

COMMISSIONER: Professor, thanks very much for your time. We'll adjourn till 11 o’clock when we've got Prof Heinson.

ADJOURNED **[10.27 am]**