COMMISSION RESUMES ON TUESDAY 18 OCTOBER 2011 AT 9.30 AM

MR MILLS ADDRESSES THE COURT - PANEL

MR MILLS CALLS

JARG PETTINGA (AFFIRMED)

MR MILLS ADDRESSES THE COMMISSION

JUSTICE COOPER ADDRESSES WITNESS:

Can I just say, you probably don't need me to tell you this but what I said yesterday when Dr Webb was giving evidence about the desirability of using words to describe things to which you are pointing, it's important for the record that's created and also I learnt this morning the internet audience doesn't actually get the pointer. They only get what's displayed on the screen itself so that's another reason, assuming there are people at home watching, to use words to describe the things that you're pointing at. Thank you.

JUSTICE COOPER FURTHER ADDRESSES WITNESS, USE OF WORDS

WITNESS REFERS TO POWER POINT PRESENTATION

EXAMINATION: MR MILLS

A. We start with the first slide, 10B.1. Thank you. I'm hoping that that's reasonably visible. It's because we've got the lights on right overhead it's quite hard, probably for people at the back of the room to see that image.

JUSTICE COOPER REFERS TO LIGHTING

EXAMINATION CONTINUES: MR MILLS

A. So my presentation is concerned with, it's delivered in two parts. The first part is to talk about, just briefly about the plate tectonic setting that is giving rise to the geological activity, the earthquakes faulting. I'll talk a little bit about the history of earthquakes in Canterbury over the last 150 years that we have records for and also introduce the studies that we've been doing over the years to understand better the active faults that are present in the central South Island and the Canterbury region in particular. From there I'll move onto talking about some of the more recent investigations which have been targeting the presence of faults in the sub-surface beneath Christchurch and beneath the areas adjacent to Christchurch where there was a gap in our knowledge in terms of, of sub-surface structure and we've been targeting that with some further investigations in recent times. So the next slide please. Thank you. So New Zealand straddles a tectonic plate boundary. It's the plate boundary between the Australian plate and the Pacific plate and the boundary tracks down the eastern side of the North Island offshore following the Kermadec Trench and the Hikurangi Trough and reaches to just offshore the Kaikoura area north of us here from Christchurch. The plate boundary then steps across the northern part of the South Island and links through a relay of faults into the Alpine fault which is located immediately adjacent to the west side of the southern Alps and extends on offshore to the south-west of New Zealand and links into the Puysegur Trench. In the northern area beneath the North Island and extending north beneath the Kermadecs the Pacific plate is being sub-ducted which means it's being recycled back down beneath, into the deeper earth and its associated with deep earthquakes as well as shallow earthquakes in that region. The plate boundary zone that is accommodating the tectonic deformation and collision associated with the two plates moving extends right across the island to the Taranaki area, central North Island volcanic area and we get earthquakes throughout the region. As we move towards the South Island the plate boundary then steps across the northern part of the island and if we look first of all off to the east side of the North Island we see these arrows with 50 millimetres per year to the north, 60 millimetres per year and immediately off from Christchurch and, and Kaikoura here an arrow 40 millimetres per year. That's the approximate rate of movement of the

Pacific plate moving into the Australian plate and so if we keep the Australian plate fixed that's the driver for the tectonic activity that we experience in New Zealand. Now the plate boundary zone in the South Island is somewhere around 150/200 kilometres wide and so there's earthquake activity across much of the island and we'll also notice that in this diagram on the right-hand side the areas in yellow represent the thicker continental crust and so we've got a collision of Australian plate continental crust with Pacific plate continental crust in the central part of the South Island and that's relevant because all the earthquakes that we experience in the central part of the South Island are shallow earthquakes and they're typically the most damaging and the most difficult earthquakes from the point of view of, of what's happened in Christchurch. I'll talk more in detail in a moment about the other faults that are, that are shown on this map. This is just a very synoptic summary map. It's not detailed in any sense. We've really just emphasised the major plate boundary elements here. Just as an aside really this tectonic activity has been ongoing for millions of years and if we look to the north-east of the North Island there's a boundary here parallel to the Northland Peninsula which extends all the way towards East Cape and that marks the boundary of the continental crust in yellow with the oceanic crust in blue and originally if we wind the clock back many tens of millions of years, 40, 50 million years ago it used to line up with the boundary of the Chatham Rise east from Christchurch and this light blue area which we refer to as the Hikurangi Plateau, so that gives us sort of an overall displacement across the plate boundary over the last 25 to 30 million years or so.

0940

Q. Is the Hikurangi trough the western boundary of the Hikurangi Plateau?
A. Plateau, yes it is, yes.
Q. Right.
A. So I think we go to the next image please, thank you. So I guess looking at the right-hand image first of all, it's a sort of a cut away model of the South Island and what I wanted to emphasise here is the

presence of the mountainous landscape in the South Island which is very much a reflection of the active faults which are present as part of the plate boundary development. The alpine fault is clearly visible in the digital elevation model that we see here running to the west side of the Southern Alps and I've put a cut through the middle of the – part of the South Island here just to kind of give a bit of a synoptic view of the faults that are possibly present there, it's a very generalised view and we can see on the west side of the Southern Alps here the alpine fault inclined in beneath the Southern Alps, and then as we look to the east through the Southern Alps towards the Canterbury Plains we see other faults associated with the development of the mountain ranges. As we move towards the north of this block diagram we have another cut away model through Marlborough here and we can see a number of faults present in the upper crust and with clear surface expression in the digital elevation model, these are the linear valleys of the Wairau, the Clarence and the Awatere Valleys in Marlborough and extending through into North Canterbury including areas like Hanmer Springs and over towards the West Coast. So these major valley systems are controlled by major active faults which link with the alpine fault system and beneath Marlborough and only beneath the northern part of the South Island we also have the presence of the Pacific plate being sub-ducted from the trench off to the east side of the island, down towards the west, so it’s inclined down towards the west and there are deep earthquakes beneath the northern part of the South Island, but not beneath the central part of the South Island. Now on the left-hand side the map that I've included here is a summary map that we prepared about 12 years ago as part of a regional study for Canterbury Regional Council to address the question of active faults in the Canterbury region which were relevant from the point of view of the hazard analysis for earthquakes. At the time that this work was done there had been a considerable body of work completed at the University of Canterbury through a co-ordinated programme from the 1987 forward and work that had been done by the GNS science and other organisations as well, and this was all captured in a series of reports that were prepared for Environment Canterbury and this map just showed a summary of that. Now if I could just make a comment there that in the mid 1980's perhaps there were eight active faults documented in the Canterbury region. By the time this study was completed in 1998 we realised that there were well in excess of 100 active faults capable of generating large earthquakes in the Canterbury region, so there's a very significant advance in our understanding of the geologic activity in Canterbury. I think it's worth noting also that while some of these faults are quite extensive, for example if we take the Hope fault, which extends from Kaikoura through Hanmer Springs to the West Coast linking with the Alpine fault to the south-west of Greymouth and Hokitika, south-east of Greymouth and Hokitika, it's about 220 kilometres long, but this fault is actually divided into a series of segments or individual pieces which are each capable of generating large earthquakes, so it's not just a single fault with one earthquake source, it's a fault system with multiple components able to generate large earthquakes. Next image please – and what I've included here is a similar image to one that Dr Webb will show later on, on the right-hand side, it's the shallow seismicity across New Zealand and these earthquakes are all crustal earthquakes, generally upper crustal but it's taking all crustal earthquakes and it's a surrogate really for the zone of deformation associated with the active plate boundary in New Zealand, and I think it's very evident from this image that in the central South Island we have significant earthquake activity, especially of course in the Alps, but also extending out to the east and some events beneath the Canterbury Plains and north from Christchurch along the eastern side of the South Island. Next image please. Looking now at some of the larger earthquakes that have affected our region, these are summarised in the report that we prepared for the Commission, but I'll just comment on a few of the key events I guess, so in this right-hand side image we've got earthquakes of magnitude 6 to 6.9 shown in red dots, and those larger than 6.9, those from 7 to 7.9 in purple dots, and we can see that over the preceding 150 years there have been a significant number of large damaging earthquakes, many of them though in quite remote parts of the island. The most significant of those of course would be the 1929 earthquake up near Murchison, and there was some comment yesterday about the elevated activity in that region over the following 70, 80 years. The 1888 earthquake south-west of Hanmer Springs in the centre of the island north from Christchurch which was felt quite strongly here in Christchurch and at the time also damaged the top of the Cathedral spire, damaged chimneys, especially in the eastern part of Christchurch, and the 1929 earthquake near Arthurs Pass. Other events which have impacted on the city include the 1901 earthquake near Cheviot and the 1922 earthquake near Motunau, both of those earthquakes caused damage in Christchurch, not significant but notable including in 1901 some liquefaction in Kaiapoi which has been documented in the literature.

JUSTICE COOPER:

Q. May I just ask with respect to these old earthquakes, 1888, and I see further north there's one 1848.

A. Yes.

Q. How is the earthquake magnitude derived with respect to earthquakes that obviously pre-date modern methods of measurement, it must be a matter of inference is it?

A. It is, and it's based on the accounts that we can get from newspapers and diaries and also in many of these of course there are also geological accounts taken by the early geologists that were working for the geological survey, and so we look at those accounts, we look at the descriptions of the shaking damage that occurred and the extent of the felt effects of the earthquake and we're able to come up with what we consider to be a reasonable estimate of the magnitude, but the magnitude range has got some margin of error associated with it always.

Q. Right. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. I think we can move to the next image thank you. What I've done in this image is to focus a little bit more on the northern and central part of the Canterbury Plains and the base map here is a published map by GNS Science, it's the one to 250,000 scale map, so it's a regional map rather than a detailed local map, and associated with that I've highlighted the active faults, and unfortunately in this image for some reason the faults have just slightly shifted, and I'm not quite sure that's happened, but I think for the purpose of description we should be okay. I've highlighted in red the faults that are considered to be active faults that have accommodated displacements associated with large earthquakes, mostly of course pre-historically, not historically.

0950

I've also included on this image the more recent Greendale rupture from September last year, but I've not at this point of the presentation included any of the evidence of faults beneath and in and around Christchurch here, I'll come back to this image towards the end of the presentation and add that information in. And that includes also faults that have been analysed now from a marine survey in Pegasus Bay offshore from Christchurch. The main structures to perhaps note here are right up towards the north-western corner and shown on this map. The Porters Pass-Amberley fault zone which extends from the Lake Coleridge area which is not shown on this map through Porters Pass passes around Mount Oxford in a complex sort of almond shape geometry in this image here and then continues on towards Mount Grey sort of at the top and centre of this, this map image. That map, sorry that Porters Pass fault zone we've done quite considerable amount of work on to try and understand the pre-historic earthquake activity over the last 10,000 years and some trenching work that we did on Porters Pass itself has shown that this fault zone has ruptured at least five times over the last 10,000 years at reasonable regular intervals not, I wouldn't say it's, it's highly regular but it's of the order of 1500 to two and a half thousand years between events. Our estimate is that this fault is capable of generating earthquakes perhaps up to magnitude 7.5. To the east and south-east from the Porters Pass fault zone there are other perhaps less continuous faults shown on this image. That includes just north of Rangiora at the top end of the Canterbury Plains the Ashley fault zone up here and if you follow this through you'll see that it relays or links westward with other structures that head more or less in an east/west orientation which I think is significant from the point of view of when we look at the Greendale fault as well. As we move further to the south along the range front of the Melvin Hills the, in the centre left side of this map we can see these areas in blue and green those are some of the basement rocks from beneath the Canterbury Plains that are exposed and to the south-east side of that bordering the Canterbury Plains we've got the Hororata fault structure which doesn't have a very good surface expression in terms of fault trace but there is clearly deformation and tilting and folding of the surface formations and then at the north end of the Canterbury Plains so the following to the north-east from the Hororata structure across the Waimakariri River back towards Rangiora and there are a number of folds which are driven by active faults in the subsurface just starting to daylight into the Canterbury Plains' gravels and the ground surface and in particular I wanted to highlight one of those, next image please, which is the Springbank fault which is this structure just to the left side of the, of the Springbank name here that I've indicated and I'll, I'll show you an image in a moment of that structure. So the key, the key issues then, the presence of these east-west faults at the northern end of the Canterbury Plains including the Ashley fault, the Greendale fault west of Christchurch which of course is now recognised at the surface through the surface rupture and also other faults at the southern end of the image here the south-east, west end of the image here near the Rakaia River. There are other active faults in an east-west orientation and I'll come back and talk about that more later. And the second really key issue is that there are then these faults and folds driven by faults in the subsurface which are more in a north-east, south-west alignment and that includes the

Springbank structure and the Hororata structure that I've mentioned as well as some of the structures that have been recognised and documented in Pegasus Bay. Next image please. So this is a couple of images to explain the Springbank fault. Now the Springbank fault is one we've studied about seven years ago and the fault itself is shown by the edge of an area which is being uplifted and arched and in this particular photo in the top of this image we can see a shelter belt extending over a very symmetrically warped surface it's the actual flat Canterbury Plains surface which has been arched up by faulting in the subsurface and if we come into the near foreground at the front of this shelter belt and follow this line of trees off to the right and also over to the left we can see there's a very distinct break in the, in the paddocks and that is the leading edge of the Springbank fault just starting to break out to the ground surface. In the image underneath here we've got some subsurface data taken from oil exploration company research work here which was run more or less across this structure near this shelter belt and we can see from the seismic reflection survey depicting the layers of strata in the subsurface beneath the Canterbury Plains that the deformation we see at the surface is mimicked by the way that the strata have been buckled and, and displace and distorted driven by the Springbank fault which is shown as the yellow relatively steeply inclined line coming up in this image from deeper down. Now we've had no luck in getting helioseismic data on the last series of earthquake ruptures here but we can get an approximation of that by looking at the rate at which these faults move with respect to the age of the different gravel deposits that have been deformed and in this case we've had at least evidence of a couple of earthquakes significant large earthquakes over the last 10,000 years so perhaps if you average that you'd say maybe on average one every 5000 years. Next please. Okay now this next part of my presentation is to talk a little bit more about some of the more work we've been doing because clearly there are faults hidden in the subsurface, it's a very challenging problem for us because of the thickness of the Canterbury Plains' gravels and the lack of evidence of whether these faults are active or not because of the gravel cover. So following the events in September last year and then very much I guess focused by the Christchurch earthquake in February this year we recognised that we had significant gaps in our knowledge of the subsurface geology and there were some imperatives for us to, to get some, some more detailed understanding of the fault structure. So we targeted several knowledge gaps with seismic reflection surveys and the first of those, next image please, is probably very difficult to see this but I'll use the pointer. If you go from east side of Lyttelton Harbour here I've put an ellipse here in white dots on the map encompassing pretty much all of the Pegasus Bay area and NIWA, National Institute for Water and Atmospheric Research, conducted in I think it was April this year a seismic reflection survey in Pegasus Bay to provide much more detail about the presence of faults in the subsurface beneath Pegasus Bay and especially targeting any evidence at all for which of those faults are active and have moved in more recent geologic time versus faults which are present but are not showing signs of reactivation or activity. The next image please. We also targeted as part of our research two areas on land to try and gain better understanding of the presence of faults. The first was very much focused around the area between the CBD and Brighton beach because of especially the Boxing Day aftershock sequence which obviously was of concern in that it was located right beneath the city and we needed to understand more about what was down there in the subsurface we we've, we've done some seismic profiling to address that area and the next image please.

1000

Finally the area with very significant aftershock activity, both following the February, sorry the September Greendale fault rupture and the subsequent February and June events, it's the area between the Greendale and the Port Hills faults that ruptured in February, and so I've got another ellipse on here just identifying the area that we targeted with our seismic reflection survey.

JUSTICE COOPER:

Q. Do you intend to explain what seismic reflection surveying involves at some stage?

A. The next image, yes.

EXAMINATION CONTINUES: MR MILLS

A. Next image please, thank you. So there is no suitable equipment in New Zealand for the particular survey we were trying to run, and we were given the opportunity with the funding to bring in a state of the art system from the University of Calgary which involved a small truck which you see here, it's a seismic, a Vibroseis system which basically puts a plate onto the ground surface and induces a vibration into the ground which then is transmitted through the geologic strata to the different layers and is reflected from the boundaries between the different layers. The reflected signal is then recorded by a series of sensors laid out on the ground surface. These are the geophones that we refer to here. Now this system involves extending up to six kilometres of geophone lines, typically in straight lines, the geophones themselves have to be planted into the ground, it usually just means that they have a good connection into the ground and pick up any vibrations coming back. That information is then captured in a recording system and it allows us in the field to record and do some initial processing to make sure the data quality is satisfactory. Now the survey that we used was targeting in particular the top two kilometres of the sub-surface and the reason for that was we were particularly interested to see if there was any evidence of faults with displacements of strata extending up towards the ground surface. If that is the case then it gives us some understanding of whether these have previously had earthquake ruptures associated with them, significant earthquake ruptures which would be during larger earthquake events. The presence of the faults is not normally revealed directly by the reflected signals coming back, it's revealed by the displacement of the boundaries between the different geologic strata, so for example if we look at this diagram we've got the grey near surface layer and the blue second layer, and the boundary which is a sharp boundary in the way this has been drawn, might act as a reflection horizon for the signal and if there's been fault displacement then we would recognise at some point that this boundary is being displaced and is either deeper or shallower as we track it in the sub-surface. The survey that we conducted was done in two parts. Next image please. We initially ran a series of profiles in the eastern part of the city, so on this particular image we ran a line about eight kilometres long from the south end of Brighton Spit, along the beach north of Brighton Pier towards the North Beach area at Brighton, so that's our line 1. The second line in this particular survey was the one in the city centre here, labelled number 2, and you can see that we targeted in particular the Boxing Day aftershock sequence beneath the city centre, so this line I'll talk about more in a moment as well, but it followed the railway line from Ensors Road to Moorhouse Avenue and then followed directly north along Barbadoes to Bealey Avenue. That survey was completed prior to the red zone being opened up again in that area, and the reason that that's relevant is that we would not be able to run these surveys really with normal city activity going on. The noise of the city actually significantly deteriorates the quality of the data that we were able to collect. So that was an opportunity just before the red zone was reduced around that part of town. In the second phase we targeted the significant aftershock activity to the south-west and west of the city and there are two particular areas here of interest, the Greendale fault rupture terminated just north of Rolleston which is near this number 6 out here, and right to the left side of this image, and you can see on this aftershock map the very significant number of aftershocks extending both north and south of State Highway 1, Main South Road here, and also there's an area of aftershock activity that extends from Lincoln, west of Lincoln township up towards Halswell between Prebbleton and Halswell in this area through here, and so the seismic lines we completed in this area, line 3, line 4, line 5 and line 6 were to try and get some better understanding of the faulting in the sub-surface associated with this aftershock activity. So what I'll do now is I'll have a look at some of the data from each of those lines. I'm not going to present data from line 5 or line 4, that is available if the Commission would like to have access to that information.

JUSTICE COOPER:

Q. We'll see, before you go on, all of these investigations involve the use of the vehicle from Calgary?
A. Calgary, yes.
Q. Is that vehicle still in New Zealand or has it returned?
A. No the vehicle was brought in in April and was returned to Calgary in mid May.
Q. And I infer from what you're saying that whilst it was here it did very valuable work?
A. Yes.
Q. What's the cost of a machine like that?
A. The new one is of the order of $1,000,000. There are units available which have become –
Q. Even better?
A. – surplus to requirements at quite reasonable prices, probably of the order of half a million, the – I'd have to say that the one thing about running this type of equipment is you do need some dedicated personnel to look after it, it is specialised equipment and so you need to set up a team or a group, which is what Calgary have done, and they are able to maintain the system because of the contracting arrangements they have with oil industry in the Calgary area.
Q. Well, what determined the date of its return to Calgary?
A. It's need in terms of contracted work back on the Calgary plains, they have a window of about four or five months in which they survey and then the winter sets in and the equipment is basically not able to be used anymore there because of the conditions, so we were sort of fitting it in just ahead of that window of time.

Q. So leaving considerations of funding on one side, it seems to me from what you're saying so far that there may be merit in investigating having one of these machines available for use in New Zealand?
A. Yes, I think that there is – I think there's a national need in the sense that this sort of equipment would not just be helpful in terms of finding active faults in the sub-surface, which is obviously the target we have here, but there are other applications and one could think for example of the Canterbury Plains that the significant resource of information we would get with respect to ground water resources, it's equipment perfectly set up for that type of survey.
Q. So it locates lenses of available water?
A. It locates the strata and the structure of the strata and we can delineate the aquifers on the basis of that sort of data coming in from the survey, probably you'll see a little bit of that as we go through the, some of the images of the data in a moment or two.
1010
Q. And if a machine of this kind was available all the time, I take it, it wouldn't just be in, in Canterbury, that it was of value?
A. No, it, it has application, it can be used throughout the country.
Q. Yes.
A. It's, in a sense the Canterbury Plains are an ideal environment for these types of surveys because it's a flat survey with a grid of roads which makes the surveying and the, and the, you can survey on the adjacent, sort of, you know the road verge if you like.
Q. Yes.
A. But the same conditions exist in many parts of the country and the equipment is, is ideal for that. It –
Q. So it can go everywhere a truck can go can it?
A. Yes, yes, yes and it's because it's like a tractor in terms of how, it's quite articulated, it has large wheels, it's four-wheel drive, it's able to go across farmland and hill slope terrain. The problem with hill slope terrain in a seismic survey is the analysis of the data becomes more

complicated. It's do-able but it's preferable to work across reasonably flat terrain but it's not impossible to work in, in more hill slope terrain.

Q. And apart from the use for understanding seismic conditions in New Zealand I take it that surveys conducted in New Zealand might be of interest overseas as well.

A. Yes, yes.

Q. And that might open up other sources of funding for such a device potentially.

A. Yes, yes definitely. I mean it can be run in a quasi commercial arrangement in that sense but the other thing is that we, it's not as if we don't have seismic equipment in New Zealand. We in our own department at the university we have a, a seismic system which is, it's much more modest. It's nowhere near as, as robust as, as the set-up that, that came from Calgary but for studying the top two to 500 metres it is, it is quite well set-up for that but we, it's much more labour intensive to roll out and it's, you know, we, we did 50 kilometres of lines in about three weeks with this equipment. If we were running our equipment it would be totally impossible to do that, logistically and time-wise, the resources we'd need.

Q. So just on a sort of headings basis what are the comparative advantages of this machine from Calgary?

A. It, it's, first of all its ability to survey significant areas and the relative ease with which you can deploy the system given that the source is a, is a truck rather than either explosives or trench compactors or whatever we, you know, whatever we use. Secondly, because it's a 600 channel system it has the capacity for some very high, high precision detailed data to be collected, ours by comparison is a 48 channel system so it's quite, quite modest in comparison to that. It, it's particularly tuned for the top two kilometres, that's about the capacity of this particular equipment. Oil industry typically is looking at depths of say five to eight kilometres so the resolution of information is quite poor in detail whereas the Calgary equipment is much higher precision, much higher detail. So it suits the near surface type investigations and the investigations for active faulting especially. The oil industry survey lines typically require several of those trucks, much larger capacity trucks and so the cost factor goes up substantially with that and there are units operating in Australasia, mostly in Australia but they do come over to Taranaki and they have worked in the Canterbury region as well but the cost is, is very high comparatively.

Q. You've spoken of a cost of about a million dollars for the Calgary type -
A. Getting the Calgary equipment to, to say put the Calgary equipment on the shelf in New Zealand –
Q. Yes.
A. Probably all-up cost might be around the three million mark I suspect.
Q. Yes.
A. There's all the, the cabling and geophone arrays to bring in as well plus the processing equipment so the, the all-up cost is of that order I think.
Q. And then you have a team of people who can –
A. Yep.
Q. – work it and work with it?
A. Yes, yes.
Q. And with the other machinery which you say is typically used by the oil industry, more expensive again –
A. Yes.
Q. What's the comparison, do you know?
A. No, I, I think I'd be, I'd be guessing. I know that the actual day-by-day survey costs for the oil industry equipment are about three times the costs that we were operating at.
Q. Yes. Well in the GNS report that we've received there's comments to the effect that it's not possible to map the faults, all of the faults that might in the event of rupture effect a city such as Christchurch because of the absence of surface expression.
A. Mmm.
Q. But I – understanding from what you're telling us that to a certain extent it's really, rather that it's not practical, rather than it's not possible. Is that a fair …?

A. I think, there is, there's just, there is a limitation in terms of how much information we can collect in the timeframes but I also, I think, maybe looking at the map is a good indication. If we think about the two lines we've run in the city here –
Q. Yes.
A. – and I'll show the data in a moment, we've got information now from the sub-surface beneath these lines but there's still a big area in here where we have no information so there's a lot of detail we're still missing.
Q. But that's an indication of where you need to look isn't it?
A. It is –
Q. Not that it's impossible to get the information.
A. Yes although there are significant survey problems in areas like this.
Q. Because they're built up and because of the motor vehicle traffic –
A. Yes.
Q. – and so on?
A. Yes. We chose, we were fortunate to be able to choose these lines in particular. We looked at trying to run –
Q. I'm sorry to interrupt but is it a matter of just ongoing development with the consequence that means will be found eventually of being able to exclude such, such effects from the information gained?
A. I think, I think –
Q. Like noise in the general sense that –
A. There is, there is actually, there've been huge advances made in the ability to process the data and remove the noise, the unwanted signal from the wanted signal.
Q. Yes.
A. And that's very much what takes the time with this data, the processing time. There's a substantial investment of effort goes in after we've collected the data but unfortunately as you filter out the noise you often filter out some of the wanted information because –
Q. The baby goes with the bath water.
A. – it sits in the same frequency range, yes.

Q. Yes.
A. The problem is as we go to higher and higher frequency which takes us away from the cultural noise, the sort of, we're dominated by 50 Hz noise say. Once we go to 120, 150 Hz the signals ability to penetrate into the ground is reduced and that means that the amount of information extending down into the sub-surface becomes quite limiting. So there is a, there is a point at which that cultural noise, that, that environmental noise that we're trying to deal with does really impact on our ability to collect good quality data down to the sorts of depths we would be looking for.
Q. Yes.
A. But there is, I mean as we've shown, as I hope I'll be able to show you it's not impossible but there are limitations around it.

JUSTICE COOPER ADDRESSES COMMISSIONER CARTER
1020

COMMISSIONER CARTER:
Q. We're interested in what we've been told about the layered gravel, silt and sand deposits under the city and those extending down some several 100 metres. Presumably this, this survey actually penetrates through that material. Can you get, because of the complexity of those layers can you actually see what you're looking for in that top, top 500 metres?
A. Yes I'm going to hopefully show you some of that information in a moment and we can, we always need a little bit of calibration. It's, it's not as if you can just simply look at the data that you get from a survey like this and build up if you like a detailed layer by layer picture of the strata so sand, silts, clays, whatever, but we do get an idea of the different packages because the reflection signal that we get has characteristics which allow us to say this looks like a gravel and sand dominated part of the sequence versus the sequence which may be has finer grained it might be silt and clay dominated and we, we would use drill hole data to provide that calibration as well so for example in

eastern Christchurch there's a deep well that was drilled I think about 15 years ago by ECan at Bexley and that goes down to about 440 metres I think which provides us with a wonderful opportunity to calibrate what we see in the seismic line with what was in the well records.

Q. I was just observing the Springbank surface exhibit which I thought might show an elevation of four or five metres or something like that?

A. Yes.

Q. In the swelling and thinking that those sorts of differences occur naturally within the gravels, how one would detect that being induced by an earthquake versus just the way it was laid down in its alluvial form –

A. Yes.

Q. – is the subject that's exercising my mind so I'd just –

A. I'd love to, I'd love to show you that, that data in more detail but the Springbank structure actually has a height if you like, an amplitude of probably about 15 metres, it's actually quite a substantial structure but the real giveaway for us when we're doing the land form analysis is how the rivers are able to cope with a structure that's growing if you like episodically across them, so the rivers then respond by incising and starting to trim. If the structures start to grow too quickly then the rivers become deflected and they'll cut through in some places so it's more a holistic landscape analysis that gives us –

Q. Yep.

A. – the difference between it being just merely a channel and bar feature of the ground, Canterbury gravels versus what is genuinely a tectonic structure in that sense.

Q. Thank you.

COMMISSIONER FENWICK:

Q. Presumably this data then gives you some indication of potential basin effects on earthquake activity?

A. It could do yes if we, if we – especially if we're able to approach the margins of the basin then it starts, it will be part of the information we can bring to the table for that basin effects analysis and it struck me yesterday when Terry Webb was presenting that some of the discussions that you brought to the fore in one or two of his images about basin edge effects probably I will be adding some, some insights there today with some of the imaging that we've done with the seismic work.

Q. Yes thank you.

A. Um, could we go to the next image please thank you. So this is the first of the lines that we surveyed at Brighton beach and we can see in this case, we just followed along the, along the beach at just above high tide level so a couple of images of the survey. It extends this, this image is a if you like it's like taking a vertical slice down into the ground and it extends if we go over to the top left of this image from south, that's the south end of Brighton Spit north to about where the golf course north of Brighton Pier so that's over on the right-hand side of this image. The scale is something that we need to talk a little bit about because across the bottom of the diagram here I've got a bar which shows that the line was about eight kilometres in length and going up the left-hand side on the vertical axis you can see here that the depths are around about a thousand metres so we were getting good quality data down to about a thousand metres out here. So the point about that is that this image is highly exaggerated, it's, the horizontal scale is squashed versus the vertical scale which is highly extended so what tends to happen is that the relationships are not true they're distorted so we have to remember that when we look at these images. It helps us with the interpretation in a way. The key thing I guess just turning our attention now to the profile is that at the south end over to the left side here I've put in a yellow bar just to show the top of the Banks Peninsula volcanics and you can see that as you go north from the south end of the Spit it gets deeper and deeper and deeper progressively down to more than 500 metres at the north end of this profile. That surface we don't have an exact age on it of course but it's of the order of six to nine million years, that's the age of the volcanics. It's quite irregular here suggesting that it's part of the actual lava flow volcanic cone structure that we're seeing. Later I will show you an image which extends both further to the north just immediately offshore from Brighton and what happens is that you go from the volcanics on to what is essentially the ring plane of debris that washed out from the volcanics on to the area of underlying Pegasus Bay so that's, if you think of Mount Egmont you've got the volcanic cone and you've got the ring plane of eroded sediments around it, much the same exists in the subsurface as we get further and further away from the Lyttelton and Akaroa volcanoes. Now there is clearly in the middle of this image a displacement recorded on this volcanic interface and you can, there's unconformity here between the younger strata, the gravels and the sands and the silts and the clays that make up the younger deposits sitting on top of the volcanics and the volcanic rocks and you can see there's very little data from here because of the volcanics the volcanics actually don't give us a very good image once we get to that interface but what we do see clearly as an offset in that interface here that's also visible offshore in the seismic profiles collected by NIWA and this particular structure that I've included here as a fault doesn't seem to offset these layers in the near surface. You can see that these reflect horizons just go straight through pretty much but it coincides precisely with the boundary denoting uplift to the south versus subsidence to the north, that's been recorded from the Geodetic information following the February earthquake. So our view is that this is the structure that ruptured on the 22nd of February but its surface rupture did not actually extend or the rupture didn't extend right to the ground surface but we did see surface warping with down-throw and uplift north and south of this line. At the north end of this line as well I've included another fault here just dashed it in which means there's a degree of uncertainty with it but the important thing to note is how the reflectors have been slightly buckled up, they're showing a bit of uplift and distortion maybe similar to the sort of Springbank type structure that we were looking at before. I think this is a structure that is also showing some evidence of having had displacements on it and you can see that the amount of distortion diminishes as we reach the ground surface or as we go up towards the ground surface but there is clearly evidence of at least two faults in the subsurface in this particular line.

JUSTICE COOPER:

Q. I'm sorry I'm a bit confused with this diagram maybe if we could go back to the previous one which is –
A. Yes.
Q. That's the one.
A. Yep.
Q. Can you indicate, we're dealing with the line marked 1 aren't we?
A. That one, that one there yes, that's right, so this is the south end of the line.
Q. Yes.
A. That was on the left-hand side.
Q. Yes.
A. And that's the north end that tip there.
Q. Yes.
A. And basically what we are now doing, this is the map view.
Q. Yes.
A. The next image is just a vertical slice down.
Q. Yes. Along that?
A. Along that line.
Q. You talk about the location of the rupture?
A. Yes.
Q. Where would that be?
A. That's –

1030

Q. In that view?
A. It's approximately through this area here so it's about beneath where I've put the dot sort of at the north end of the Estuary up here, so that's

about what? About one third of the way along the line from the south end I guess, maybe a little more and that fault of course, based on the seismicity, the aftershock activity, that fault is extended towards the south-west, towards Halswell and so the comment I guess is that we see evidence for it in this seismic profile.

Q. I see. So did it extend the other way as well, the north-east.

A. To the north-east, it does extend off shore but not very far, the seismicity actually cuts off not far from the shoreline.

Q. So you know where the rupture began?

A. The rupture was initiated in this particular image just near the Heathcote Valley here, where the very large aftershock dot is.

Q. Yes.

A. So that's in the sub-surface so the fault plain is inclined towards the south steeply, and it then ruptured up the fault plain, most of the movement of the high block, the Port Hills block if you like, was directed towards the city centre.

Q. Thank you.

A. I'll just go back to that image, so actually remembering that this is very exaggerated, the scale is not true, that means that even though this is inclined very steeply in this case the fault in the centre of this image denoted as the Port Hills here, fault, is inclined very steeply to the south if this scale, the vertical scale and horizontal scale were equal, then the inclination of this structure would be reduced and that starts to project us towards the south where the epicentre, sorry the focus of the earthquake was located at a depth of, was it, I think it was six kilometres or so. Does that, is that a help?

Q. Yes thank you.

EXAMINATION CONTINUES: MR MILLS

A. Okay, next image please. Now going to the city centre, there's two lines shown here, associated with the area around the city centre, so we've got the four avenues area with Hagley Park just immediately in the centre of this image, Moorhouse Avenue running just south of Hagley

Park here, Bealey Avenue to the north and Fitzgerald Avenue off to the east side, and the yellow line is our seismic survey line which started at the south-east end here on Ensors Road and we followed the railway line, we were able to follow or survey along the railway line and then the Waltham over bridge is where the kink in this yellow line occurs, we crossed across Moorhouse Avenue and then followed up Barbadoes Street as far as Bealey Avenue. It was impossible, we would have probably liked to have been able to survey a bit further but it was really impossible given the issues with traffic and there was – I would have to say there was a degree of sensitivity also for the property owners with the seismic unit, it does put a vibration in the ground, it doesn't do any damage to properties but people were highly sensitised by the earthquakes and so we found ourselves having to really decide that Bealey Avenue was as far north as we could go. So I –

JUSTICE COOPER:

Q. I'll put one question on that, how long would it have taken you to complete the survey to the extent you wished to do so.

A. If we'd extended all the way up here that would have been another, probably day and a half, something like that, yeah.

Q. So you could actually, it occurs to me, plan for that, tell people what it was all about?

A. Yeah, we did –

Q. Do it in advance, give them warning.

A. We did a leaflet drop, and actually knocked on everyone's doors to tell them we were coming up with a survey over the next days so there was a reasonable engagement with the group of people that would be affected.

Q. Yes.

A. It was just because we were still quite close to February and people were just really uncomfortable about this.

Q. Yes, when were you doing this?

A. We did that, both for this line and also at Brighton Beach.

Q. Yes, when was that?

A. Oh, this was in April, these ones were done in April.

Q. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. The second line I've shown here, the red line, is a line of cross-section that I'm going to show you next, and Terry Webb showed yesterday the same image that I'm about to show you, so what we're going to do now is to basically look at a upper crustal slice going down to a depth of about 10 kilometres, extending from the edge of the Port Hills here at the south up to north of the city centre here and, go to the next image please. So this is this crustal, upper crustal cross-section, so here we are on the left side of this diagram in the south and on the right side in the north, and this is the ground surface running across the top of the diagram from Port Hills to north of the city centre, so BR is the location of Brougham Street and BE is the location of Bealey Avenue, and on the left side here the scale goes down to a depth of about nine kilometres, it shows basically a crustal section beneath Christchurch city, and here we have the aftershocks, most of this are associated with the day or two around the Boxing Day activity. Next please. We can infer, based on the location of these aftershocks and they're sort of approximate clustering that there is a fault in the sub-surface here revealed by that seismicity, so it looks to us as if during the Boxing Day activity, stressors had built up to a critical level on this particular structure and it initiated these aftershocks. They weren’t very long lasting, they took a few days and then the activity died down again. You’ll notice that there's no aftershock activity in the near surface above four kilometres or so depth, and of course for the last maybe 1500 or 2 kilometres, bit less than that 1500 metres, we would have these relatively soft gravels and sands and silts and clays filling the basin beneath Christchurch. The volcanic, the bedrock comes in sort of at a depth of about 1500 metres or so in here, we’ll see that in a moment, so our seismic survey really targeted any evidence for fault displacements in this near surface upper two kilometres, and obviously what we were looking for is something that might extend from this deeper structure associated with the seismicity following this red line up towards the ground surface in this case. Next image please. So this is the line from the Barbadoes Street railway line area so again we've got the south in the top left here, north in the top right, we've got on the left-hand side the depth scale going down to more than a kilometre, in fact I got the numbers slightly wrong in terms of depths here, you can see as we did before the volcanic, the top of the volcanic shown by the yellow boundary in here, with a bit of variability in the relief in the sub-surface, the total length of the line is just around 3.7 kilometres and again, we can see these relatively flat lying basin fill sediments on-lapping onto this volcanic helio relief helio topography and I won't spend so much time on this image, but here’s the railway line end of the section, there's Moorhouse Avenue where I've got this vertical bar in the middle of the diagram with the two little diamonds attached to it, that's Moorhouse Avenue, you can see there's a little bit of a gap in the data because we couldn't actually survey right on Moorhouse Avenue itself, we had to get the cables across the road, and then we followed the line to the north along Barbadoes Street. In the sub-surface we saw evidence of two faults with some displacement association but not significant offsets on them and I think that's important to note. So let’s go to the one in the centre here first of all, there does seem to be some disturbance here in the reflectors but there does not appear to be a lot of evidence of offset of the volcanics. Now this, and this is always a puzzle when we look at seismic sections, and obviously we're still analysing some of the data, but remember that some of these faults are not necessarily vertical displacement faults, they are actually accommodating horizontal displacement, so one may not actually always see significant offset in a vertical sense on these markers.

1040

So what we look for are evidence of disturbances or areas in which the reflectors are not connecting very well and that’s definitely some evidence that we can see in here. Over on the north end of this line we see a very similar story to what we saw at Brighton Beach with this fault in the sub-surface, again no evidence of it breaking out to anywhere near the ground near and this very subtle warping that, that squeezing of the strata again evident just at this north end. So it's possible that this is the same structure we see at Brighton Beach and, but this is not the same fault that ruptured on the 22nd of February. It's a structure that we think is associated with the aftershocks on Boxing Day but it's north of the February 22nd fault that ruptured in the sub-surface. I think it's also worth noting in that sense that the aftershocks following the Boxing Day activity, the aftershocks on that structure ceased, pretty much have stopped post February 22nd. So it looks as if the seismicity basically was switched off. That means the stressors were relieved when the February event occurred. The other feature that we've picked up here is a substantial channel in the sub-surface which lines up quite well with some of the information that I think is in front of you with respect to liquefaction and the fact that these channels from the old course of the Waimakariri River through the city have the sorts of sediments associated with them which are prone to liquefaction and it's visible in the sub-surface here. It's quite a deep channel. It's, looks as if it's sort of 30/40 metres deep. Next image please. Okay the next area now is to the south-west of the city so just to get ourselves oriented here on this map, it's quite a dark image, I'm sorry about that. At the top right here we've got Hornby and Templeton, this is the main highway south to Dunedin with Burnham right on the edge of the map over here on the left-hand side and Rolleston on State Highway 1, just by the state highway marker here in the centre of the, getting towards the centre of the image. Some other landmarks here, Lincoln township in the centre lower part of this, this map and Springs Road going through Prebbleton back into the city. Now we completed a number of lines out here, the biggest line, the longest line was the, the line 4, the central one here. This is Robinsons Road. It extends from its intersection with Ellesmere Junction Road at the south-east end here all the way to State Highway 1 and then it becomes Curragh Road and that extends all the way to the intersection of West Coast Road and Halkett Road in the north.

Q. Just spell Curragh please.

A. C-U-R-R-A-G-H, Curragh. So what I've done with this, this line is to divide it up into a couple of sections which have got some features that I'd like to, to present. So first of all we're going to look at this south-eastern end of the line, south of Prebbleton, roughly half-way between Prebbleton and Lincoln and it bisects an area which is rich in aftershock activity. Next image please. So here is the, that particular line and again we're just quickly orienting ourselves now from south-east on the top left to north-west. We've got Ellesmere Road, Springs Road, Shands Road, the major roads heading south-west from the city and the depth's down again to just over a kilometre here. Next please. I'll put the interpretation on here for you. So between Springs Road and Shands Road in the middle of this image we can see clearly evidence of fault activity in the sub-surface but, again, these faults are not rupturing right through to the ground surface. There's no evidence of a surface break if you like but there is evidence of sub-surface displacement and activity associated with these. Now this interpretation shows a number of, of faults, some of them don't reach up towards the ground surface, others do seem to have evidence of extending closer to the ground. The green line in the middle of this, at a depth of about 500 metres here is, again, the top of the Banks Peninsula volcanics. It's a strong reflector which we're able to pick up and interpret quite easily from the data. Next image please. So just looking again now at the aftershock activity, our line runs roughly through the centre of this map here and the area we've just been looking at is this area in the middle of the, of the map and what I've done in, in here is to present this cross-section line, the red line which extends sort of from a north, north-west to south, south-east direction and we're going to take a slice down into the upper crust and have a look at this central area, I'll point it out by hand, this central area of aftershocks sitting in this map. Basically what we do with these, these vertical sections, I'm getting tangled up here is to collapse those aftershocks onto that cross-section line to see what their orientation and position is extending into the sub-surface. Next image please. So here we, we have that cross-section so going from on the left side here, the north to the south and in the middle of this, this is the ground surface, at the top of this block diagram or this diagram, "SP" is the location of Springs Road and on the left side the scale here is in kilometres beneath the ground surface and one of the striking things here is the strong clustering of the aftershocks that have occurred in this area post September 4. Next image please. And the interpretation is that we do have a fault extending down into the sub-surface to depths of about 10 or 11 kilometres and extending right up to pretty much the interface between what we think is the quaternary and younger sediments beneath the Canterbury Plains and the basement rock, the greywacke.

Q. The first word was?

A. The quaternary, the younger sediments.

Q. Could you spell that for the transcribers please?

A. Yes, Q-U-A-R-T-E, sorry, Q-U-A-T-E-R-N-A-R-Y.

Q. Thank you.

A. Quaternary. Sorry about that.

Q. That's all right. You understand why I asked you to spell it.

A. Yes. Basically those are the gravel deposits forming the Canterbury Plains. The aftershock activity in this case is extended to within two, one and a half, two kilometres of the surface. Next image please.

COMMISSIONER CARTER:

Q. Could you give us a general idea of the time period over which each of those individual aftershocks occurred?

A. They, okay, that's a really good question. The, these, all the aftershocks between September 4, and I think this image was actually put together roughly late April, so it's that period of time. It includes aftershocks which happened following the Darfield earthquake but before the Christchurch earthquake but it also includes aftershocks post Christchurch 22nd of February.

Q. Each one of those would have been, would have arisen through some, some displacement, measurable displacement if you had a, if you were able to get down there and, and measure a distance?

A. Yes, yes.

Q. So they're, they each, do you have any idea of the total amount of displacement that might have occurred on that –

A. Well I think, I think, okay let me maybe expand that a little bit around that. First of all there's, there's a few aftershocks. I think there have been two aftershocks of magnitude five or larger on this.

Q. Yes.

A. There have been a number and I, I'm just sort of thinking of the order of probably five or six magnitude 4 to 5 events and there've been, of course, a substantial number of magnitude 3. Now when we start to look at the amount of displacement, magnitude 3, magnitude 4, we're really talking magnitude 3, just millimetres, magnitude 4, just centimetres and maybe magnitude 5 some 10s of centimetres. There's not going to be much more than that. The thing that varies with the magnitude will be the area of the fault plain that ruptures. In the case of a 3 it's quite a small, modest area.

1050

Terry might be able to provide some additional comments about exactly how large but a magnitude 3 might be the size of a football field sort of, it's quite small areas isn't it. Now of course not all those aftershocks are happening just on what we infer to be this, this fault, this red line that we've drawn here. It's really that there is activity on that fault plane but also the fractures that are adjacent to the fault plane so there's a kind of a zone around the fault which is accommodating these, these smaller and larger aftershocks. The net effect though is that it has imaged I think a fault in the subsurface in this area and, but there is no evidence of it breaking through to the ground surface and there hasn't been an earthquake large enough to, to have caused that sort of displacement.

Q. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. Next image please. So this is how we've gone about checking that you know is there any evidence of ground surface displacement on these structures, not necessarily just in this period post September 4 but looking for evidence of displacement in the ground surface from previous earthquakes in this area. So this particular aerial photograph dates back to 1940 and they're particularly good photographs for the sort of work that we like to do because culturally there hadn't been a lot of modification. I think even just looking at this image as we see it the old channelling of the Waimakariri River can be seen here the braids of the river can be seen clearly, the channels and bars and so on and what we've got here is the intersection over on the sort of centre right of this image between Springs Road heading from Prebbleton to, to Lincoln and Robinsons Road running sort of obliquely across this image towards the top right, top left sorry and that's the road we surveyed along and approximately in this part between Shands and Robinsons Roads so here's Springs Road, sorry, slow down a bit, Springs Road on the right-hand side going more or less north south and right up towards the left corner here Shands Road parallel to it north south. Approximately half way between these two roads I've shown as colour bar which is roughly the target area where I would expect any evidence of surface displacement to be present from our seismic survey it's, it's in this central part of this photograph where there might be evidence of surface rupturing and I think even with, with the untrained eye one can see there's really no evidence of surface displacement present in this area so these faults have not broken through over the last few thousand years these, the, the Canterbury Plains surface here is not 10,000 years old it's much younger than that. Next image please. Moving on to the central part of the Robinsons Road line so this is now the, if, if we go back to this image with the Robinsons Road line extending from the bottom right to the top left corner in the central part I've put two bars across the yellow line, one between Springs Road and State Highway 1 and one between State Highway 1 and West Coast Road and the next image is just to look at that part, that cross-section. Thank you. And again with the same overlay interpretation here we have on the top left south-east top right north-west, going down to a depth of about 1500 metres one of the things that happened with our survey was the further to the, to the west we went the better the quality data that was coming in from the seismic survey to do with the ground conditions and in this case we can see right in the centre of this image a fault with clear displacement of the marker horizons here the green, the darker green horizon here at a depth of about 500 metres, there's the volcanics and then above that we've got another marker which I've picked out in blue here and you can see again displacement but even reaching up quite close to the ground surface here we can see the reflectors are being clearly distorted and displaced. If we project that right up to the ground surface up here it is absolutely in line with the north-eastern most part of the surface rupture of the Greendale fault and so we, our interpretation is that this is the continuation of the Greendale fault to the east but there was no evidence of surface rupture in this particular area just sort of close to the intersection with State Highway 1. Dr Webb showed yesterday some cut away three dimensional block diagrams of the faults extending into the subsurface and on those he showed actually that there was modelled on to the fault displacement at depth but not at the surface adjacent to State Highway 1 and I think we've got the fault that was doing, that – present in this image showing that accommodating that. I think it will come out later but, but I make the comment though that as we go to the east from this location there's no aftershock activity following this line of the fault so I think the fault is close to the end we've just nipped it across the end and there's, there's no suggestion this fault just keeps heading towards Christchurch city, otherwise we would see aftershock activity extending in that zone. Just to make the comment while we're on this one right at the bottom right-hand end of this image towards the north, north-west I've got the word "basement" and this is you can see some strong reflectors coming in down here. That's the greywacke basement so that's, that's all Canterbury Plain basin sediments down to the greywacke here at a depth of about 13, 1400 metres. Thank you, next image.

COMMISSIONER CARTER:

Q. And just before you leave that one?
A. Can we go back?
Q. Just picking up your point that there's no aftershocks occurring along that line going closer to Christchurch city, are you implying that that means that, that fault line is unlikely to extend onwards into Christchurch city?
A. Yes, yes.
Q. Okay I just wanted to clear that point.
A. I was going to make a comment that given, given that we’ve had a substantial slip on the Greendale fault and even that strand just to the north of Rolleston that north-eastern strand had a metre of slip on it, there will be significant stress concentrations at the end of the slip zone.
Q. Yes.
A. And so one would expect if the fault continued that there would be aftershocks going off around the end of that, that rupture. If there's no fault there then I, I suspect that really there is no structure to be able to take further slip so that's the interpretation I would put on that.
Q. That's interesting. The material that is, that is moved away when I looked at the green line you see that, that depression which you’ve signified as being indicative of the presence of the fault line, of a few metres of vertical displacement, what's your interpretation of where that material goes longitudinally, I mean –
A. Oh yes okay. Could we perhaps – yep thank you. So you’re thinking in terms of what's going on in and out of this image?
Q. It’s got to go somewhere?
A. Yes.
Q. If that huge volume of material is moved down that amount?

A. Yes.
Q. Where does it go to?
A. So, I mean I think you've just touched on another issue of, of if you like the sort of the, the information that we don't have a very good understanding of yet but we're, we're working on it. This area clearly is under extension so it's being stretched and so you, you can see these two faults effectively are accommodating the slight extension of the area.
Q. Yes.
A. And so it's like a keystone dropping down.
Q. Yes.
A. I think also that these faults are accommodating significant movement parallel to the fault line so in and out of the board in and out of this image so there are horizontal slip faults with a component of vertical slip on them, does that help?
Q. Yes it does quite a lot thank you.
A. Thank you.

EXAMINATION CONTINUES: MR MILLS

A. Okay so this image really is just to reinforce the point I made before, this is the map underneath here shows the rupture of the Greendale fault and right over on the right-hand side we've got Rolleston and Burnham right in the bottom right-hand corner of this map and the north-eastern most splay of the Greendale fault that ruptured it's got this blue box around it here is shown and it was up to about a metre of slip on the ground surface, rupture of the ground surface.

1100

Now one of the things that we've been doing is we've taken this area boxed in blue and I show the 1942 aerial photograph of this area in the top left of this diagram, and approximately have shown in dotted lines where the future Greendale fault rupture will be located, and again what we've done here is to look very carefully at the channel pattern on the aerial photograph to see if there's any evidence at all of previous ground surface rupture, and there's none in this particular image. Thank you. So putting some of that material together now into this map, going back to the aftershock map image here, so we've got our Brighton Beach line right out to the east here, and we picked up first of all at the south end of the Brighton Beach line, shown in heavy white dots, the approximate location of the Port Hills fault in the sub-surface and I've shown two yellow arrows which is just an approximation of what happened when that fault ruptured, there was both some horizontal and vertical displacement on that fault. Also shown here are the combination of what we saw at the north end of the Brighton Beach line and on the city centre line, just around that cluster of aftershocks adjacent to the Four Avenues area, and so here we've got at least a couple of faults in the sub-surface, the extent of these I've indicated some question marks here both at the north-east and south-west end of that structure, because we simply don't have any other information to constrain that, but we have used the lack of aftershocks out to the south-west and north-east as an indicator perhaps that that is some sort of sensible length to put on that fault for the moment, given the information we have. Maybe a little bit more convincing in the sense of using aftershock activity if we go to the centre of the image, the fault line and the sub-surface extending from near Lincoln in the south-west corner here, just in here, following a line of aftershocks up towards west of Halswell, just close to Wigram area, that is the structure with a lot of seismicity on it, and clearly showing up in our seismic line. I've also shown another very weak, sort of weakly dotted white line here, because we had several faults in the sub-surface, not just one, but the one was the most obvious with the seismicity, and finally out towards the west, centre west here, we have the two yellow arrows and the Greendale fault, its extent showing here, and then I've dotted in its extension to that Robinsons Road, Main South Road intersection, so where I think the fault terminates at that point and what we were just talking about in the previous slide, you can see there's no real aftershock activity in this area at all so we take that to be that there is fairly strong crust and no evidence of seismicity associated with the extension of those faults. Next image please. Okay, now this is a line we did in April, we had a day or two to spare before the Canadian crew had to go back to Canada for a week or two, and this is Highfield Road which is north-west from Rolleston and Burnham, and we ran the seismic system over the Highfield Road section where the Greendale fault actually ruptured out of the ground surface, and the reason that we wanted to do this was first of all just the opportunity to look at the surface rupture trace versus what we see in the sub-surface with the seismic gear, nice connection there between surface mapping and sub-surface geology. Now remember that the Greendale fault was mostly horizontal slip, not vertical slip. That is indicated by this red dot with a cross in it. Think of that as the back of a dart going away from you and then think of the one on the other side of the fault zone here, the red dot with a dot in the middle is the dart coming at you, so this side of the fault, the left side in this image is going away from you, the right side’s coming towards you. The other thing that you can see from this image though is that in the sub-surface we've got some very strong reflectors from the different layers, the different strata, and they suggest also some vertical displacement and that's indicated by the two arrows here, so there's again the south side is down, the north side appears to be up, so if – next image please. What I've done here is just to approximate the amount of displacement that's represented by these different layers in the sub-surface, these different reflectors. So going right up close to the surface here this is in the again, those younger gravel deposits, a strong marker, and we get approximately 16 metres of vertical displacement. Now remember this fault is mainly horizontal slip at the present time, but there is evidence of some vertical offset of the order of about 16 metres. Our interpretation is that this is probably the 125,000 year old surface sitting under here, that's a marker in the younger deposits. That means we have a sort of long term slip rate of about .1, .13 of a millimetre, so it's very slow. If we go to the deeper levels here we can see greater offsets, 42 metres, 62 metres and that tells us that this fault has ruptured previously and, but it's been doing it over a very long period of time and the total accumulated movement on it is relatively modest in that context. Now I'm going to talk in my next part of the presentation about the offshore data and we'll talk a little bit more about the activity of these faults and the long periods that seems to be between earthquake events, large earthquake events.

COMMISSION ADJOURNS: 11.07 AM

COMMISSION RESUMES: 11.26 AM

PROFESSOR PETTINGA CONTINUES:

EXAMINATION CONTINUES: MR MILLS

A. Perhaps if I could just cast back for a second to Sir Ron's question about the, the slip rate and the movement on that zone of aftershocks between Prebbleton, Halswell and Lincoln. There has been some calculations done to try and understand the sort of total amount of slip versus earthquake magnitude accommodated in that area and that aftershock sequence in that particular zone amounts to about the equivalent of a magnitude 5.5 earthquake if you, if you add all the earthquakes that have happened in there. That includes, I think there was a couple of 5.2, 5.3 events and, of course, more 4s and a lot of 3s.

COMMISSIONER FENWICK:

Q. Can I just ask one further point, slightly intriguing me. In that area between the two faults you said the, on the south side the Greendale fault's gone down.

A. Yes.

Q. And in terms of the Port Hills fault the south side's gone up. There's quite a sort of confused movement in between the two zones isn't it?

A. Yes, yes. Maybe, not wanting to put you off completely here but I'm, I'm going to come back shortly, once I've looked at the offshore stuff to talking a little bit more about, you know, where did these faults come from, what was their origin. Basically what we have in the basement beneath Christchurch, Pegasus Bay and much of the eastern South Island is an inherited fabric of faults which, which are millions of years old and relate to the time when New Zealand separated from Gondwana and the crustal block was being stretched and started to thin and today the plate boundary motions are actually over-printing onto those inherited faults and exploiting them and so they're often not oriented in the sort of optimum way if you like to accommodate the present day crustal strains and so some of these faults are inclined to the south and others are inclined to the north but they are weaknesses that the plate motions can take opportunistic sort of advantage of it you like and so we do see these rather contradictory I guess orientations than one might expect. I might come back to that and you might like to quiz me a bit more deeply on it, right, thank you. Could we have the next image please. So moving now to the offshore area, this is work that was completed by Dr Phil Barnes and others and it was conducted in April in response to the February earthquake to try and understand better what's happening in the offshore area from Christchurch. Now the same methodology was applied looking at marine seismic reflection surveys. It's, it's a much easier environment to operate in both in terms of the quantity and quality of data that you can collect and I haven't included it here but there's a very detailed survey grid that was completed in Pegasus Bay and this is a synoptic map just to show the data compiled, it's new data as well as faults that were previously known and included in this data set. So first of all if we look in the Pegasus Bay area offshore from Christchurch you see black and red line work, the black lines are some of the faults which are inherited from that previous period of geologic activity millions of millions of years ago and those faults have remained inactive. So there's no evidence of them having been involved in any more recent geological activity and in red we've got faults which are showing active movement, let's say in the last one million years or so. So it's, it's quite a, a complicated figure in the sense that some of the faults that are active are sitting in amongst faults that are not active and it just, just really highlights the complexity of how the, the stressors are being accommodated and also that some of the faults, I'd say right now the data set remains incomplete because it's very difficult, for example, to survey in a very shallow water environment so there's a limit to how close to the shoreline they can come, there's a problem with the quality of the data close to the shoreline because of the, the, Terry Webb mentioned yesterday the problem of reverberation with seismic energy going down and reflecting backwards and forwards between the, the harder rock, the volcanics and the surface and so they often lose data in the near surface and, and shallow water environment close to shoreline.

JUSTICE COOPER:

Q. In fact the methodology that is employed –
A. Yes.
Q. – to derive this information is obviously different which applies on, on land?
A. Yeah it's exactly the same methodology it's just the way it's deployed is different. Essentially what they do with a ship survey, instead of having the geophone cables laid out and the geophones planted in the ground they're inside a long PVC tube which is towed behind a ship and that can be anything up to three/four kilometres or longer and the sensors which are called hydrophones are usually spaced at metres apart –
Q. Yes.
A. – and then the ship actually puts a sound source over the stern immediately behind the ship. It's called a, usually an airgun which is just a compressed air cylinder which, which simulates explosions rather than actually having to create dynamite explosions you just use compressed air.
Q. So this, the apparatus that is needed to do that is available full-time in New Zealand?
A. Yes the, the equipment is actually the equipment that NIWA use routinely for their offshore surveys.
Q. Yes.
A. They have the expertise, the group, the marine geoscience group at NIWA as well as the marine geosciences group at GNS have very good coverage in this area and it's deployed from, it can be deployed from the *Tangaroa*, the research vessel that NIWA operate as well as, I think they have a smaller vessel called *Kaharoa* and it was the *Kaharoa* that was used for this survey.
Q. Right. Thank you.

A. So I guess that maybe while this image is up it's worth just pointing out some of the key features. Shown here in approximate location right over towards the lower left corner here the Greendale fault rupture extending out towards, towards the east end, just running adjacent to the CBD we've got the Port Hills structure from the 22nd of February. This image was created before the 13th of June event so that fault isn't actually shown on here. Then offshore, especially in the northern part of Pegasus Bay, we've got a number of quite extensive structures showing up here and so these have got evidence of seafloor deformation and significant displacements and deformation in the sub-surface and they're part of what one might call the wider plate boundary zone deformation that extends all the way to the coast in North Canterbury. So the, the hills of North Canterbury are essentially reflecting the geologic activity and the fault activity taking place and that extends into the offshore area. So I think that if you go to the centre of this image and you recognise the Pegasus Bay fault in here that's the point at which we start to come into an area which is just sort of on the feather-edge of plate boundary activity and these faults that are picking up activity closer to Christchurch are quite short and discontinuous as you can see in that, in that situation. The other comment I'll make because it will be relevant later on is that the overall tectonic compression, that's the plate boundary compression, across the South Island, is part of the South Island, is oriented in this north-west, south-east direction here so that's the arrow that's shown on here. That's what's fundamentally driving the fault movements, the fault activity and when you look here on this image all these black faults offshore, the inactive faults, if you just look at those in a generic sense they are very much east-west oriented but locally there's quite a lot of, one would describe as dog legs in it if you like, there's a lot of variation but the overall trend of them is in an east-west direction and if you look at the faults in the north Pegasus Bay area up here, north from Kaiapoi if you like, you'll see that progressively the active faults in red are starting to overprint that but they're taking a more northeast/southwest orientation so the modern plate boundary movements are progressively overprinting onto that east/west fabric of the inherited faults and yet in the South Pegasus Bay area that northeast/southwest orientation is not becoming prevalent. They're just tweaking these pre-existing faults at this stage.

1136

Next image please. So, and I apologise for the quality of one of the images on here. It hasn't scanned well. It's quite weak but I'll explain what that shows in a moment. Top right we have the same map of the Pegasus Bay area with the active and inactive faults. Now the addition to this image is a heavy red line running from the north side of Banks Peninsula here right up into the centre of Pegasus Bay and that is one of the seismic survey lines that the Kaharoa people collected and it's the line that's shown in this panel in the bottom of this diagram so if we turn our attention to this seismic profile in the bottom here so this is the offshore equivalent of the ones I showed you for on land. Over on the left side here we've got south and north at the top end so that's south to north there and in the subsurface again we have a very strong reflector which is right up at the ground surface here at the south end and can then be traced extending down into the, and I'll try and get out of the way a little bit here, extending down into the subsurface here and that's marked by these arrows as the top of the volcanics. So close to Banks Peninsula those will be the volcanic rocks in the subsurface and as we extend out beneath Pegasus Bay this contact, if you like, flattens out and that's the alluvium that's washed off the volcanics and gives us a very strong reflector horizon in the seismic data. That's a very useful time marker – six to nine million years – sitting in this profile. In the deeper subsurface then we're able to interpret a number of faults. These are the black lines with the arrows shown and the interpretations of the geology is also shown on here and I don't think we need to go into that in too much detail but these have been identified as faults that were formed in the period of 90 to 60,000,000 years. They are referred to as normal faults because they are faults which accommodated crustal stretching, crustal extension, quite a different geologic period to the one we're in at the present time. Above the volcanics we can see the shallower basin fill and the reflectors that are present in the basin here are pretty much all flat lying, as you can see, and onlapping onto this volcanic contact. Now in this particular profile one of these faults in particular does extend right up close to the ground surface and we'll have a look at the evidence for activity on that fault in a moment because it is active. It is considered to be active and you can see that it's been active because the volcanic horizon down here is displaced, visible displaced, even at this very small scale. I wanted to just talk a little bit about this diagram up the top on the top left side here which is an old diagram taken from a publication in the early 1990s which was a regional geological study done by the geological survey in those days of the Chatham Rise and even though this is a very poor quality diagram, right over to the left-hand end of this diagram, so right up in here, we can just see the coastline and Banks Peninsula sitting in here so the rest of this diagram extends out east across the Chatham Rise and you can see the network of faults that exist in the basement rock of the Chatham Rise. There's a very extensive network of east to west oriented faults but notice that there are places where these faults swing into a more northeast/southwest orientation and especially on the south side of the Chatham Rise, sorry this is quite hard to do here, maybe that's the best way to do it like that, these faults in that area here, and they take on an orientation which is perhaps much more similar to the structure that we've delineated in the subsurface from Lincoln to Halswell, that area.

WITNESS INDICATES BOTTOM LEFT-HAND SIDE OF THE TOP LEFT DIAGRAM

Next image please. The comment that was there has just disappeared. It was there. That's fine. There are faults but they have very slow slip rates so they only occur, the earthquakes on these occur with very long time intervals between them and the amounts of displacement on the faults that have accumulated, and I'm thinking in particular of this structure in the middle of this image extending right up towards the sea floor so that's this fault line here and I'll look at that in a bit more detail in a moment. That has a very slow, long-term movement associated with it so if we go to the next image we'll look at that in a bit more detail. This shows some very high quality seismic and we can see right at the top of this diagram, again going from south to north so it's just a blow-up of that middle little piece and on the left side here you can see the approximate depths down to about 800 metres. Now right near the bottom of this image, this seismic panel, you can see the Banks Peninsula volcanics again there's a very strong reflector picked out and this active fault right in the middle of the image is indicated with the black line. Now at the tip of the fault, the top of the fault up here, extends to within several tens of metres of the sea floor, or maybe 50 metres of the sea floor, but the tip of the fault is indicated here as not disturbing sediments younger than about 15,000 years, possibly older than that, so we can straight away infer that the time between earthquake movements on this fault is very long. There's extensive time periods, the recurrence times of large earthquakes is quite long. The other thing to notice here is that the offset on the volcanics, 30 metres, this is at a depth of 700 metres or so below the surface, we think about the age of the volcanic surface there, that's a relatively small offset over what is geologically a very long period of time and it really emphasises that while these faults are active they are punctuated by long periods of inactivity between earthquake events, between the times when these offsets are taking place and that 30 metre displacement will be an accumulated displacement from a number of earthquakes, we don't know how many earthquakes, but probably of the order of 10 or more earthquakes over that time-frame. The other comment I'd make again is that because this is a vertical cross-section we're looking at a fault and we're seeing displacements which are vertical displacements but we know from what we've experienced over the last year or so that these faults are also accommodating horizontal displacement and in these seismic images that we're showing you we don't have any way of really getting the numbers for that. That's not possible to do that from this sort of data directly.

Next image please. So the active faults just filtered out now, the active faults in Pegasus Bay are shown here. A number of these faults have been known for the last 15, 20 years. I'm thinking in particular of the faults in the northern part of the Pegasus Bay so the ones sort of north from the Kaiapoi/Woodend area right up to the top of this image whereas some of these faults to the south offshore from Christchurch were not recognised as active but have now been picked up from this new seismic survey and in particular the ones I wanted to comment on is some activity on these faults just north of Port Levy and offshore from Lyttelton Harbour where some activity has been picked up and of course that's relevant if we think in the context of, of the June 13 events.

1146

Next image please. So I'm sort of close to the, to the end point and coming back to this, this map that we had at the beginning and fortunately this one has stayed registered so it's not too bad. What I've done now is I've added some of the structures that we've identified both from the seismic reflection data as well as from the seismicity data that we've collected from the aftershocks over the last year. So for example if we think about the fault line that ruptured on the 13th of June immediately offshore from Brighton, it's shown on this image running more or less north-west, south-east parallel to the coast and offshore from, from Lyttelton Harbour here. We couldn't pick that up in the surveys because the seismic surveys offshore can't get close enough into the coast and from onshore we couldn't see it either so it just sat in the wrong place for us. The onshore faults that we've been talking about this morning are all shown both beneath the city and to the south-west and, and the Greendale fault is there and I've talked about the other structures. What I haven't included on this diagram are the other structures in Pegasus Bay. That, that's not on this particular image yet.

Q. So do you know the extent of the fault that ruptured on the 13th of June or are you inhibited in that respect by the same problems?

A. We're inhibited, yes we're inhibited by that as well and in fact there was a little bit of discussion yesterday that, that came up around this I think during one of the breaks. The aftershock activity since the 13th of June has in more recent times shown to be extending sort of towards Akaroa, towards the centre of the peninsula suggesting that perhaps there is some sort of a fault zone that continues further underneath the peninsula than is indicated on this particular map. The problem we have is these are faults in the deeper sub-surface, we have no surface expression and we can't run seismic surveys across Banks Peninsula to, to try and pick these structures up because of the topography, the terrain. It's just too difficult and also there's a significant issue with the, the strength and the velocities of the volcanics which are quite high compared to the strata that are underneath and that causes us problems in the analysis as well but given the aftershock activity there's clearly something extending further to the south-east. Now I, we don't have any real answers, definitive answers but I suspect that rather than being a single fault extending all the way through it's more likely to be a series of shorter segments sitting between the more prevalent east-west fabric that, that we've been talking about in the last couple of, of slide images. So I'd like to talk a little bit more about why we have a north-west, south-east orientation here. That's completely contrary to what we're seeing in many respects so I'd like to talk a little bit about that in a moment. Okay let's go onto the next image. Thank you. So this is really what, what we're just talking about. If we look now at the blue aftershocks post 13th of June we can see that the aftershock activity extends right to the south, getting into towards the centre of the peninsula here, south from Port Levy and so that, that's really just coming back to that point about how far does that structure perhaps extend.

Q. Could I just ask you to pause for a moment?

A. Mmm.

Q. What's the number on that – that's 29?
A. That's 10B29, yes.
Q. I think we've got the wrong 29.
A. You are going to see the other half of this in a moment. There's, there's an animation, not an animation, there's a second layer on this.
Q. Well it would have to be something completely different from what we've got as our number 29.
A. You've probably got a piece of paddock with a couple of red lines on it?
Q. Well that's one way of describing it, yes.
A. Yes, okay, well that's exactly right.
Q. Okay.
A. The reason, the reason I, the reason, this is just kind of by way of explanation. Remember just before I mentioned that if you think about the South Island as a whole there's an east, north-east, south-west, sorry, north-west, south-east contraction going on. That's what the plate boundary's driving and it's part of the explanation why we see faults in an east-west or slightly north or east-west orientation and the 13th of June structure which is in this north-north-west, south-south-east direction. So if we go to the next image here we are out at Greendale and we've got the water race which has been displaced a metre, about three or four metres here and we've got fractures, sheers in the paddock with off-sets beautifully shown by the, by the size of the water race and if we could now perhaps add the line work, the next image, we can see that the, the, the high, sorry let's, the most obvious fractures are these ones here, these, these are running through in this direction but that's not actually the orientation of the fault line. The fault line is actually this one that runs horizontally across this image. If you look at the fault as a whole these are forming as tears in the turf at a slight angle. At the same time we see evidence of tears which are at much higher angle to the main fault trace so this, this, in the top centre here I've got a red line with arrows and it follows some of these fractures that we see running through the turf, much more in a sort of north-west, south-east orientation and if you look carefully at these arrows they're doing

different things. This is in a sense, if you like, anti-clockwise on that top one whereas the arrows on the main fault trace here in the middle of the image are clockwise and if we, I don't have it on here, but if we were to add that compression direction across the island it would bisect these two so it would sitting coming in approximately from over here like that. So these orientations are totally consistent with something that's being squeezed and then fracturing on two directions. That, that's a very standard geological interpretation so to have the 13th of June event with quite a different orientation in terms of a tectonic setting it's actually okay, it works, it's not totally out of the blue from that point of view. Okay, could we go to the next image please. Before I do that could we go to the JRP additional slides that we put up this morning and just go to the second one of those images please, the 18th of October ones. Thank you.

Q. Now is this in our material?

A. Sorry, this is one I added this morning. I can give you this one if you – Sorry I just added that this morning. So what I wanted to do here was just to step back a little bit and look back at the big picture of the South Island again because of the plate boundary activity. Now this is quite a complicated diagram but the work that was done by a team from GNS has been looking at the rate of deformation across the South Island and recognising that about 75% of the plate motion is accommodated along the Alpine fault. The other 25% is mostly accommodated east of the Alpine Fault, across the rest of the South Island and a substantial proportion, probably about 20 of the 25% is accommodated by faults within the Southern Alps and the eastern foothills of the Southern Alps and that leaves about, let's say 5% of the deformation to be accommodated out to the edge of the plate boundaries somewhere near to the east coast of the South Island and the reason I've put this in is because if we, for example, take Banks Peninsula using this data which is largely, by the way, based on geodetic data, so that's high precision, global positioning data, since 1990 we're able to show that, for example, Banks Peninsula is moving on average let's say two to three millimetres closer per year to Porters Pass every year so this is the driver for the tectonic activity that occurs beneath the Canterbury Plains.

1156

Next image please. Which, if we think about the Greendale fault just for the moment, we had an average slip of about three and a half metres, maximum slip about five metres but let's say the average slip is about three and a half metres, if we have between two and three millimetres per year of strain accumulating in this eastern block of the South Island and we get an average movement in an earthquake of three and a half metres, that means we would have to have one of these earthquakes in this eastern region roughly every 1500 years, plus or minus say 250 years, to continue to accommodate the plate motion rate. Now it's a big region as you can see. It extends all the way and down the eastern part of the South Island and the Greendale fault is just one element of faulting that accommodates that plate motion. We have other structures to the north. For example I showed you the Ashley fault which has ruptured several times, there's the Springbank fault which is part of that system, the Greendale fault as Terry Webb showed you yesterday is quite a complicated structure with multiple components to it, we have similar faults that we've identified down south towards the Rakaia River also in an east/west orientation, and so if one takes this more global picture of the South Island and we think about what happened over the last 14 months and we recognise that we can put some sort of overall sort of bucket numbers on the plate tectonic rate, then we get a feeling for the frequency of these large earthquakes if we were to take that region as a whole. I hope that maybe adds some explanation to it.
Could we go back to the summary points now please. That was the last image on the last group of images on the other one. So really these are probably self-evident. The onshore and offshore investigations in and around Christchurch have revealed a number of hidden faults in the subsurface. These can be considered active in some case because we see evidence of displacements extending up through the more surficial strata. Others are picking up seismicity but are not necessarily by

definition active faults in that context and that interpretation is really supported on the basis of aftershock activity as well as the seismic reflection survey work. On the basis of the work we've done there does not appear to be a single through going fault that extends from the Greendale structure right through beneath Christchurch and out to the east.

Next image please. The faults imaged have low movement rates. In other words they have a low slip rate which means that there are long time periods between earthquakes, large earthquakes, on these structures.

Next one please. The complex pattern of aftershocks both in space and time reflects this progressive overprinting onto this inherited fault system in the basement beneath the Canterbury region. I think that's a really important aspect of why the aftershock activity is such a complex pattern. It's not a more sort of systematic simple pattern that we might expect in fault systems that operate on a much more regular basis with large earthquakes say on a cycle of hundreds of years.

Next please. I think the gap, if you like, between the Greendale fault and the Port Hills fault that ruptured on the 22nd of February is quite a complex zone and we are gathering constantly more information, seismological data, geodetic survey type data, geophysical subsurface investigation data and geological data and we will continue to try and better understand that area but I hope that at least some of the data that I've presented this morning will have provided some clarity around what we understand of that area.

Next please. And I guess the last one is also self-evident from what I have said and that there are other large earthquake source structures in the region and, in a sense, nothing's changed from before the 4th of September to now in that context because those source structures rupture with large earthquakes on a very much more regular basis and they are still there and we need to remember that as part of the overall setting of the region. The other comment I'd made is obviously we've got some new faults that we have unearthed both in the onshore and offshore area that will be part of the overall assessment that has to be done. That's the end of my evidence thank you.

COMMISSIONER CARTER:

Q. Just an observation perhaps of all that you've shown us and the question is the volcanic intrusion that created the Banks Peninsula hasn't been related to any faults that you've illustrated –
A. No.
Q. - Is that of any significance?
A. The fault system tends to operate from a greater depth in the sense that many of the larger earthquakes in the upper crust tend to nucleate somewhere in that sort of 12 to six kilometre range and I think, as you've seen from the images today, the base of the volcanic pile or the volcanic edifice, if you like, is much shallower. In fact it's of the order of hundreds of metres deep and extending to greater depth as you go further north into Pegasus Bay and west into the Canterbury Plains. Within Lyttelton volcano we actually have some of those basement rocks – the greywacke basement exposed in the floor of the volcano so the basement is actually very high right under the volcano. That's probably because the area is, because of the heat anomaly that exists with the volcanic activity, probably that area became a bit buoyant, bit more buoyant, so there's a sort of a basement high sitting under there. I think there's no doubt that the whole business of having a volcanic centre forming in the area, magmas intruding up towards the surface, would have created fractures, would have additionally conditioned the bedrock if you like for fracturing but everything we're seeing in terms of the aftershock activity, the earthquakes that we've been affected by, suggests that really the structure that's inherited in the deeper part of the upper crust is more relevant in the overall development of the sequence. At the moment I'm not detecting any direct connection and it maybe that Terry Webb might like to comment further based on the sort of seismological perspective but I think that the volcanics are not significantly impacting in that context. There has been some discussion

in the past about whether maybe the activity is going around the edge of the Peninsula because of the volcanics but I think that the 13th of June and the activity propagating right beneath the volcanoes probably is, to some extent, negating those comments.

COMMISSIONER FENWICK:

Q. I'm just intrigued by one of your points you raised before where you had the direction of compression going from the southeast to the nor'west yet the direction of relative movement between the two plates on the Australian side of the Alpine fault it's going north and the movement is almost sort of east/northeast or something down towards sou'west, almost normal to the direction of compression, sort of counter-intuitive.

A. Yes

1206

Q. I agree the lovely little map, the pictures on the fault where you could see the direction of compression from the tears but sort of counter-intuitive. You'd think if the motion was this way that would be the direction of the compression force.

A. Yeah I guess that's partly because we're taking the plate boundary zone as a whole and then thinking more about the sort of, the, the regional contraction that's going on.

Q. You, you made the comment that Banks Peninsula was pushing up towards Porters Pass.

A. Porters Pass.

Q. Which of course is exactly in line with your compression. I wondered whether there was a local disturbance there. Is that what's –

A. I think it's more of a South Island wide sort of aspect of the tectonic so that was really looking at the whole eastern block is moving into the plate boundary zone because the plate boundary is, in a sense it's narrowing, I mean it's constantly uplifting as well but the, the shortening direction driven by the plate rate is that shortening across the island in that direction and the fractures are responding to that compression rather than to the plate driver in that sense. When we take the plate motion it almost parallels faults like the Hope fault which extends from Kaikoura to, close to Hokitika and Inchbonne in that area. So that, that almost falls along the plate motion sort of vector if you like but it's the shortening across that plate boundary that's, that's actually dictating the fault mesh that's operating.

Q. It's a rather complex play of forces?

A. It is, it is, yes.

JUSTICE COOPER:

Q. The, as a result of the earthquakes since the 4th of September have you, have your priorities for research been altered and in what way?

A. Maybe if I could give a little bit of context. We started the active tectonics and earthquake hazard mapping programme at the university in 1987 and perhaps if I could pull up the first image of the additional slides I gave you this morning – thank you. There's something gone wrong with the boxes on, on this but what this is showing are the university research projects that have been completed over the last, let's say three decades or so, two, two and a half decades and for much of that time we've been targeting what we consider to be the most obvious and active faults in the region. So the high slip faults and the structures that have got good surface expression. Now you'll see that this includes projects through to about 1988 –

Q. 2008.

A. Sorry 2008, thank you. But in more recent times we've started to focus more and more on the sort of inner and central Canterbury Plains area because we've recognised increasingly that structures are just starting to daylight through the gravels and beneath the plains and also we've got some new research equipment available, the, the seismic reflection equipment we have at the university for an example and I think increasingly our research, I mean it's a moving feast. We, we tend to target the areas in which the most important research questions are facing us. A lot of this was driven by the fact that we had large earthquake source fault lines which may impact on not just Christchurch but other population centres in the, in the South Island but we now have some quite imperative questions much closer to Christchurch, Kaiapoi, Rangiora et cetera and so over the next, I think, five years we're going to add much greater detail to some of the work that I presented this morning. So, for example, looking in the top 100 metres exactly how do these faults play out into the near surface sediments. Do we see any evidence of them having ruptured with maybe larger earthquakes right through to the ground surface in the geologic past or is the extend of rupturing limited to 100 metres or 150 metres below the surface. That will tell us quite a bit about the frequency of these, these events. It will tell us also whether there are issues in terms of where the city might develop in terms of its future growth. So the areas that we're targeting will probably be quite close. We've actually got a number of studies underway in that context now.

Q. And is that work that you might not otherwise be doing?

A. I think we probably would have continued to target some of the larger fault lines. For example, we've got a project going on in inland Canterbury looking at the Esk fault which is clearly a large earthquake source structure, magnitude 7½ probably. We've got another study taking place near the Mackenzie's Pass and so those are continuing the sort of work we did in North Canterbury and the northern part of the island. We still have a lot of territory to the south and south and mid-Canterbury that hasn't really had a lot of investigation work done on it but I think now the Canterbury Plains have got a fairly significant sort of level of importance attached to them and we've also got access to some of the oil industry seismic data that was completed over previous decades and that will give us some guidelines as to where we want to target. I have to say the oil industry data doesn't have the resolution that, for example, the Calgary equipment is giving us close to the city so there's a sort of complementarity [*sic*] rather than overlap in terms of what that data might do.

Q. Are you planning on the return of that Calgary apparatus?

A. We've been looking at that. If we can get the funding that's one of the, one of the things we'll been looking at. The Calgary team is very keen to continue to work here. One of the areas we've been looking at is, is ground water investigations in Canterbury as well. Does that, does that answer your questions?
Q. Yes I'm just wondering, I mean the return of that equipment would seem to me not particularly, not particularly difficult to justify.
A. No, no.
Q. Is that your view?
A. I think, I think it would be, with the right sort of defined project in mind it would be a very good move and I think that there are projects, not necessarily all focussed on Canterbury I have to say, but I think that the opportunities to maybe target some areas where we would like to see if there is relevance and urgency for more data, that would be something that's worth discussing, yep.
Q. And you've mentioned also I think as one of your current priorities increasing your understanding of what you refer to as the gap?
A. Yes.
Q. Is that, do you have a work programme in relation to that?
A. Yes we do, yes.
Q. What are the, what are the major aspects?
A. The first part of that is continuing that air photo analysis that I've given you some indications of today just to see if there is any evidence, not just in those narrow areas where we've done the seismic line but in a more general sense across the plains between, between the fault systems to see if there's any evidence at all in the surface geology and geomorphology of any faulting, any warping and influence on the way that sediments have been distributed. The second part is we're going to go and target some of the faults that we've identified with the Calgary equipment and look at that top 100, 150 metres in much more detail and we've identified half a dozen locations and we've actually got that project starting over this summer period to get on with that. The GNS people of course are continuing to work with the aftershock data

because that's a very valuable additional component of insight and it's quite slow work because all the earthquakes that we record as aftershocks have to be relocated with high precision, high accuracy to give the sort of insights that we've been showing you this morning. It takes quite a bit of time to do that but that's work that's in progress as well.

Q. So is it possible to predict when that work might be completed?

A. I think we, yes, we will have made significant progress even before you finish with some of that work, definitely.

Q. So would we be wise do you think to ask for an update –

A. Yes, yes.

Q. – from you and others –

A. Yes, one thing, I think we're, we're finishing off a report on the Calgary survey and I'd be very, very happy to provide that so it's available to you.

1216

Q. Well can I ask that we do receive it that please?

A. Yes. Yep, mhm.

Q. Because we may want to make some observations about its –

A. Yep.

Q. – utility.

A. Yes. Absolutely.

Q. You see the merit of that I'm sure.

COMMISSIONER FENWICK:

Q. You indicated that two and a half millimetres per year in Canterbury amounted to a sort of what 1500 years or the total movement to be accumulated in the three and a half metre movement. Now I was wondering can that give us any guide as to the likely return period for the Greendale type fault or the other fault, I mean the, you hear numbers that –

A. Yeah.

Q. – which have varied from 16,000 years for the Greendale to something in excess of 8000 years?
A. Mhm.
Q. So not in conflict and I guess we're getting the same sort of numbers coming through officially or unofficially on the Port Hills fault?
A. Yes. Yes.
Q. Now as engineers because we're really concerned about –
A. Yep.
Q. – how frequently this sort of event might occur, might be expected to occur?
A. I think, I think the answer is no, there's, there's a different, different sort of approach in what I presented in that last slide because that's more of a regional perspective and why I commented that you know there are a number of faults which are operating in that region and any one of those faults can from time to time when the stress levels have built up sufficiently rupture so that doesn't relate directly to that two to three millimetres of accumulated strain being cycled through the region. It's unlikely that it would ever be cycled on to the same fault because it takes much longer to build those stress levels up so we are looking and I guess a very poorly constrained number at the moment would be say 10,000 year return times those, those are the sorts of numbers people are talking about. You saw the, the example from Pegasus Bay which there is no evidence of rupture in the last 15,000 years at least. The Greendale fault at Highfield Road there's no evidence of any surface displacement on the Canterbury Plains there at all and that's one of the older parts of the Canterbury Plains so you are starting to look definitely at the sort of 10,000 year period. As you come closer to Christchurch you're getting on to younger and younger elements of the Canterbury Plains surface and so we're less and less able to make statements about the return times because the surface that we're relating the fault movements to is much younger and therefore less, less helpful to us, and it's really difficult to get recurrence times on faults which don't daylight and don't have geomorphic expression but I guess it's a work in

progress it's a long term process but I think that that given the evidence from offshore, given what we see in the subsurface beneath Christchurch and the limited evidence for offsets this has happened on our watch and so it has, it has tremendous impact on us but it doesn't happen very often and it really looks from the data that we have that the return times on individual faults is definitely of the order of many thousands of years so does that put a context around it? I'm trying to avoid giving you any sense of really definitive numbers because we don't actually have those but I think that we are confident about very long time periods of the order of that 10,000 years.

COMMISSIONER CARTER:

Q. Which tends to bring us to the smaller but very close, very proximate events so the more knowledge you can give us about, about the potential –
A. Yeah so the –
Q. For maybe smaller faults but very close to the city?
A. Yes I mean I think that's really one of the highlighting issues isn't it that a magnitude 6 or 6.5 earthquake very close to a population centre is the one that a lot of focus is on, it's, it's one that we don't have really any information on because they rarely leave any trace in the land forms or the landscape. Indirectly and you'll probably have evidence from others over the next few weeks, indirectly one might for example look at the cliffs around Sumner and Redcliffs and say that there's really no evidence of the similar type of earthquake having occurred in the last 10,000 years in the Holocene period because there just isn't that amount of rock fall debris lying around at the bottom of those cliffs so I think we can take a degree of comfort from the fact that prior to September and definitely February 22nd and June 13th there was very little evidence of large earthquakes right beneath the city. We go back to 1869 and 1870, 1869 we had a significant earthquake beneath the city it was identified in our studies for Environment Canterbury in 1998 and '99 as one of the scenario earthquakes that we had to think about

and the interpretations are that that was roughly magnitude 4.7 to 4.9 and that it gets back to the comment we made before about you know how can we estimate those magnitudes but you can give a window and it looked like it was a sort of a high 4 in 1869. Damage to chimneys around the city, there was you know brick work damage because there's a lot of development at the time but we recognised that that as an earthquake immediately beneath the city had significant impact on us and so we, we realised that those earthquakes need to be further thought of, that's the only historic event right beneath the city that we could draw on 1869. 1870 was down at Ellesmere it was a larger earthquake further away, little bit of impact in the city in terms of damage brick work and so on.

Q. And would I be correct in saying that all of that sort of background is, relates to the reason why you're thinking so hard about the aftershock?

A. Yes.

Q. From the sequence of earthquakes that we're just experiencing now?

A. Yes. Yes definitely and, and the need for us to really understand some of the structures that have been picking up seismicity and what's the evidence of them, how do they operate in a longer geologic timeframe and how relevant is that in terms of our codes, in terms of our future urban planning?

COMMISSIONER FENWICK:

Q. Can I just come back to the return period for Christchurch CBD?

A. Mhm.

Q. Now we've had the Greendale fault and then you've got the area around Prebbleton where things are happening?

A. Mhm.

Q. And then we've got the Port Hills fault and then the one on the 13th of June, now these all occurred as a result of movements where the strain energy in the ground which has built up over centuries has been released now there will be little areas of course where it hasn't been released because they're slightly stronger and concrete you know not concrete sorry rock creeps and so they will continue to go in the aftershock sequence?

A. Mhm.

Q. But if we look at the end of this aftershock sequence we have reduced the stress in quite a local area haven't we?

A. Yes.

Q. So wouldn't this mean that we're unlikely to get this type of earthquake in the Christchurch area for quite a long period of time would that be a conclusion?

A. I think, I think having relieved the stresses on the structures beneath the city if one looks ahead over let's say decades rather than, than a year or two, one would expect that it will take quite some time for those stress levels to build up again to critical levels. I think what's important to recognise though is that as you move away from the CBD you're going to come to other faults which will have accumulated stress on them.

Q. And the stress may be increased right?

A. And it may have been increased in some areas and it may have been slightly reduced in other areas and I think Terry Webb indicated that yesterday in his presentation and so there is this issue of seeing elevated levels of seismicity for some time into the future because of this area having been affected or impacted and the fact that some faults over previous thousands of years have been accumulating stress and at some point that will have to be relieved I mean I, I think what we're doing at the moment is adding quite a bit of new knowledge to the fault lines that exist. We can continue to try to do some modelling to see what the stress changes are on some of those structures and that might inform us about maybe slightly higher levels of stress in some areas and lower levels of stress in other areas, but the immediate Christchurch city area has had a significant amount of stress relieved and, and so that if you look, take a longer term perspective is the, the positive aspect of, of that.

1226

Q. So if the, the sort of 6.6 to 6.5 magnitude earthquake is typical for this area –
A. Mmm.
Q. I don't know whether it is or not. Okay the reduction in stress over this area results in an increase in stress out here. So we might expect that sort of earthquake to occur but it will be presumably some distance away from the centre of the city. Would that be correct?
A. That, that's my view. It may be a question that would be worth putting to Terry because as the seismologist he will have a much better, I think a much more rigorous answer for you than I can give you but that's, I would see that as a consequence as there will be areas in which stress, and it's a relatively small stress increase. I think that's the other thing to remember is that these faults are accumulating stress up to critical levels over long periods of time so there's a cycle of earthquake activity and the amount of stress increase is probably not huge from, especially as you move away but it is, it is there, it's a real thing but it's also being reduced in some areas so you may be setting the clock backwards in some areas as well.
Q. Yes.
A. But maybe it's a question worth putting to Terry later on today.

JUSTICE COOPER:

Q. From your point of view putting on one side your ongoing work which you've described in relation to the gap has the work that's been carried out identified the faults close to Christchurch whose rupture could do damage?
A. We've identified some. I think the answer is there is more than likely to be more faults in the sub-surface than we know about. Those that have been picking up aftershock activity I think we've targeted with the seismic reflection surveys to date but there will be other structures that we haven't identified because they're not picking up seismicity and it would be quite a random process for us to try and get those. I think there's something to be said for looking at the offshore surveys and

seeing what we can pick up in terms of targeting some onshore areas to, to look at the continuity or the extension of some of those structures to the onshore area because, because the offshore data is much more complete in that sense I think. Does that, does that help to –

Q. Well, yes but one answer leads to another question. What I'm trying to get at is whether there is the potential for other ruptures under the city, under the existing extent of the city or is it likely, or is it more likely that if there are other hidden faults close to the city they will be further away than those that you have already found?

A. I, I think, I think the second scenario especially, maybe could we go back to one of the images?

Q. Certainly you may.

A. Perhaps if we could go back to, I think it's image 10B.24. Thank you. I, I think the offshore picture we have there is quite informative in the sense that it really does start to show us the complexity of what's underneath and you can see that as you look towards Christchurch city given that even though some of our recent survey results beneath the city centre and out to the south-west are not on here there, there is obviously going to be much more structure under the eastern, north-eastern part of the Canterbury Plains than is, is evident at the moment but I think there are some structures there which highlight the need for us to do some targeted research and perhaps a couple of the areas that one might look at would be this structure offshore from Kaiapoi. There's obviously an area up here that, that is devoid of data, that potentially needs to be looked at, to the north the Pegasus Bay structure and one notes the, the existence of these structures running east-west onshore and structures offshore and what the relationship might be. Now coming back to your question in that context those are further away from the CBD –

Q. Yes.

A. – and so that's, that's totally relevant but it of course becomes much more relevant, relevant for other communities further north that some of that data is, is brought forward.

Q. Yes. Well I'm thinking about the rebuild of Christchurch -
A. Yes, yes.
Q. – in asking these questions, largely, because when you look at what you have illustrated on this diagram it, it's not really possible to, well I'll put it another way. The Port Hills fault and the Greendale fault are both very close to Christchurch, the centre of Christchurch and the areas that you've highlighted for further research whilst they may have greater impact on other communities I'm really wanting to understand whether you're saying it's likely if the faults that could potentially rupture and impact on central Christchurch are now known –
A. I, I think, I think I've made the comment before. I think we know of one or two new ones.
Q. Yes.
A. But I think that we don't have the complete picture.
Q. You don't have the complete picture but in terms of likelihood they would be further away than those that recently ruptured?
A. Yes, I think in terms of the CBD yes but there may be faults beneath the northern part of Christchurch city which is still very proximal, very close but we don't have any data and they're not showing up with any aftershock focus. I'm thinking really in terms of what happened in the CBD on Boxing Day where that activity highlighted immediately an area that we needed to investigate, we needed to understand why those earthquakes were happening there. Unfortunately the survey wasn't done in, in the timeframe of the 22nd of February and had we done the survey I don't think we would have seen the Port Hills structure beneath the city centre anyway because it's to the south of it but we may well have, if we'd done the Brighton Beach line we may well have seen that Port Hills structure as, as is shown in that first seismic line I presented. But I think that there are areas in the west of the city where we've had very few aftershocks so there's no suggestion at the moment that there are structures that are showing up with the aftershock activity. In the northern part of the city as we, we head through the northern suburbs there's been no sort of focussed, concentrated activity in there but that's

not to say there are not structures there. As, as we've discovered out towards Rolleston we see lots of faults in the sub-surface which are picking up seismicity but with no sign at all of rupturing up towards the ground surface. I didn't show you those lines north of Rolleston township but we, we went across one of the very intensive zones of aftershock activity, north of Rolleston, and there are no surface faults showing up in that seismic line at all, you know, close to the surface faults but there are faults down in that basement rock at 1500 metres plus and they've been picking up a lot of seismicity down there. So it's, you know, it's absolutely likely that we will have other fault lines beneath the city but that are not currently switched on with activity and they will be difficult to detect just because of the problem of having a city sitting over the top.

Q. Well could one infer after all that has occurred since the 4th of September that if those other faults that may exist have remained quiescent throughout –

A. Yes.

1236

Q. – this activity then if they rupture it's unlikely to be as a result of what has happened since the 4th of September. That they're …

A. Mmm. I think, I think probably that's a difficult question to answer actually. It depends on the time-frame because right now there's no evidence that they're going to but of course as we saw on the 4th of September there was just no pre-warning that that particular earthquake was going to happen. If we, with the benefit of hindsight, can look at the Port Hills and the 22nd of February event and we could say, well yes actually the Wednesday after the 4th of September we had a significant magnitude 5+ aftershock beneath the Lyttelton area and, looking back, we can say well that's probably on that fault that ruptured on the 22nd of February. At the moment beneath the northern and western part of the city we're not seeing that type of activity ongoing so that's a positive but I don't think it's any way –

Q. Conclusive –

A. – a certainty that's not going to happen you know. I think we have to be very careful how we think about this because the comment we made, that Terry made yesterday in his evidence is really that the aftershocks, we don't see a reduction in the maximum aftershock magnitude, we see a reduction in the frequency of earthquakes over time and so quite late in an aftershock sequence you can still get quite a sizeable event and that can happen anywhere in the whole of the aftershock region from the west Canterbury Plains right through to the offshore area. So I don't think I can kind of give you any better insight other than to say well at the moment we're not seeing activity on structures that might be down there. We don't know what structures are there but I'm almost certain there will be other faults in the subsurface and I think one thing about it having had several large earthquake ruptures, it has done a lot to relieve those stresses that exist and that probably will have a positive impact but I think maybe I should defer to Terry to talk more about the statistical aspect of that rather than for me to get into that.

Q. Just let me have one more go at this. You've said it's likely that there are other unknown faults in proximity to Christchurch but there is no indication in the data that you are observing that they are likely to become active as a consequence of events since the 4th of September. Are those propositions correct?

A. Yes but recognising that the seismicity in this area will remain somewhat elevated for quite some time, some of these faults may in time show up but that doesn't mean to say we're going to necessarily be heading for a magnitude 6+ but we may certainly be expecting some more aftershocks and I suspect that the influence of that region will probably continue to extend for a period of time outwards but again it takes you away from the city at that point.

WITNESS EXCUSED

MR MILLS CALLS:

TERRY WEBB (AFFIRMED)

Q. So likely future rates of seismicity affecting Christchurch is what we're talking about now. So the next slide please.

WITNESS REFERS TO POWER POINT PRESENTATION

A. This slide is really just to refresh us on the enormous number of aftershocks we've had so I guess over 3000 of magnitude three or more and that would be an incomplete number so if we look at the next slide here we show a plot of the rate of aftershocks since September the 4th. So, going from September the 4th through to, this was up-dated on the 13th of October this year, so covers more than one year and at the right-hand side of this plot the little yellow stars are more spaced out and that's because for that time period we currently only have monthly sums of activity whereas to the left-hand side, say from the label "April 2011" back to September 2010 for that period we have weekly totals for the number of aftershocks occurring each week and so the Y axis is just showing that with a peak around for that star in the middle of the diagram, a peak around 45 aftershocks of I think it will be magnitude four and above for that week so if we start at the left-hand side for the beginning of the sequence there's a solid green line and that's marking a model prediction of the likely number of aftershocks per week and you can see that probably intersects the Y axis well above the first yellow star that occurs just below the number 40 per week so that would seem to indicate that when it started off the sequence was somewhat less active than we'd expect. There's always a problem, however, with the completeness of the earthquake data right near to the main shock because there's so much ground movement going on it's very hard to pick out all of the magnitude four aftershocks. You have to be a little bit careful at that point but you can after that time the activity of the aftershocks dropping very rapidly. The shape of that curve I guess a mathematician would call an "exponential decay", dropping very very quickly but some variability about the green line which is expected and so that drop off continued right through of course until February the 22nd when suddenly there was a very large aftershock, magnitude 6.2 and it in turn had, initially anyway, probably more aftershocks associated with it than the original main shock.

1246

So a very, very intense rate of aftershocks that again this time dropped off even more quickly which is sort of what we expect for a smaller earthquake, has ruptured a smaller area of fault and will trigger, well the, the rate of aftershocks will drop away quickly and it’s not, it’s a matter of months and you're approaching again the longer term background rate from the first magnitude 7.1 earthquake. The clock reset again if you like on June the 13th and we see this sort of average figure above the, just to the left of the July 2011 marker on the X axis, the bottom axis there and since that time reducing rate, getting back to levels as, as low as what we had say in April but not actually approaching levels yet that we had say in around November/December of 2010. So these later shocks have really elevated the overall rate and if you look at typical New Zealand sequences, as I sort of alluded earlier, to begin with this was probably a below average sequence in terms of the frequency of aftershocks but the, these other two large events have really kicked it up to be well above average as far as New Zealand aftershock sequences go. So, next slide. The green line is a model fit to the data that is continually updated. So currently we update that model every month and from that, the model that we use is called STEP, short-term, aftershock probabilities, I think that stands for and so we’re able to use the model. It’s a model that’s been tested in international testing centres such as the Southern California Earthquake Centre and is regarded as one of the best models for predicting aftershock rates. It is, of course, tuned to the parameters associated with typical New Zealand sequences rather than a generic, international kind of sequence and so on a monthly basis we issue updates to the probability of other aftershocks and you can see there is also some information that again comes out the way the model has been built, looking at global earthquakes, there is some information on earthquakes possibly as large as the original main shock, although you see the probabilities currently of such events occurring is quite low, down at 2%. But in terms of the discussion at the end of the previous talk, in terms of likelihoods of more aftershocks, let's say of 6 and above we're currently sitting at, say, roughly, a 14% chance let's say of something in the magnitude 6 range over the next year. This, of course, applies over the whole aftershock zone in terms of how the statistical model works but as I've already alluded to currently the zone, and if you think back to the red dots and the blue dots on the aftershock pattern, there's more activity occurring in those regions at the moment than there is over the rest of the aftershock zone. But the way these, if you like aftershocks, aftershocks decay will mean that we would expect it would become a bit more balanced over the whole zone as time progresses. So people tend to worry about the 14% chance of a magnitude 6. You should always remember, if I can do the sums right, I guess that's about an 86% chance of there not being a magnitude 6 in the next year. It's a far more positive way to look at this. So we've got to really plan around that possibility of it happening but it's something that we shouldn't really be living in fear of.

JUSTICE COOPER:

Q. Dr Webb I'll ask a question which will give you the opportunity to correct me probably but do you know enough about this predictive programme to know whether it takes into account the possibility of unknown faults that might rupture?

A. No it doesn't. It's purely statistically based so the shape of the model if you like is determined from looking at the statistics of aftershock sequences of large crustal earthquakes globally and then the particular parameters are tuned now to this sequence.

Q. So it's based on data observed?

A. It's data driven and statistically driven if you like. So it's not –

Q. So it wouldn't necessarily take into account ruptures that occurred on faults that were known as well as those that were unknown before the ruptured?
A. Well it will take account of all the earthquakes that have happened in this zone since September the 4th, yes.
Q. I suppose I'm talking about the basis on which the programme was designed.
A. It's not designed in terms of known fault ruptures or the, the geological input. It's purely developed from looking at the Earthquake Catalogue. That's the earth, that's the list of where earthquakes happened and how big they were and when they happened.
Q. So is the, does the programme only operate on the earthquakes, I mean is it based on, is the data that it's using data based on what's happened in Canterbury –
A. Yes.
Q. – since the 4th of September?
A. Yes.
Q. I see.
A. So the model does have spatial information but that is just driven by where those earthquakes have occurred?
Q. Yes I, I thought that it's, and I've obviously got this wrong but I thought that it's, on some basis it's predictive approach was based on experience of earthquakes that have occurred overseas as well.
A. The, the model is developed in that way in terms of the structure of the model but when you come to set the parameters and tune the –
Q. Yes.
A. – the steepness of the decay curve for example that's driven by this sequence. Yes.
Q. Thank you for explaining that.
A. Let's just check the next slide. This would be a good place to stop.

COMMISSION ADJOURNS: 12.54 PM

COMMISSION RESUMES: 2.15 PM

DR WEBB CONTINUES:

A. This next slide is in three frames, which are different magnitude ranges and within each frame let's look at the top frame magnitude 5 to 5.9 there are three models plotted that we can use to try and estimate future rates of earthquake activity in the Canterbury region let's say, it's not the Christchurch region it's the Canterbury region so before lunch I talked about the step model which is short term earthquake probabilities and it's a statistical model driven by the aftershocks that we've been having and so if we look at yes the 5 to 5.9 the top frame it's the light solid looking figure with the expediential decay so starting very high on the left-hand side but dropping very quickly and then flattening out to a slower drop off as we go across to the right of the diagram. So I've probably said enough about that model because we sort of covered it before lunch when we were talking about the aftershocks.

JUSTICE COOPER:

Q. What are the geographical location points, what is that location 172 65 east?
A. Oh that's Christchurch city.
Q. That's Christchurch city?
A. Yes.
Q. Right thank you.
A. But I mentioned before lunch in terms of step having spatial information –
Q. Yes.
A. Which tends to be centred on where the aftershocks have, are happening so of late have migrated more to the, around the February 22nd and June the 13th aftershock density.
Q. Right.

A. And as time goes on we would, if there are no further big events we'd expect that to even out more across the after zone, aftershock zone as the rates all drop.

EXAMINATION CONTINUES: MR MILLS

A. Next model is EEPAS, every earthquake a precursor according to scale. This is one of the few models published and been shown to work globally for forecasting the likelihood of larger earthquakes but it forecasts for the Canterbury sequence the 5 and above so there's, it's the dashed line in all frames so in the top frame is going fairly high level on the top left down through the solid horizontal line and off down to the right. It, let's talk about it a little bit more. There's this again is the statistically driven model developed from looking at earthquake sequences that have been followed by large events. Globally I think in particular Japan, California and New Zealand so as I said a statistically driven model. However, since it was developed and it's been developed over the past 10 to 20 year time frame, the model's been evolved to one that, to one that works best in terms of current thinking, more recently we've become, come to understand better the stress changes in the earth that cause earthquakes to trigger each other and we I guess talked about that Anatolian fault in Turkey yesterday as an example of that so our feeling is that the physical mechanism that underlies the success of the statistical theory is stress, stress triggering or something very close to that. So you can see that it doesn't take very long in terms of this model let's say at the left-hand end I'm looking at say 2012, 2013, at the magnitude 5 range or the magnitude 6 range, the aftershocks have dropped away rapidly and this likelihood of triggered activity becomes dominant in the three models that we're showing here. But as I mentioned earlier the likelihood of that is just a few percent but if you think carefully about that what is the likelihood of a large earthquake affecting Christchurch had we had none of this sequence. That's at around that level or a bit lower perhaps maybe around the, the one to 2% and so this enhancement of activity is significant in terms of the rates that we may face here over the next few years and you can see it takes some time for these EEPAS rates to drop down below this other PPE rate. So that's, that's EEPAS and the third model so STEP, STEP and EEPAS of course are time varying hazard models. This is a very new concept introduced these kinds of models to influence how we build buildings but you can see from what's happened due to aftershock damage in Christchurch that's a very sensible thing to do. It also contain, the models also contain information that are quite relevant for insurance issues. PPE model however is – and excuse me I'll have to just refresh on what the acronym is, Proximity to Past Earthquakes, PPE, it's constant in time and for the calculated level here in the three frames the solid horizontal line there PPE has been calculated based on earthquakes occurring in the region of magnitude 5 and greater in the past 60 years and of course given that the rate of seismic activity normally in Canterbury is very low compared to say and this came out of what Jarg presented this morning compared to further inland in the, in the Southern Alps when you add up the number of magnitude 5s affecting the region in 60 years adding in the more recent magnitude 5s that are aftershocks make a big difference to the rates so this PPE long term level is much higher than the long term level used to inform the background sources in the National Seismic Hazard model that Graeme McVerry will talk about after me. There are two issues we're grappling with, with these models that it's important to understand. The first relates to EEPAS where we're triggering large earthquakes at a distance in terms of a separate physical understanding of how earthquakes behave. The EEPAS model has been constructed so that it takes account that the larger the initial earthquake the bigger the distance over which it will have an effect but that distance is measured from zero so in other words it's measured from probably a point on the Darfield fault and it's again a theory that contains spatial information, it's more smeared out than STEP but it is centred on where the initial earthquake happened. Now if you think about that physically you'd think it should probably be a donut shape and that you wouldn't expect it to be centred on zero. If we are able to introduce a donut kind of concept and modify the EEPAS model in that way you'll tend to spread the seismicity out further and you'll lower the Christchurch or Darfield centric rate down. So that would in fact mean that should we succeed in agreeing how to do that because it's not in the original theory then, then that would be something that could bring rates down a bit lower.

JUSTICE COOPER:

Q. Can you think of some other word than donut, what's the shape you're describing, is it roughly circular or ovular? Elliptical or…?

A. In this case it may be elliptical not, if, if the original earthquake which from which you're predicting other triggered activity if you just had one it would be circular but we have other large earthquakes that have occurred since then like especially February the 22nd so you could see how that may make it an elliptical shape rather than a circular shape.

1425

But we want to have lower activity rate in the middle of that area and more activity rate maybe a few 10s of kilometres further out and then dropping away further. So that's why I'm calling it a doughnut shape. The forward path for developing EEPAS better is we're setting up an expert elicitation process. So some international people come to New Zealand in November to talk through the issues around, given the fault structures in Canterbury that Jarg talked about this morning and models such as these, how you would redistribute the seismicity and an expert elicitation process will look at various options for doing that and then experts will vote on the weight for each option and it's also being done in a slightly more sophisticated way and more robust way than usual in that people will be measured on their judgment separately and that will weight how much their votes count. So this expert elicitation process is for some other hazard estimation work has been shown to give better results than experts sitting around, all with equal weight, when they casT votes. So that's the plan for November. So after that period we hope to be able to introduce some modifications to EEPAS. At the moment in terms of predictions for rates in the shorter term for Christchurch, this isn't that important because the aftershocks are still dominating the rate but once we get out another two or three years this becomes much more important.

Q. So how long, when are you expecting that process to be completed after this process in November?

A. It'll take a while to mull over the results and process the results. I would hope that's only a matter of a few months but it could be that long.

Q. Well how does it, so would the Royal Commission be able to be informed about the result of that process?

A. I'd have to consult with the people involved to know if they'll be able to deliver it, to deliver on that timeframe. I'd hope that they would but I'd have to check to be sure.

Q. How many people are involved in this?

A. Probably, just guessing here, six to eight I should imagine or six to 10 experts, yes.

Q. Who's organising it?

A. Matt Gerstenberger at GNS Science.

Q. At GNS, all right. Thank you.

A. So that was the first thing that we're grappling with. The second thing we're grappling with is the long-term rate or the rate will end up at, in say 30 years time, and I should just hasten to add, these decay curves, be it aftershock and especially EEPAS drop away like this if there's no further large events. If there is another large event the rates kick up as you saw in fact on the aftershock plot so both models are affected by that. So we need to have, essentially, fingers crossed and hope that things continue dropping away and that will then put us in the situation unlike we had say in the Buller/Arthur's Pass, Buller region after 1929. So we just have to wait and see on that part.

Q. And what's a large event for that purpose?

A. Well 6 or 6½ plus.

Q. Six and above?

A. Yes. The bigger it is the more affects the (inaudible 14:29:13), yes.

Q. I know but I was wondering how small it could be and still be big.
A. Well the 5s won't make much difference.
Q. So 6 and above, you're happy with that?
A. Mmm, mmm.
Q. Yes.
A. So yes wrestling with the issue about the long-term rate. So, yes, PPE we've used since 1951 to now, we've used 60 years. The key thing I guess about the long-term rate, if we're building buildings and often when we're in the construction sector we think about 50 year window as lifetime of a building. That's sort of rough approximation and we go with that. So in terms of these estimates to inform building design we really want to know what's going to happen in the next 50 years. So some people would argue, let's look at the past 50 years. Problem here is, of course, the view of the past 50 years has changed radically over the past one year so how do you take that into account. Here we're taking it into account to get that level by including the recent activity and only averaging it over the 60 years, in this case it's 60 years because the quality of the earthquake catalogue is suitable for doing that over 60 years. If you had a better earthquake catalogue as in more seismographs back in 1940 and from thereon you might say let's average over 160 years because we've got this much larger history and that will be a better guide and it will tend to smooth the more recent year out more. But we heard from Jarg this morning, the repeat time of a sequence like this could be thousands of years. Why don't we smooth it over 1000 years. Well people would say that's very un-conservative would be the term in terms of how you build your model, you're actually taking on quite a bit of risk with that approach because given that we've had this, as I said before, we're interested in the next 50 years. If you, a fourth model that I haven't put here is our standard approach in the past given relatively stable rates of earthquake activity around the country, of how we build the rate of activity for the background sources in the national seismic hazard model. That uses a slightly different approach in how you average previous activity and if you had applied that to

Canterbury you wouldn't get such a large change. So it's much closer to a very long-term rate and the recent sequence doesn't carry much weight when you add it in. In particular because you take aftershocks out of it. So you're only going to add one, two or three events accordingly to your definition of aftershocks –

Q. Can I, sorry, were you in the middle of a (inaudible 14:32:18).

A. No, that's fine.

Q. The, I'm not sure that I understand what the X axis is measuring. It goes from 0.005 up to 0.1 of what?

A. That's the likelihood of an earthquake of that size in the particular year. So the X axis here going from across the bottom 2010 out to 2040. So if you think of breaking that up into years and thinking about the likelihood of a magnitude 7, let's say if we're looking at the bottom frame, likelihood of a magnitude 7 in that particular year is, let's say 2015 is roughly one in 10,000. So it's seismicity rate for each magnitude class, annual, annual likelihood. So, yes, so if the, if we used the traditional as a fourth model, I've got enough models but the advantage of having a range of models is that you can test the sensitivity of the models and agree on an answer if you use an expert elicitation process or consult with the community about what they think the level of acceptable risk is. So if you use the National Seismic Hazard model approach that would give you a much lower level than this horizontal line that we call the PPE line, not a big change from currently. Again, people might argue that's not conservative or safe enough. When you come to calculate from that though the input to engineering design it decreases the required design level but not enormously. So although these levels will look very different in the plot I'm showing here when it comes through to design input the changes aren't enormous but they are significant for engineers. So there's quite, there's, there's ongoing discussion or debate here about what these levels are and that hasn't, that, that, we haven't, that debate hasn't been had very widely yet but it will need to be in terms of trying to agree on what appropriate levels are for the long-term background. If we change the long-term background level we bring down the average over 50 years that is currently what we are feeding through to building design input.

1435

COMMISSIONER CARTER:

Q. In your second statement there I'm just trying to recognise the 700 x number in the top graph. I would have thought I could read that from the straight line, the PPE line, up to the calculated step line?

A. No, sorry, you'd have to read it off the National Seismic Hazard Model line which is probably off the bottom. Sorry I forgot to mention those figures. They certainly show that rates are amplified enormously at the moment but we are amplifying off what were medium to low rates to start with.

JUSTICE COOPER:

Q. The reference in the PPE for the past 60 years does that 60 year period, that goes back 60 years ago from today for example is 1951 isn't it. So is this an analysis, a calculation that is done from time to time looking back 60 or do you do this annually or how often is this reviewed?

A. It's an interesting question. It will have been done to calculate the Canterbury PPE level probably in April.

Q. So does the 60 year constantly move so that next year it will be at 1952 would be a base?

A. No, I think you'll find that example of 50 years is pinned off when the catalogue became good enough.

Q. 60 years?

A. 60, yes, in 1951. It's again a moot point as to whether you should use a 50 year sliding window because that's a building life and if you're looking at what would happen in the next 50, should we look back at the last 50, other people would say no, no, no, use the best data you've got and so in this example we'd say well we'll use 60 and next year if we re-did it we'd use 61.

Q. I have some questions about that 50 year design life of a building but you'd probably like me to ask somebody else about that one?

A. Yes I would yes thank you. Next slide please. Right, there's a name for these plots that I'm hesitant to use because I may be asked to spell it. Disaggregation plots they are but what these plots are doing if you've got let's say at Christchurch and yesterday we talked about spectral acceleration so it's the .5 second spectral acceleration used to build these plots but more understandably shaking of a level of .6g so the likelihood of that well which earthquake is going to cause that shaking or which range of earthquakes could cause that level of shaking or higher. That's what these plots show so if we look at the one on the left-hand side which is the original National Seismic Hazard Model pre September 2010 so it's a three-dimensional plot and on the right-hand side sort of going away from us you can see the range of earthquake magnitudes from magnitude 5 through to over magnitude 8 and more in the foreground where on that axis we're plotting how far you're away from the particular earthquake ranging from zero distance out to over 250 kilometres and then the vertical axis or height of these little towers if you like is what percentage contribution they make for causing that shaking of .6g and dominant in the old model was the Porters Pass Grey fault so at a distance of roughly 50 kilometres from Christchurch expected magnitude about 7.5, guessing off that scale, and contributing about 9% of the hazard effectively. So, once you've built your hazard model and come up with values, this enables you to separate out the different contributions to hazard and understand which earthquake sources are contributing the most and you see the other major fault labelled there, the Alpine fault, so further away but a bigger magnitude so still able to exceed .6g in Christchurch according to that model so the other thing to note is in the lower left-hand corner a little forest of towers if you like they are the smaller, closer earthquakes that Jarg was being asked about this morning and they are contributing, if you added them all up, quite a bit to the hazard but individually only about 3%. Now, if you look on the right-hand side this is exactly the same kind of plot. I have to apologise we couldn't make it look identical 'cos to run that model we had to use different software and I think we'll soon be in a position or probably almost are of being able to run it to produce an identical plot but the information is the same so the range of magnitude span considered in that diagram is the same from 5 up to about 8 and again the distance between Christchurch and where the future earthquake might occur goes from zero out to 270 kilometres, the percent contribution up the left-hand axis peaking at about 5% but it is a very different picture from the left-hand side and so for this new hazard model that I explained the various models that feed into that on the previous slide, for the new hazard model it's really really dominated by the small, moderate magnitude earthquakes at close distance at the moment. As time goes on the sort of 5% level in that right-hand diagram will subside and the spikiness in the sort of back left-hand part of the left-hand diagram will emerge out of what is essentially the noise and re-appear as local activity subsides and other activity begins to dominate again in the future. The model being driven by smaller magnitude closer earthquakes I think has important implications for design or assumptions made about what feeds into design motions and I'll leave it to Graeme to talk about that.

Can we just go back please one slide. I should add another issue with how you end up with a final model you've got to combine these three models and we've also put in the active fault model that we always have in our National model but, as you saw from the slide I've just covered, it's these smaller closer earthquakes that are dominating and we're adopting at the moment an average approach to the three models so tending to average them for each time point. To get a value one could argue you should take the maximum. Some people would say that's too conservative so currently we're taking an average but I would expect that will be another decision that comes out of the expert panel elicitation process in terms of how best you combine these models.

So two slides again please. The final part of this talk is about the effects of an Alpine fault rupture on Christchurch so if there are no questions relating back.

1445

I have to stress this is a preliminary model so it will evolve and it was, I guess of interest I forget whether it was DBH or someone else probably requested this that we try and undertake this modelling to better inform issues around the Alpine fault or at least get that process started. One advantage of having earthquakes in Christchurch is that if you have recording stations on the West Coast you can record earthquakes here and measure them here and although the waves have gone, the seismic waves have gone in the opposite direction it gives you a very good handle on what happens to seismic waves over those travel paths. So you can take those recordings from the West Coast for smaller earthquakes, you can add them up with the right scale factors and simulate a large earthquake alpine fault earthquake affecting Christchurch. In fact you can also use I guess recordings in Christchurch as part of that process. Also when you get a fault that long and if you recall back to yesterday when we showed how slip was distributed over the fault plane it tended to be concentrated in a particular place. When you have a rupture as long as you can possibly, a very long rupture that's an alpine fault like this that's been shown here there'll be parts of that rupture that have a lot of, release a lot of seismic slip and consequence radiate lots of seismic energy and they'll be other parts that release less slip. Areas where a lot of slip is released we call asperities and so in this model there, in - the four asperities have been put in of certain lengths. They will have been chosen based on studies of other large earthquakes in terms of the proportion of the length of the total rupture that involves asperities and how long each asperity is to, to give a sort of reality check and one's deliberately put in quite close to Christchurch to make sure that you're getting sufficiently high, sufficiently realistic ground motions generated.

JUSTICE COOPER:

Q. Can we just spell asperity, I think it's A-S-P-E-R-I-T-Y?

A. Yes.

EXAMINATION CONTINUES: MR MILLS

A. So if we jump to the next slide, so in terms of a recording site in Christchurch once we've run the model backwards you get the top black trace for a modelled 8.2 alpine fault earthquake. Shown for comparison at the same site I don't remember exactly which recorder this is but it will be CBD based recording and we've shown also so the shaking from Darfield earthquake and the February 22nd earthquake in red. So you can see that the alpine fault, the shaking due to an alpine fault earthquake according to that model is far, far less than what the city has already experienced but another thing to note and people have often talked about this, that shaking will go on for much, much longer and so it's starting in here, you're starting to see appreciable shaking just to the right of where the red vertical lines from the Christchurch earthquake across in the top black trace just to the right of there going on to under the word "earthquake" on the top trace so strong ground motion continuing for quite a long time. So I have to stress again it is a preliminary model more sensitivity tests need to be done and you can make probably harsher assumptions in terms of the kind of rupture or perhaps ground amplification near site effects to get higher levels than this but even so we don't, there's, there's – really doesn't appear to be any realistic way to get shaking of the levels of Darfield or Christchurch.

JUSTICE COOPER:

Q. I've seen this is a diagram which is in your original report to us of course and comment is made that the shaking associated with the alpine fault would last for a much longer period but the accelerations would be significantly less. I hadn't seen anywhere so far any commentary on the consequences of that for the integrity of buildings?

A. Well I might –

Q. And that I'm not sure if you're the right person to be asking about (inaudible 14:50:31)?
A. I'm just going to pass the buck to Graeme McVerry.
Q. All right, all right.
A. So the problem here of course it's a distance earthquake and accelerations will tend to be attenuated –
Q. Yes.
A. – that's all in this model as they travel the long distance -
Q. Yes.
A. – to Christchurch, the slower displacements if you like caused by the earthquake dynamic displacements will tend to be larger but Graeme I think has some plots that can cover that off.
Q. Yes. The measurement point in Christchurch is the Botanical Gardens site?
A. Thank you right. Mhm. Mhm. And I think that's it is it, is that the last slide, yes. Right thanks.

WITNESS EXCUSED

MR MILLS CALLS:

GRAEME MCVERRY (AFFIRMED)

A. Good afternoon, up until now you've been hearing from a seismologist and geologist about the tectonic setting of the Christchurch earthquake sequence. All the myriad of faults in the area, some aspects of the ground shaking and the ongoing earthquake sequence. I come from a somewhat different discipline I'm an engineering seismologist and the emphasis on the engineering. I'm interested in ground shaking as it affects structures and part of my task is to turn all the information we've been hearing up 'til now basically into the information that engineers can use for structural design. I should point out that I, my training is in engineering as far as my university training but I'm not a structural engineer and I've never practised in that area but I basically form the link between the structural designers and the earth scientists and today I'm going to talk about the implications of all, all you've heard so far pretty much, the structural design motions for Christchurch. I'll start off by comparing the motions that we experienced on February the 22nd with the design level motions at that time and then I'll discuss a little bit on the work that we've been doing since in modifying those design motions and perhaps where that may, may proceed a little bit, we've had a couple of alliterations but perhaps haven't reached the final level there either. Okay, next slide please. I'll spend a little bit of time talking on this slide because there's several basic concepts that I want to get across. The first thing is this is what we call an acceleration response spectrum which is the most usual way that we use for engineers for giving the characteristics of earthquake ground motions in terms of what they need to design for and what it's showing on the left-hand side is the acceleration response spectrum which is the maximum response to the structure of a particular period will experience when subjected to the particular ground motions and along the, the horizontal axis is the period.

1455

That's the period of the structure. It's natural, fundamental mode of vibration and perhaps I need to explain that first. The period of a structure, if you imagine you've got a building and you pulled it to one side at the top and then let it go it would move forward and back and forward and back and keep on going with somewhat diminishing motions but the period is, the time it takes to do one complete cycle forward and back to where it started and that, that's what we call the period. Structures are not quite as simple as that though because taller structures actually have what we call several modes of vibration. There are several natural periods associated with them and you can imagine the second one would be if you pulled say the middle of the structure out this way and the top back this way and let it go, you'd then have the different parts of the building moving in different directions. But you have, they would do that rather short, shorter period than the fundamental mode that we have the same concept and in fact this diagram, engineers sometimes have to add up the contributions of several of these modes to get their final answer. But this is basically giving the information about the ground motions. And what I'm showing here, the, so the somewhat uneven curves there, there's five examples of these response – four examples of the response spectra for sites around central Christchurch. There's the Christchurch Hospital, the Catholic Cathedral College, the Botanic Gardens which Terry showed you motions from just recently and Resthaven a rest home on the outskirts of the CBD and we've chosen those four because the motions are somewhat variable and one motion on its own mightn't be representative but it's to give you a feel, if you look at those different, different curves it shows that they're, they're, they've got sort of the same general features but they are somewhat different. You'll see a somewhat thicker red curve through there. That is like the average of those motions. It's actually something we call the geometric mean but for these purposes think of it as an average of those four motions. I should point out that these have all been plotted for the largest horizontal component which is what we use in design in New Zealand, American practice they often use the, the geometric mean of the two individual horizontal components which is always smaller than the larger component.

Q. In the box the legend says, "GM Max H." Is that the, is that the line that you're –

A. Yes that, that's saying it's the geometric mean of the max of those four, so the max correspond, talking about the four individual components which are the larger and the GM is that that line is, we use the geometric mean rather than the average but it's, it's taking each of those four individual components and calculating what we call the geometric mean. That, that, instead of just adding up the four and dividing them by four you actually multiple them together and take the fourth root. There are mathematical reasons for, for doing that which I might be able to perhaps mention a little later, it might be a little more obvious why we do that on a later slide. But that, that is a reasonable representation of the typical shaking that we're getting from those four sites. What I'm comparing it with, two curves out of our 11/70 design standard. The first one which is bottom dashed one. The first thing you'll note it's sort of rather smooth compared with the individual ones. That, that is the motion that is estimated to have an annual rate of exceedance of one in 500 which is what we typically refer to as the 500 year spectrum and that is the design level for Christchurch, or prior to February anyway, for normal use structures. So most of your office buildings and all those sort of structures would be designed to that and the design acceleration would depend on the period of the structure. The period of the structure is basically related to its height. So basic rule of thumb is that each storey's about .1, corresponds to .1 second but you have some structures that are stiffer than average and others are more flexible. So a 10-storey structure for example might have a period of either .7 seconds or something a little bit shorter but it's very stiff or maybe 1 ½ seconds if it's somewhat more flexible than usual. Now we'll go and the second curve is what we call the 2500 year spectrum. That gets called into play for essential facilities such as hospitals that need to be in service after a big earthquake and those sort of facilities. It would only apply to a few structures in Christchurch. The reason I'm showing that though is you can see that that's sort of, somewhat sort of close in, in various period bands to, to what was actually experienced but if you look carefully you can see obvious departures from that and these are things that we need to understand. Are they systematic things that if we get other earthquakes will show up again in Christchurch or are they something that's just a feature of this earthquake and there's two areas I'll point out. If you look at the, the peak of the 2500 year spectrum you'll see that from about the middle of that, so somewhere around about .3/.4 seconds the measured motions, look at the red one which is the representative for the measured motion – it starts exceeding that and stays above that 2500 year motion way up to about 1.7 seconds. So we're exceeding even the severe 2500 year motion over that period range. So that's going to be covering most of the medium- to high-rise buildings in Christchurch, some of the really taller ones will be maybe a little bit longer period than that. See there's a little bit of a dip below that curve there and then we have another sort of peak out in about the 2.7 seconds out to about four second range. It looks pretty insignificant on there but it is actually quite important as I'll show in the next slide. That peak is at about three seconds. It turns out that if we look at the deep sediments under Christchurch we're talking about maybe 30 metres which in some locations is very soft material and in others it might be quite stiff gravels but then that's on top of rather stiffer materials or gravels and silts and sands that are all sort of inter-bedded until you hit the volcanics at about 600 metres under this particular site which you've heard Professor Pettinga mention several times today that underlies Christchurch. Then you have about 300 metres of those over the basement greywacke and it turns out that three seconds happens to be very close to, to the estimated natural period of Christchurch. So that suggest that that peak has probably got something to do with the ground itself. However, we have other records from Christchurch from smaller magnitude earthquakes, they simply have no energy in that long period band so that peak only seems to get excited in some of the larger earthquakes, larger in terms of magnitude not necessarily in terms of the strength of the shaking. For example, several of the aftershocks of the September event, there was one about, I think it was on the Thursday morning just after the September event which gave very strong shaking in central Christchurch. The peak ground accelerations were almost as strong as they were in the September main shock. That, that, because it was a lower magnitude event though it had no long period energy so that peak didn't show up. On the other hand if you took a magnitude, I think it was a 7.2 or 7.3 earthquake down in Fiordland in 2003, that was a long way away so the shaking wasn't very strong but it did show a peak at this period again because there was that long period energy in the wave train. The other peak that's probably sort of more

COMMISSIONER FENWICK:

Q. Excuse me Graeme can I just get something clarified there. That peak, about three seconds, is a natural period of the ground?

A. That, that's what we believe, yes.

1505

Q. Right now if you have the Alpine fault earthquake which goes on for three minutes or intense movement for a minute or something like this that gives it the chance for this resonant effect to build up doesn't it?

A. Yes I would expect so. It wasn't particularly prominent in those plots Terry showed you. One issue I've discovered recently is that the person who put that model together had forgotten to put the sharp impedance contrast for change of velocity at that 700 metres depth so we're re-running it to see if we can produce that. It does show up a bit more but it's not as prominent as we're getting here so I think there must have been some particular energy in this earthquake that perhaps was exciting that more strongly than our Alpine fault model.

Q. Would you normally, because of the resonance effect, would you normally expect a Hope fault or a Porters Pass type fault or an Alpine fault to accentuate that?

A. I would expect so but we need to understand a little bit more what's causing that, whether it's just a simple one-dimensional-type model or whether it's a basin type model which depends on what direction the waves are coming in and the rebounding off perhaps the base of the Port Hills and some of these sorts of effects that Terry Webb talked about yesterday. Certainly, part of it is associated with the site period but whether it's a simple model or a more complicated basin model, it depends on which way the wave train comes in. We're doing a number of forms of model to investigate that at the moment.

Q. One more quick thing. Every engineer you've talked to comes up with a different number about what the frequency or period of vibration of a building is on average and the value being put round by the Engineering Advisory Group now is divide the period by six so that would actually correspond to an 18 storey corresponds with three second earthquake.

A. Okay, that's fine.

Q. So there are some which are expected to cause that and so that can be very significant?

A. Yes okay I should have said that that .1 end rule is certainly not recommended for design anymore. It was trying to just give you some sort of idea though for people who had no idea what the period of a building is and in fact in analysis engineers usually work that out for a specific building knowing their mass and stiffness distribution rather than using necessarily these rules of thumb particularly for the taller structures. The other very significant peak is this one here where you can see it greatly exceeds the 2500 year motion.

Q. That's the brown line is it?

A. That's, well the brown line is the worst example but even if we look at sort of like the average it's quite a bit above as well and the indications at present is that's basically, it could be either the second mode of the whole depth of soil 'cos soil behaves just like I explained for buildings or has several modes too but it looks as though some calculations were done so far and other people have done in some cases up to maybe 20 years ago is it's a period that's associated with about the top 30 metres of the softer soils in Christchurch. Both of those are things that we're investigating further but both of those peaks look likely to be associated with the site. That one perhaps expect to be set in motion by rather more earthquakes because it doesn't need such long period energy to set it going. The final point I mentioned earlier that doesn't look very significant but the reason it's important is that it controls the maximum displacement demand on some longer period structures and if I could have the next slide please. This looks rather different but it's plotting the same information in a different way. This is now showing the maximum displacement of those simple representations of building. That's the displacement relative to the ground and again we've got the two design curves shown there and here you can see the three second peak that didn't look very significant in terms of acceleration. It looks very significant when you look at the displacement. You might think okay that's only going to come into play, as I think Richard said, for 18 storeys or 20 storeys, 25 storeys but in fact it can come into play for structures at quite a bit shorter period than that because these plots are all for a structure that stays elastic. That means that the acceleration is just basically proportional to the displacement. The structures are actually designed to yield. They have a certain strength and then basically to limit the forces that get into the structure they then yield, the displacement increases, the acceleration or force stays reasonably constant, it might grow a little bit and when that happens the stiffness which depends on the ratio of the peak acceleration to peak displacement lengthens so that means that as you start yielding a structure that may have been somewhere in this lower peak round about one and a half seconds it's period changes from that out to somewhere in here potentially, somewhere in the big peak out around three and a half seconds. The situation isn't quite as bad as it looks because once a structure yields it also dissipates a lot more energy, the effective damping increases. These curves are all shown for 5% damping which is about the damping you get initially in a structure but once it starts yielding, the damping increases so these peaks tend to get pulled down a bit but you can see that potentially you could still get caught up there. A typical design ductility which is the amount of displacement that you actually design for divided by the yield displacement is about three and a rough indication of the period is that it goes up like the square root of the ductility so it would be about a factor of 1.7 and if you started off in here that final, what we call the sequence stiffness would correspond to somewhere round that peak so that's one reason why that is possibly important for more than just the very tallest structures is that some of the more mid range structures could end up being affected by that if they have large inelastic displacements as many of them would probably have had in the February earthquake because the actual motions that they were excited by was about twice their design motions. The final point I want to make on this slide, there's been a lot of talk about base isolation and I should point out I'm a proponent of base isolation. I have actually been involved in that since the beginning of my career back in the mid '70s. I actually came up with the design parameters for New Zealand's first base isolated building, the William Clayton building, and have been involved in a number of those projects since but one of the things with base isolation is it tries to give the structure a period that's longer than the dominant period of the ground. I was sort of showing you how structures would go backwards and forwards. If you imagine that you're vibrating the ground very rapidly the structure if it's very flexible will hardly move at all. You'll have a big displacement between the ground and the top of the structure but the structure hasn't got a tendency to move at those high frequencies so if you can give the structure a long period by setting it on a very flexible base you can isolate it largely from the ground motions and often the sort of periods that you try and give even a short structure to get away from the peaks of the acceleration is often in the two to three second range. There was a base isolated structure in Christchurch. It seems to have performed very well and unfortunately I don't know what its design parameters were but you can see if it just happened to be around the two second range that would have been sort of quite favourable. The displacement demands wouldn't have been all that great but if they'd actually tried to perhaps give it more isolation by giving it longer periods and it happened to be out here somewhere there could be some issues. Again base isolation has quite a lot of damping involved with it so the peak would come down a bit. I'm just mentioning that but certainly doing base isolation we'd need to look carefully at what was the period of your isolation system was, whether this sort of peak is going to occur repeatedly in Christchurch in big earthquakes so that's really just a warning for those, not saying don't use it, just to be aware that base isolation isn't the cure to everything.

1515

A. Sorry, if we could just move to STA001 page 4, I'm just going to take a couple of curves out of our New Zealand Design Standard to, to explain, explain how we arrive at our design levels in terms of the definitions that engineers use and this, this – the top figure there is the, sorry, the bottom figure there is the one I'm interested in and this shows the shape of the spectrum for various classes of soil. We have the, the rock class which is relatively low and you'll see it's only got a short, it only covers a short period range at the peak then we move out to shallow soils which get some amplification but still mainly a quite short period motion. As we go to deep soils which is the plots that you've been seeing up to now you can see the design requires a broader range of structures to be designed in those peak levels and then there's about a 60% difference between those two curves and here and if you get to the very soft soils which these are extremely soft soils they, they're the order of 10 metres of material that would probably liquefy right through the 10 metres so even in Christchurch there will be these soils in Christchurch but you may have liquefied soils in Christchurch that don't meet these criteria so it's a, it's a pretty extreme case but you can see that, that in the long period range that has greater enhanced motions and the, the design level is the product of that if one of these curves depending on your site conditions which are defined in our New Zealand Standard that I won't go into any detail here and if I could now have page 11 of that same document please? That basically gets multiplied by something we call the, the hazard factor Z it's called Z because it used to be a zone factor in an older standard but now it's a continuous thing. For Christchurch that value is about is .22 so that was where those orig- those curves I was showing you originally come from it's one of those spectral shape factors with each soil multiplied by this .22 factor and remember .22 because for the rest of the presentation you'll hear quite a bit about it. The 2500 year spectrum I showed you that's, to get to 2500 year spectrum you multiply by something called the return period factor which is how much you amplify the basic 500 year motion to get to 2500 years and that's a factor of 1.8 and if you, the, the product of RNZ which I think was on an earlier slide but I forgot to mention it is about .4 so the motions that we had in Christchurch in February correspond effectively to a Z factor of about .4 or higher where those peaks came above that top curve in those plots. If we could perhaps now go to the PSHA slide? There's been some question of how, how we derive these values from our analyses and this is, it's not an ideal slide it just happened to be one I – that one of us had with us but I'll try and explain how we do seismic hazard calculations and there's really two parts to it. One is modelling the sources of all, all the earthquakes, how frequent they are, where they happen, what magnitudes and we have two sorts of sources. We have fault sources so in the most recent model we've got something like over 500 fault sources for New Zealand, in the older model which is what 1170 design standard's based on we had about 350 and each of those faults has been assigned a magnitude and a average recurrence interval based largely on, on the geology and so some of those might be like the Alpine fault, the Porters Pass fault that got mentioned, the Springfield fault, Springbank fault, there's quite a number, some, some distance from Christchurch but up until recently we didn't believe there was anything really close. We've also got things like the Pegasus Bay faults that you saw this morning they all come into that category and get treated as sources which are modelled as having a length and they're, they're plane sources that dip into the earth and we can measure how far we are from the closest point on that fault which is what, is a measure that's used for ground motion. The other sort of source is what we call a distributed seismicity source and this is where to the extent that it was represented the February 22nd earthquake would have been modelled it wasn't represented very well but what, what that accounts for is it uses the historical seismicity record over the last 150 years from 1840. For the first 100 years of that we believe we know about our biggest earthquakes those from about magnitude six and a half and up so things like the Wairarapa earthquake in 1855 will be in there, some of the other large earthquakes back in the 19th century earlier 20th century, Hawke's Bay earthquake would be or Napier would be another example. Then more recently once we started getting seismographs we were able to locate rather more earthquakes so we believe from 1940 or thereabouts that, that we've, we know about our, all our earthquakes from magnitude 5 and up so it sort of takes account of all those and then more recently since about the mid 1960s we had a better seismograph network and we were able to record and locate everything down to magnitude 4 and a lot often lot lower but we're pretty certain that we've got all the ones down to magnitude 4. These days we're probably getting around magnitude 3 or thereabouts but we haven't actually adjusted our model as yet. But the way we take account of those earthquakes is we've divided the country into a grid, it's a .1 degree by .1 degree grid which is about 11 kilometres by seven kilometres and it's actually a cube because we've got several layers from zero to 20 kilometres, 20 to 40 and for the places where we get deep earthquakes we go down to 100 kilometres depth and what we've done is we've counted all the earthquake and their magnitudes that occur in each of those cubes and then that gives us the rate of earthquakes and then the magnitudes follow something we call the Gutenberg-Richter relationship basically –

JUSTICE COOPER:

Q. Gutenberg? G-U-T-T-

A. G-U-T-E-N-B-E-R-G and Richter R-I-C-H-T-E-R.

EXAMINATION CONTINUES: MR MILLS

A. And that is shown by stat two here which is for the distributed sources, the rates of earthquake falls off by approximately a factor of 10 for each increase in magnitude. There's a little bit of variation about that and we actually calculate throughout the country what we, the, the parameter that determines that rate is what we call the B-value which is usually about one but it can vary from about .8 to maybe 1.2, 1.3 so we calculate that it does vary a little bit round the country so, so for each grid on this - each node on this grid we've got a rate of earthquakes associated with it and also what is the distribution with magnitude. So between the fault sources and the distributed sources they're all the models that we account, all the earthquakes we account for in our model. The next thing we need to do in are hazard estimation process is to estimate the ground motion that we'd expect for each of those earthquakes so the (inaudible 15:24:27) faults we'd work out at our site of interest, what, what would be what we call the median motion we'd expect from that earthquake given its magnitude and distance and other things like the site conditions and the type of earthquake and various other parameters come into it but it's mainly magnitude and distance and then – so, so we work that out for each of these potential earthquakes and then we go in with, we do calculations for set acceleration levels.

1525

A. It might be .1 g .2 g and we step from very low accelerations up to very high accelerations and this model, as you saw, you saw some of these attenuation curves yesterday which were showing the ground motions as a function of distance and you saw there was a lot of scatter on that so we account for that, that scatter, Terry talked about the 84 percentile level which is one standard deviation. That's typically a factor of about

1.7 either side of that curve. So we take account of that and we can work out what, what is the probability of any one of these particular sources and it's particular magnitude giving a ground motion, if that earthquake occurs the probability of exceeding, say, .2 g and to get the total rate of .2 g we take the frequency of each of the individual earthquakes which either comes, because we assign them to the faults or we've got them off this Gutenberg-Richter relationship for the other sources, we multiply that by the probability of exceeding the motion and add all those up and that gives us the rate of exceeding our particular acceleration level. We go through that all through the country and for a whole range of acceleration levels and that's, from that we derive what the 500 year, the 500 year motion or the 2500 year motion or whatever it is that we're interested in. So –

Q. Step 4 has the heading, "Hazard at Site." You're not describing something which operates on an at-site basis are you?

A. Yes the attenuation curve is using the source to site distance so finally we get, in the final step we can express it in terms of probability of exceeding some ground motion level in some time. So, so a 500 year motion is sort of a probable exceedance of one over 500 in one year so that's, that's what that curve, curve is representing. For each ground motion level, the low ones have got a high probability of being exceeded and the very high accelerations have got a low probability. So that's just summarising.

Q. Well these are the four steps towards an end point aren't they?

A. Yes.

Q. What's the end point?

A. The end point is basically that curve but we can express it in a number of ways. We can, from the series of curves for the different spectral periods we can then give the response spectrum for the 500 year motion but, but the calculation for each spectral period or each structural period is going through this process. You're understanding there or –

COMMISSIONER FENWICK:

Q. When you do this process what are you assuming for the ground conditions. Are you just taking this -

A. If, if we've got –

Q. When you apply the code then you've got these different soil types which amplify those out. So when you do go through this process are you working this out for the base rock and then modifying it for the shape factor or how does that fit in. What are you assuming for the soil conditions at the site you're looking at?

A. If, if we've got a specific site that we're looking at we determine what site condition it fits in and then do the calculations for that, for the appropriate site condition.

Q. And what about for the national seismic hazard model where you don't know what soil conditions you've got?

A. For the national seismic hazard model what we have done is we've calculated for each of the site conditions around the country, we don't calculate the whole spectra at every location but we've taken some representative locations and calculated the spectra which you'd expect at each place which is how we get the code spectral shape factors by taking each of those calculated spectra for say deep soil and put in a curve that in the main comes fairly close to enveloping all the individual shapes when they're normalised by this hazard factor. So, so when we go the other way around we calculate our hazard factor, multiple it by whatever our site classes at our particular location and get the code spectrum from it.

Q. So if I can summarise that. You get the spectra of the soil conditions there and then you divide it back out to get your seismic hazard factor?

A. That's right, yeah.

JUSTICE COOPER:

Q. So the variance in the R and Z factors is based on calculations which are made in respect of the land classified into that grid system that you referred to earlier?

A. That's right. So the Z factor as it happens is the normalising factor for all our spectra. It's actually calculated for shallow soil conditions but we've worked out what the relationships through those spectral shape factors between the different soil conditions so we only have to calculate the Z for one site class and then that normalises the spectra for all the different site classes using those spectral shape factors under the code.
Q. Well site class, is that what the standard NZS1170.5 calls the soil type?
A. Yes.

COMMISSION ADJOURNS: 3.31 PM

COMMISSION RESUMES: 3.54 PM

INTRODUCTIONS

MS FORD:

Our submission alongside reviewing some of the others about seven questions we've actually trimmed them down from the brief that you were sent really concerning the detail and research that's gathered around a likelihood and the severity of a consequences of a quake disaster. I've got three questions in one set to start with. Was GNS consulted about the quality of Tonkin Taylor's report that was compiled after September which we note that information on blind faults advocated that the mm8 shaking experienced in the Darfield quake would be a one in 700 year event.

DR WEBB:

Well I guess Rachel one response to that would be I mean it's my understanding that the T and T report was formally reviewed but I don't believe that GNS Science was involved in the formal review of the T and T work but others here may know who did undertake the review of the T and T report?

PROFESSOR PETTINGA:

I'm not aware of who undertook that review at all no.

MS FORD:

Okay –

JUSTICE COOPER:

So GNS did not review it is that what we're being told?

DR WEBB:

That's right, perhaps I could add that part of that work would have been informed by a report we did probably in early April before we did the Z factor report and that was the reports which calculated, it was actually joint with Misco Cubrinovski from University of Canterbury I think Jarg might a bit involved. Using our model for likelihood of future shaking we worked with Misco looking at soil characteristics and thus calculated likelihood of liquefaction and I would have thought T and T would have been given that information.

DR McVERRY:

I was certainly involved in passing that information to T and T what the expected acceleration levels were, were given site conditions and then they did the liquefaction analysis based on that.

MS FORD:

Would you say it was missing a lot of essential data to be making those sorts of forecasts of a one in 700 year occurrence? Well you don't need to - I was just expanding on that question but if you don't (inaudible 15:59:05)

DR WEBB:

I certainly wouldn't comment because I haven't read in detail the T and T report. Sorry, yeah.

PROFESSOR PETTINGA:

I don't think I can comment in any more detail either, I think we would need to look at that report in some detail to really be able to make a, a sensible response to, to you.

MS FORD:

Okay, next question, do you think that GNS have provided Environment Canterbury with sufficiently detailed information to meet their legal responsibilities to assess and prepare financial hazards by the 16th of February 2010 which is the date that ECan only advised the regional emergency management office meeting that science showed the small and decreasing chance of a significant aftershock at that time?

DR WEBB:
So that's 16th of February 2011 you mean?

MS FORD:
20, yeah 2011. Sorry.

DR WEBB:
Yeah, okay, sorry, I'm sort of detecting picking up perhaps two aspects to that, there'd be one about ECan's responsibility as a regional council in terms of having hazards information say pre September 2011 and then the period perhaps 2000 – September through, through February?

MS FORD:
Yes.

DR WEBB:
Is, is it helpful if we look at each of them? I'd probably pass to Jarg to talk about the pre September work that Canterbury, University of Canterbury and Genius have done for ECan.

DR PETTINGA:
Yeah, so maybe just a little bit of context, going back to the, about 1996, '97 just not long after the Resource Management Act really was starting to become established it was recognised that there were significant responsibilities that regional and local territorial authorities had to take up and we were asked to join in a meeting, so that's GNS Science, University of Canterbury and also one or two of the local engineering consultancies in Christchurch. To assist Environment Canterbury in compiling existing knowledge about earthquake fault lines, earthquake source structures if you like and other relevant earthquake hazard information and that includes for example the National Seismicity data base which GNS maintains. Out of those meetings which I think mainly were run in 1997 it was decided to

establish a multi-year coordinated programme. It wasn't so much designed to generate new research data because the resourcing, financial resourcing for that wouldn't be available but it, it was intended to gather together all the information that was in the various organisation, in particular the University of Canterbury we had probably in excess of 40 research projects which students had undertaken under supervision as well as staff and other academic visitors who had done research projects over the years and GNS Science also held a significant data base which had accumulated over the years and some of that material was published, some of it is not always published because it, it was client related work done for various major infrastructure projects. So the intention of ECan was to resource a programme of research which was divided up into quite sort of substantial chunks of work on an annual basis and progressively through a series of reports that information was gathered and placed with Environment Canterbury. That was – it was, the first step in 1998 I, I led that that was the earthquake fault lines and source structures review. That was followed in 1999 by the historical earthquake, review of the historical earthquakes in Canterbury and we published in 1999 also the first of the probability hazard studies for the Canterbury region. Environment Canterbury then continued to implement various other phases of study including landslides likely to impact on the river system such as the Waimakariri in response to large earthquakes. There was also a phase of work focusing on the liquefaction and that was published in the, I think it was about 2002 or 2003.

1604

As part of the work we were required to resource Environment Canterbury with substantial data so, for example, we included maps with all the known faults categorised according to an activity class which we defined in those reports. Those maps included not only data from the University of Canterbury but also included data from GNS Science as well as other organisations so it was a reasonably comprehensive effort I think and the focus, as you can imagine, for Environment Canterbury was on the Canterbury region so that's its territorial region if you like but we included also information on earthquake sources or source structures which lay outside the Canterbury region but were likely to impact so the most obvious one there would be the Alpine fault. I know that over the last 10 years we've up-dated that database. On two occasions. Environment Canterbury have come back to us and asked us to input new data as its been acquired and to maintain the, if you like, the database up-to-date. They also undertook quite a substantial project of digitising the maps because in 1998 we didn't have the resources to digitise maps so that was planned for and undertaken in more recent times and the other thing we've done over the last few years is twice reviewed the probability hazard analysis for the Canterbury region so the most recently published version of that was done in 2007, 2008. I say that in each case the work that we did jointly with GNS Science was presented as reports to Environment Canterbury which have been made available, not only to them but also were circulated to each of the local territorial authorities in the Canterbury region and we always followed up those projects by formally publishing the results in peer review journals so it was an opportunity for us to demonstrate that the work actually could pass through the International Peer Review process as well. What else can I add there. That's probably a sort of an overview of the programme that we've undertaken. I think it's been reviewed on a regular basis and we've maintained our involvement. Maybe the other comment I should make is that one other significant development in the last probably five to six years is that GNS Science have developed a national database of active faults and the database that was held by Environment Canterbury and was compiled by the University and GNS team over the last 15, 16 years or so has been captured in that national database as well and that's available through the GNS website.

DR WEBB:
I'll talk a little bit about post September.

MS FORD:
Yes.

DR WEBB:

And so the person most involved was Kelvin Berryman who can't be here today but I talked to Kelvin yesterday and so he spent quite a lot of time in the Emergency Operation Centre post September and regularly briefed the group controllers on likelihoods and size of aftershocks so mentioned that you could have an aftershock of magnitude 6 and I'm not so sure about the likelihoods when we were citing them accurately but certainly after a few weeks I think we were calculating probabilities of aftershocks.

MS FORD:
The reason I ask that question is that the information we got that you'd just been giving vague advice which is what I just quoted in the question. That came through an Official Information Act request and comparing that to overseas they have much more detailed advice and I just wondered whether that was, you know, acceptable really.

DR WEBB:
Right, so we do have in the evidence somewhere advice provided to Orion from memory early October with precise probabilities of aftershocks.

MS FORD:
Okay. They didn't produce that. We asked for that but they didn't produce that with the Official Information Act request so that's why we asked that question. Would GNS assertion that directivity caused the strong shaking have less serious implications for rebuilding than the view that's been advocated by the peer reviewer that directivity wasn't so significant and other factors like basin effects were more so in causing the high amount of damage in the city.

DR MCVERRY:
That is an issue that is still under discussion with the peer reviewers. Two peer reviewers have got slightly differing opinions on that – one was of the view that stress drop was perhaps more important – the other one directivity and also more recently that it might be based on the site effects but a

presentation made this morning by Terry Webb sort of showed that the site effects weren't as clear cut as it was thought in that conversation. In fact they were treating different sites as the same site so I think that's something that is going to probably be discussed in the panel tomorrow with one of our peer reviewers by video tomorrow and then the panel quite likely but I think, yeah, there are differing opinions on what was the more important factor.

MS FORD:

Would there be implications for rebuilding depending on the waiting?

DR WEBB:

There will be different implications for how one would incorporate these effects into the seismic hazard model. The problem with directivity if you know there's an existing fault even the existing national model for 11 faults has a directivity effect built in but you'd need to build in a slightly different effect for these smaller faults. That can be done but you do need the knowledge of where the faults are and then I guess you make an assumption that half the time you might be hit by bad directivity for example. So you can factor in directivity in that way and in the same way if necessary once we've had time to model and better understand basin effects that too I guess can be incorporated. I'll let Graeme comment on how one would incorporate a basin effect in the model. All these things have to be looked at.

DR MCVERRY

Yes certainly once we do our modelling and compare it with data if we find that there is a consistent enhancement in a particular period range we would be promoting a factor to account for that. It would be quite a new thing for New Zealand Constructional Design Code so there would be quite a bit of discussion. Certainly GNS would incorporate that sort of thing in any specific site analyses we did from then on but I say it's quite a leap from what we've had in the past to go in a National Level Code.

MS FORD:

Thank you. I do just need to give some context for our last four questions. So Dr Archuleta's peer review has stated that quakes maybe precursors to something larger as it's possible that a fault lies within five kilometres of the CBD but GNS told the Commission it's not practical cost wise to identify all blind faults in a region and mapping resources should be targeted. GNS further advised the Commission that before the recent earthquakes few quakes on the Plains were local and local damage was mostly from large quakes from distant faults and asserted the earthquakes generated by the Alpine fault or other major ones in North Canterbury remain the most likely source of trouble once the current aftershocks subside and given the theorised long return period that the long-term hazard for Christchurch won't much alter but our geologists who trained at Canterbury questioned some of the assumptions noting that the spire came off the Cathedral roughly four times in 120 years and says this was likely wrongly assumed to relate to activity of the relative distant Alpine fault and he questions the assumption that distant faults are the biggest risk when the local blind fault system is not even modelled and he can't say if later shakes were aftershocks or were new quakes on different faults so in that context we are framing our remaining questions based on that understanding that we have. You might like to correct some of that if you don't agree or if you dispute some of that but the first question, how confident is GNS that the return period for severe shaking is several thousand years or a minimum of 1200 as Dr Pettinga has suggested today and that the main risk is the Alpine or North Canterbury faults and do you consider that a research programme to study local blind fault systems could completely change that assessment even to the point that the return period could be as little as 150 years, worst scenario?

1614

PROFESSOR PETTINGA:

Maybe if I could start Rachel with some comments because you've raised quite a number of issues so I'll try and work through them but interrupt me if I don't pick up on anything. First of all, just getting back to what I said earlier today. What we were looking at there was the sort of overall budget of plate movements across the South Island and so we have approximately 5% of that plate movement being accommodated if you like on the, on the outer edge on the eastern block of the South Island and given that we've had a particular earthquake, the Greendale/Port Hills system that's ruptured over the last 12 months that particular event, we would need to have an earthquake of that sort of order of, of slip every, what did I say, 1500 years plus or minus 250 years approximately to take care of that plate motion budget. How in that eastern block we've identified as you'll be aware several structures in the North Canterbury plains area which are capable of accommodating that but, of course, it can be accommodated further south where we don't really recognise any faults because they're still, in a sense, hidden beneath the plains. But it is worth noting though that we've got at least some idea of what the sort of long-term budget of slip is that we have to provide for in our hazard modelling for that eastern part of the island so even if we don't know where the earthquake fault lines are we know that within that region we have to expect earthquakes with that sort of return time and, and of the order of, of Greendale at least. The question about trying to determine or detect hidden faults, maybe I could start off with a comment there. We are tackling this. I mean it's a notoriously difficult task as, as you can imagine because unless there's some surface evidence of these faults we really would have to go through a very long-term systematic survey to start developing a more comprehensive sub-surface image if you like of all the faults that are present and there are a lot of them present from the inherited tectonic fabric going back over tens of millions of years. I think that we have made some progress. We've been targeting some of the structures across the North Canterbury plains and I showed a little bit of information I think earlier today in relation to the Springbank fault and to the Ashley fault and we're aware of structures further south as well. The issue of the equipment we need in order to be able to run these surveys has obviously come up today in discussions at the hearing and I think that that's going to probably continue to be something we'll work in discussions. So I think there is a plan there in terms of continuing to focus on those, those hidden structures if you like. There are some real challenges when we get to beneath the metropolitan area just because of the difficulty of surveying in this sort of environment, the limitations that are placed on us around the sort of energy sources we can use beneath, or within a built-up area, and dealing with that sort of cultural noise, city noise if you like that exists. Maybe I should pass over there to Terry to continue.

DR WEBB:

Yeah I'd sort of like to comment Rachel on the fact we do work in what we call a risk management framework so we look at where risk, in terms of earthquake risk we look at where that risk to people is coming from and that involves right through from the earthquake sources or fault sources right through to buildings and of course we're not, we don't want to touch on buildings today in terms of the various risks different quality buildings pose to us but if we go back to the fault sources or the earthquake sources the risk really comes from faults certainly near to cities, shallow faults near to cities but they do need an appreciable risk, sorry, slip rate to pose much risk. So if you, Jarg showed the off-sets of the volcancis which are, you know, five plus million years old, off-set of 50 metres in that time, that's a slip rate if my arithmetic's right of about 100th of a millimetre per year whereas the Alpine fault is accumulating stressors at a rate, what, 15 or 20 millimetres per year. So you can see the enormous difference between these faults in the Alps, or the foothills, the foothills faults that are then a bit more seriously close to Christchurch and in fact on the de-aggregation plot I showed there was the Porters Pass fault was in fact posing the most hazard, hazard to Christchurch before all this activity started. So given that there are always limited resources if we wanted to do more stuff with land seismic there would be some very good candidate areas to go but that, and, and Christchurch could well be part of that due to the public concern. So in this kind of approach public reassurance is very important, reassurance of insurers is also important but beyond that in the longer term you'd pick some other target areas where you've got relatively young soils that might be covering faults that have got higher activity rates but you also might want to do better investigations of faults we know about and getting better parameterisation of their earlier history.

JUSTICE COOPER:

What was that word sorry?

DR WEBB:

Well getting more information about their earlier, earlier history of earthquakes because it's information like that that will feed directly into the hazard model and affect and influence building design.

MS FORD:

That sort of leads into the next question. I think you're talking about the studies that are being done and I wasn't clear whether that was city wide or whether it was just trying to look at anything that might affect the CBD but the Royal Commission interim report recommended that the National Seismic Hazards Model should account for hidden faults near cities and GNS say that they support GPS studies as a way to work out where they should be doing those studies. To what extent is GNS advocating that the GPS studies and fault mapping should be done – is this just in main population centres, around infrastructure and what budget would be required for a long-term research programme such as California has, allowing Christchurch to receive perhaps similar attention to the kind of studies that Wellington has received in this area?

DR WEBB:

One thing, one you can do, I mean Jarg sort of mentioned the plate tectonic motion accumulating and understanding what he calls the, the budget you have for how you distribute that motion and what you can do is make transects so for large dam safety evaluations on the Waitaki River, for example, in the past we've sometimes done a transect so we know from the West Coast to the East Coast how much motion per year there is, we've got information on a number of faults and we know their slip rates. You can put them all into the transect and see whether the numbers add up and usually when you do that you find you're missing some plate motion and you have to make some guesses or do some other, do some more work to figure out where that missing motion is being accumulated and what, what fault structures or buried earthquake sources are likely to release that motion eventually. So that would be an approach and part of our thinking behind saying, well in certain areas where it's justified by risk which comes back to population centres or if you're worried about economic risk, major infrastructural assets perhaps, you look at it in terms of risk what's the GPS telling you in terms of plate budget, if you're missing some motion you might want to worry about that if it's significant and try and do more work to pin down why the motion's missing and figuring how it could be released in dangerous earthquakes.

MS FORD:
Is that how they worked out where to do the California studies do you know or not?

DR WEBB:
Sorry I missed that.
1624

MS FORD:
Was it through, through that sort of modelling that they worked out where to target the California studies or on blind faults or not or?

DR WEBB:
No. I think those studies I would, sort of guessing I'm sorry, I expect those studies preceded very good GPS information. GPS information's got better over decades. Firstly because we've got a much longer time span of observation so it's more accurate but also the accuracy and analysis of the data has improved as we've gone along. Can you comment on the California approach?

PROFESSOR PETTINGA:

Yeah I'm not entirely familiar in detail with the California work but I think that they have been acquiring and making use of GPS data because they've just had a greater network of GPS recorders to be able to, yeah, GPS recorded points to be able to analyse. The other thing is California is probably seismically got areas which have been much more active than New Zealand has. I mean we've, we've moved into a period of activity at the moment in Canterbury but if you take southern California they've been having larger earthquakes over the last two decades much more routinely and so these ongoing GPS campaigns in California have probably had a much better opportunity to inform the earthquake cycles that they're experiencing there as well. The GPS work in New Zealand probably started in the early 90s and has picked up significantly in the last 10 years as part of the overall development of the GeoNet resources if you like the, the recording network we have and so we have much more in the way of GPS data available. The, the best information still comes from the campaigns that were run, the transects that Terry mentioned, across the island. I think there were three across the South Island over the previous let's say 15 years or so but now we have stations which have got permanent GPS recorders and remembering GPS data is real time, contemporary information. So that has to be looked at both in the context of earthquake activity, seismicity data if you like as well as fault specific studies and so when you bring those together then you can start to look for anomalies both in the short-term and the long-term and that might provide much better insights as to how the fault system is really operating. Again, I think because we've had relatively few large earthquakes over the last let's say seven/eight decades in the South Island it sort of does limit what you can squeeze out of those data sets but I think increasingly we're moving into an era now of much higher quality data. Does that help to put some context around that for you?

MS FORD:

It does but I'm not sure if it's answering the question which really, yeah, there's been a period of a few decades of quiet but before that our geologists were saying well it wasn't quiet before that so we've been a bit complacent about risk in Canterbury. So I'm really saying, you know, what would be the ideal world for GNS. If the Government was to fund a national research programme where would they put the studies. What areas would they put the studies and how much would be required to, in an ideal world, to assess the risk for Christchurch of blind faults and active blind faults, yeah?

DR WEBB:

Well if you looked nationally and it's a bit awkward with Christchurch because you've got current activity which creates issues of its own. So in that sense, as I alluded to earlier, it's a bit of a special case but if you look nationally, if you set that to one side and look nationally you may look at areas as I mentioned before of young soils that are potentially covering reasonably active structures and you'd look in the higher seismic regions of New Zealand so those higher seismic regions where you've got cities you'd look, just set aside the recent soils, but if you look at the cities you're talking of the likes of Whakatane, Rotorua, Taupo in volcanic zones, step across to Gisborne, Napier, Hastings down through Palmerston North, Wellington, Marlborough, Nelson and probably down through Queenstown I guess in terms of major populations so it's that kind of band through the country that probably presents the highest seismic risk and areas where blind faults are probably reasonably poorly known. Jarg might help but Kelvin mentioned immediately, say, potentially Palmerston North, Hawkes Bay region could be two obvious regions. So that would be the sort of national priority and as I mentioned earlier we shouldn't forget that what will also improve our models is more information on faults we can see on the ground. Firstly, accurate mapping which should be responsibility of local government so that our own active fault, building near active fault guidelines can be better used and implemented to stop – so that you've got setback zones well defined, as the same as you mentioned in your submission for California. Christchurch itself I'd probably let Jarg answer that in terms of where he'd take the crux on investigations further.

PROFESSOR PETTINGA:

We did talk a little bit about this earlier on today in the, in the sessions as well but obviously over the last two decades we were really addressing what was a significant knowledge gap if you like in terms of many active faults in the Canterbury region for which we hold, we held very little information and so the research that's been done has really focussed on filling that in and again we've actually focussed on those faults with surface expression where we could quite quickly and effectively gather information about the return times of large earthquakes which have a surface expression and fault lines which have a relatively regular earthquake cycle on them. So especially the fault lines with hundreds of years between large earthquakes because those are most likely to be the events that we're going to be confronted with. Part of our discussion earlier today was so what would happen after the, this earthquake sequence we've just had, are there some priority areas. Maybe, maybe the focus of the research programme is changing and I think that's a fair comment and I think that will happen and it is happening. It will always –

MS FORD:

You mean moving –

PROFESSOR PETTINGA:

Sorry, go ahead.

MS FORD:

Were you meaning away from liquefaction to more public safety type research or –

PROFESSOR PETTINGA:

Well I'm thinking particularly about the fault, fault line studies and identifying –

MS FORD:

Yeah.

PROFESSOR PETTINGA:

The earthquake faults, faults that are likely to generate future moderate to large earthquakes and in and around population centres in Canterbury obviously is where our focus is and there will continue to be over the next period of research activity a strategic focus on that and we've identified some faults around Christchurch now that we need to do more work on and we'll continue to do that. But we mustn't forget that when a fault is buried in the sub-surface it's actually quite hard to extract. If it has no surface expression it's quite hard to extract understanding of the return time between large earthquakes events because it's very hard for us to get that record of the timing of earthquake ruptures. So we recognise the faults there and we recognise in the sub-surface that the strata have been displaced but we only see that displacement extending to maybe 100 or 200 or 300 metres beneath the surface and so to then extract from that the sort of information we need to update our national hazard model becomes quite complicated and we do fall back on this plate motion budget that we were talking about earlier as a way of providing some constraints around the return times on these fault lines. It's quite challenging and it's a project that will obviously have an extended time period into the future in which we'll be trying to fill the knowledge gaps but it's, it's not one that we can fill very quickly in that sense partly because of the lack of, if nothing else just the personnel resources to throw at it, if you can imagine.

MS FORD:

I think they've got about 60 scientists working on the Alpine fault at many millions of dollars so, and they've got a lot of scientists at GNS working on finding resources in oil and gas and things so a bit on public safety wouldn't go astray. The last question. Many submitters expressed surprise at the proposed Z factor of 0.3 and given that shaking exceeded 25 hundred year design levels on three occasions do you think suggestions to modify this Z factor or to change the distance to 10 kilometres are wise and that such matters as well as the geological research need more resolution before any major building consents are contemplated in the CBD?

1643

DR McVERRY:

Perhaps I can answer the first part of and I'll turn to Terry for the later part. The Z factor is something we are still working on. Our current estimates are .34 to .41 so I realise that that higher figure is only just sort of getting up round the motions you experienced in Christchurch in February. Certainly things could change with information on blind thrusts if we knew their recurrence intervals and they were very close to Christchurch, at the moment the information on the recurrence intervals is, is missing. Plus I think there may have been – I'll get Terry to answer and then I think there may have been some point I missed which you can come back.

DR WEBB:

Well can you, what would you like answered next Rachel?

DR McVERRY:

On the same, yeah we've answered part of that question, can you just refresh we've had about four bits so…?

MS FORD:

What's the, what's the important information you need to get any certainty about things like the Z factor, the blind faults, the recurrence periods, things like that how, how much information do you need from those studies before you can really be confident about issuing building consents and knowing that you're giving the right factor for issuing building consents for major construction in the CBD, is this something that can realistically be done soon or do we need to wait for a few years before building a cathedral again or what have you?

DR WEBB:

Right so when I talked earlier today I talked about the models we're using to monitor aftershock decay and so aftershocks pose a significant elevation if you like to the risk levels for another year or more and then that model I called the EEPAS model which is probably to do with triggering of other large earthquakes perhaps at greater distances that starts to dominate. Both of those models together means that here in Christchurch we've got to live with higher level of hazard for some time. Those, that elevation in the level if you like is so great that more information on low slip rate faults won't have any impact at all so where the – because when you put it in the kinds of models Graeme talks about the recurrence intervals are going to be so long that all these other things that are currently happening in terms of aftershocks and low probability of larger events they are going to dominate the model. Now where the active fault work can help firstly is public reassurance and we've already seen that as Jarg mentioned in his summary slide no major through going fault detected under Christchurch as an extension of Greendale. That's very reassuring I would like to think. It is for me. Should be for people living in Christchurch. That's the first thing. But the – well there's probably two other aspects to this. When I mention the challenges we're facing with this EEPAS model and saying that it's too centred on Christchurch is one line of argument and we'd like to space the triggers earthquakes out further away and that will lower the current hazard that buildings likely have to, to cope with knowledge of the fault structures and how these next earthquakes are going to occur will help inform those decisions that's where that information becomes quite helpful. So just to summarise it helps us given our statistical models it helps us with the interpretation and modifying of them to be more realistic but actually information on those faults won't contribute to the level of hazard.

DR McVERRY:

I would just like to add to that because I saw Rachel's reaction which I can quite understand to the comment that even if we knew about the, these blind faults they're not going to contribute much to the hazard and in purely risk terms that, that is correct. What occasionally we, we do in seismic design is what we call deterministic analysis which we consider what motions we'd get if a particular type of earthquake occurred and we perhaps do some assessment of, of that versus the what we get out of a purely probabilistic point of view and that's where some of these ideas that have been discussed about floating earthquakes and the like and it could be that, that there's some determination on how we treat those where they're, they're, they're very low probability of having an event on them but if we do have an event on them they're likely to give very strong motions and potentially catastrophic effects and that is where perhaps the risk based approach can pull that down at times and so, so that is sort of I think one of the issues that will probably be talked through over the next few, few months but certainly if we just consider in terms of its probability of happening it, it will have little effect if it's, even if it's as short as 1500 year occurrence or if it's 10,000 years even less so. I'm sorry that's not reassuring but it is an issue that I think a number of us are grappling with.

MS FORD:

No the reason I was slightly surprised is because having researched our submission and things I found that some places have either building 3 zones or very tight building restrictions close, within – I can't remember the distance but within a certain distance of nine active faults and so I guess that sort of raised the question of, of are we rushing forward too fast with rebuilding without having enough information but I guess what you've just said has sort of put that in perspective and also the other, my co-submitter has said, he's a geologist, has also said that you can't say that straight above a fault is where you're going to get the damage it can be moved over from that and things like that as well so, I think we've pretty much covered everything.

DR WEBB:

That, can I just comment on that Rachel in terms of I mean I referred before to our guidelines for building near active faults so they're about for a known fault if the slip rate and hence the, the hazard is likely to be high enough there are setback zones. I think the zones vary according to how well determined the trace of the fault is. Sometimes it's poorly determined and the zone, setback zone has to be bigger but also it depends what you're going to build over the fault so if you're going to build over, a hospital over a fault I'm not sure you can for any fault actually or maybe the slip rate has to be incredibly low or it has to be classified as inactive, if you want to build a garden shed you can put that over any fault and that's a continuum so that's how our guidelines work and this is to avoid buildings basically being torn apart by fault movement, it's not to do with the shaking hazard so much because as, as you yourself pointed out the shaking can be directed a bit to one side or happen in the hanging wall of the fault so you can get some pretty intense shaking even if you've got a setback zone.

MS FORD:
There was one thing that wasn't answered I don't think about the blind fault studies that are happening, have they just been concentrated on looking at risk in the CBD or are you going to be doing blind, looking for any faults, active faults that go through the north, north of the city or the west of the city or those suburbs because I guess they're residential so they don't matter so much but if they're not having any major buildings and you know shopping malls and things but is that worth doing those sorts of studies if you're going to have a Westfield, a new Westfield put in some area where you don't know the risk and is that likely to happen in Christchurch that it, you said there's difficulties I heard you say there's difficulties with doing those sorts of studies because of the urban area but is it something that's going to be seriously looked at doing or, or not?

PROFESSOR PETTINGA:
I think that's, that's definitely the case, we, we are looking at trying to get more information on these structures now but maybe divide this up into two parts. The first thing is we're actually targeting a number of faults that we're now aware of in the subsurface and we're still continuing to gather information on those. I presented information on that in the submission today and the data we have on those you know we've located them. The key thing is that the structures we were targeting have been showing aftershock activity associated with them so that's why we went in there to try and understand

more about what was located in the subsurface and in each case the aftershocks I think we can now quite clearly associate with the presence of a fault which we weren't aware of previously.

1644

Secondly, we're not just focusing on the CBD. We are looking in a much more holistic way at the greater Christchurch and surrounding area for all those reasons but there are constraints in terms of what we can do in areas like say you mention Northern Christchurch. The equipment that we have at the University of Canterbury is not really suitable for the sorts of investigations that we are able to undertake with the equipment that came from Canada and so part of the discussion today that we've had with the Commissioners is what if a resource like that were to be available, is it an area that one might be able to gather further data in and what would be the value of that? So if the questions are relevant then it is a thing we can do. It's not easy to survey in a built up environment I have to say. It's very difficult to run this equipment with a lot of properties and people around partly because of the background noises that interfere with the quality of the signal and partly because there has been and there continues to be quite a heightened sensitivity in terms of putting vibrations in the ground and people sensing that in their houses and so on but it is a technique that is available and obviously we will be continuing to look at, you know, targeted survey areas. One of the areas we discussed today with the Commission would be some of the fault lines we've identified in the seismic surveys offshore from Christchurch and North Canterbury Plains – Kaiapoi, Woodend and up in that area. I think there is an opportunity for future studies to look at how those faults extend through underneath land. We can see them in the offshore area. It would be quite surprising if they all just happened to stop at the coastline and it's much more likely that they will continue in some form in a network of faults beneath the Plains and so there are some challenges there. Faults that show signs of activity offshore I think would be ones that we might want to learn more about if they are relatively close to Christchurch City so those questions that you've raised are definitely on the table and they are things that we will be looking at. We can't provide instant answers but we can provide a degree of urgency around future research priorities I guess.

MS FORD:
That's good because Dr Bollard said in a paper today that we shouldn't panic over a one-off event and it hasn't really been a one-off event has it so, yeah, I think, yeah, that's pretty much covered it for us unless anyone else wants to add to that.

JUSTICE COOPER:
Mrs Ford thank you very much for your questions which have actually shed fresh light on matters that we have already been discussing today so I thank you for that and the manner in which you've asked your questions. So thank you very much.

MS FORD:
Thank you for the opportunity.

JUSTICE COOPER ADDRESSES COUNSEL – TIME-TABLING

COMMISSION ADJOURNS: 4:50 PM