Canterbury Earthquakes Royal Commission

Te Komihana Rūwhenua a te Karauna

UNDER	**THE COMMISSIONS OF INQUIRY ACT 1908**
IN THE MATTER OF	**CANTERBURY EARTHQUAKES ROYAL COMMISSION**

Before: The Honourable Justice M Cooper
Judge of the High Court of New Zealand

Sir Ron Carter
Commissioner

Associate Professor Richard Fenwick
Commissioner

Appearances: S Mills QC, M Zarifeh and M Elliott as Counsel Assisting

U Jagose for the Department of Building and Housing

N Hampton QC for Mr Alec Cvetanov

TRANSCRIPT OF CANTERBURY EARTHQUAKES SEQUENCE AND IMPLICATIONS FOR SEISMIC DESIGN LEVELS HEARING HELD ON 17 OCTOBER 2011 AT CHRISTCHURCH

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MR MILLS:
So if there's no questions about any of that I will call Dr Webb.

MR HAMPTON:
I'm sorry sir.

JUSTICE COOPER:
That's all right. You're with Mr -

MR HAMPTON:
With Mr Taylor.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Appearing for Mr Alec Cvetanov.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Whose wife has been mentioned in the list of casualties.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Dr Tamara Cvetanova.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Who died on the 23rd of February 2011 and I deliberately note that as being the date.

JUSTICE COOPER:
Yes.

MR HAMPTON:
I came, having, there having been lodged an expression of interest –

JUSTICE COOPER:
Yes.

MR HAMPTON:
On behalf of and came as a courtesy of the commencement of the first public hearing.

JUSTICE COOPER
Well thank you.

MR HAMPTON:
I thought that appropriate to do so sir.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Not having been told otherwise.

JUSTICE COOPER:
Yes.

MR HAMPTON:
But note our appearance.

JUSTICE COOPER:
Yes.

MR HAMPTON:
Note that in due course, and I understand it may be at some time appropriate when we get nearer the CTV building that there will be raised on behalf of Mr Cvetanov and of his two infant children an issue that relates to the death of Dr Cvetanova on the 23rd of February, she having survived the initial failure and collapse of the CTV building so that there are issues there that in due course we will want to raise and following from that for the future some aspects about collapse survival zones, access to such zones and escape tunnels and procedures for evacuation of failed buildings and I won't go into the argument now if the Commission pleases but it might well be seen as falling with certain of the terms of reference in the inquiry and of certainly I suggest within recommendation C. So I just flag that because I thought it appropriate to do so sir and would leave it at that at this stage.

JUSTICE COOPER:
Yes Mr Hampton I'm grateful to you. I did not call on you earlier, perhaps lulled into a false sense of security by Mr Mills's observations that he didn't think there were any more appearances and when I looked your way. I think it will be appropriate to deal with those issues which you have foreshadowed in the context of the hearing on the CTV building because that is the context of those points I think and I know you're aware of the issues that there are about the prohibititions and the terms of references.

MR HAMPTON:
Yes I am, I am indeed.

JUSTICE COOPER:

Which prevent us reaching the rescue effort, so you'll doubtless come prepared with argument on that.

MR HAMPTON:

In due course thank you sir.

JUSTICE COOPER:

And perhaps can I invite you just to confer with Mr Mills or Mr Zarifeh or indeed Mr Elliott about the arguments that you will wish to raise because there is no, we must adhere strictly to our terms of reference but apart from making that point there's nobody who would want to prevent you saying what you wanted to say for any other reason other than what the terms of reference provide so, we'll look forward to hearing from you in due course and thank you for coming this afternoon.

MR HAMPTON:

As the Commission pleases.

MR MILLS CALLS

TERRY WEBB (AFFIRMED)

Q. Now as I understand it Dr Webb you're proposing, as are the other GNS witnesses, to not go through your written report but rather to speak to it or at least some of the issues that arise by reference to power point or some kind of projection.
A. That's right, yes.
Q. And as I understand it all of the GNS witnesses are welcoming questions as they go if the Commission or counsel feel so inclined. So I'll just leave you then to –

JUSTICE COOPER ADDRESSES MR MILLS:

Can I just say if that's going to proceed in that way we have transcribers who are making a note of everything that is said and they are off-site and this is the transcription service that is used in the Courts and in a Court hearing evidence proceeds in a more predictable way in the sense that there is one person asking the questions and one person answering as a rule so I'm sure the transcribers will get used to our voices but if there are a number of witnesses as I think you've foreshadowed who might be giving evidence at the same time in such a process as the discussion that you referred to I think people are going to have to announce who they are before they start talking just for the benefit of the people off-site so that they can note who was talking at the time and if from time to time I interrupt to make it clear who it is who's talking that's why I'm doing it because the people in the room, the transcribers aren't in the room so they can't see who's talking, all right.

MR MILLS:

Yes, thank you sir.

EXAMINATION CONTINUES: MR MILLS

Q. Yes thank you sir.
A. Good afternoon everyone, could I have the first slide please?

JUSTICE COOPER ADDRESSES DR WEBB – AUDIBILITY

WITNESS REFERS TO POWER POINT PRESENTATION

EXAMINATION CONTINUES: MR MILLS

A. So the first slide would be 10A.2. Great. Thanks. Mr Mills has been through these first points here which outline what we're going to cover over the next several days so I'll jump in at the first bullet point there. I really want to make the point that in terms of what we've been through in terms of the opening ceremony and the reading of the names of the deceased, quite a moving event, after that this may seem rather clinical but we need to know about earthquake ground shaking in order to better understand firstly what's happened during these earthquakes but also why there was such an impact on the buildings in Christchurch. So, yes, what we're talking about as mentioned in the summary really is the shaking produced by the earthquakes and why that happened. The other thing to bear in mind is that this is what we would call work in progress which is, to be frank, not how we're used to working in science. Typically the loading standard which informs the design of our buildings is updated about once a decade so every 10 years or so it would be updated and when that update happens the learning and the science, the progress that science has made over the previous decade is fed into the upgrade of the standard. Here we're having to (inaudible 15:20:53) information to upgrade or make changes to the standard on a timeframe of months and so what we've agreed to do basically is provide the best information we can at any given time and that information will change as the underpinning science gets carried out and that could take a number of years but at least at every stage we're trying to get through to the people who design buildings and set standards the best information available and so people have to realise we're working in that context. So one could well ask, "Well how credible is your information given that it's going to change." Well firstly I guess the obvious thing to say around that, about that, is it's better than no information. Secondly, as we go along this work is being published in international peer review journals. So there are already a lot of journal articles published but you'll see over the next few days there are still a lot of things we don't fully understand and it'll be on a significant time scale to resolve those issues and finally, as mentioned by counsel, the report has been peer reviewed by leading international experts and on Wednesday there'll be some discussion about those review comments. Next slide please. I wanted to start the technical bit today really with a bit of a refresher on earthquake magnitude because it often confuses people but before we even start on this slide I should get across the point that generally earthquakes occur on faults. So a fault is essentially a flat plain in the earth that has probably ruptured before. It's a weakness through the rocks due to plate tectonic motion of maybe this much per year, accumulation of strain, strains build up across the various fault lines in the crust and eventually the strains exceed the strength of the fault and it ruptures and so it starts to slip one side compared to the other and that slip spreads out across the plain of the fault, roughly a rectangular shape and as that ruptures, as the fault slips and the rupture spreads across the plain seismic waves are radiated in all directions and that's an earthquake. A simple measure of the size of the earthquake really is the size of that fault plain multiplied by the amount of slip which we can actually use to calculate with the right sophisticated computer processing, what we call mw or the moment magnitude. But of course in the days of Richter in California, probably around the 1930s, they didn't have computers so how did they calculate magnitude. Richter developed a very simple Richter magnitude which really took the amplitude of the pen trace on the seismograph, on the roll of, rotating roll drum of paper, the pen recorded a trace, you could measure the amplitude, you took account of how far away the earthquake was and you could simply calculate local magnitude. Now advantages of that, it's easy to calculate, you can do it really quickly so it's very good for public information but it's not terribly accurate and once earthquakes are larger than about magnitude 7, Richter magnitude or local magnitude as we call it tends to saturate, won't get any bigger so you'll grossly under-estimate really large earthquake. Moment magnitude, slower to calculate, much more accurate, doesn't saturate. So that's the more modern magnitude to use but often GeoNet will do the first one, later we'll come along and do the second one and people see different magnitude values being quoted and they tend to move around a bit. Interestingly though for the Canterbury earthquakes and quite commonly in New Zealand the local Richter magnitude is an over-estimate not an under-estimate providing the earthquake's less than magnitude 7. Just to make it more confusing we often talk also and if you log into GeoNet and record what you felt in an earthquake the questionnaire will come up with a Modified Mercalli Intensity. That's how much the ground shook where you were. So it's a measure of shaking but it's a not a direct measure of the size of the earthquake. Remember the size of the earthquake, think in terms of the area of fault that ruptured and how much it slipped. MM intensity, measure of shakings, so your normal little felt earthquake that you just felt, mm4, onset of building damage probably around mm8.

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So intensity, the measure of shaking, moment magnitude, a robust measure of the size of the earthquake related to these geological parameters, Richter magnitude, a bit rough and ready, quick to calculate and maybe in this case overestimates magnitudes. Next slide please. Right, so, here's a picture then of the fault that ruptured in what we call the Darfield earthquake, so it was the moment magnitude 7.1 on September the 4th and just need to, some of us have a bit of a struggle orientating ourselves because this is an unusual viewing angle but it shows the fault most clearly, Christchurch is off here to the left and locals will know the Waimak and Rakaia rivers there, and Lake Ellesmere out there, so we called it the Greendale fault and the colours here really map how much slip occurred on the faults surface and different parts of the fault. Now earlier I said a simple rectangular fault under the earth, strain builds up and it slips. You can see here we have lots of rectangles, this is even a simplified model and we have about six different segments, so the pattern of rupture there was very complex. This makes it harder for us to understand the ground motions produced and the consequent stresses off the end of the fault that might affect the pattern of aftershocks around the vicinity, so here we're up to five metres of slip, mapped at depth in about the middle of the fault, and then the graying down to about two metres of slip on various sub-faults. The earthquake started here on the sub-fault, ruptured across and then down this way in the direction of the arrows, in the direction of Christchurch.

JUSTICE COOPER:

Q. Just say where they started please, where the ruptures started?

A. It's sort of on this little north extension of the fault here where this arrow is.

Q. Yes, now all that will be useless in a record, in a typed record, so what you're indicating is the arrow just to the left of the word Sheffield.

A. Yes. That's right.

Q. Right. It's just again something to be aware of, I suppose in this case there's no harm done because you've got the legend saying the earthquake started on this fault, but –

EXAMINATION CONTINUES: MR MILLS

A. I'm sure there'll be other examples so that you may have to remind me. Yes, so that's the pattern of ruptures, so the point I was leading up to here though when, sometimes when we sight the depth of an earthquake, there's been quite a bit of confusion about the depth. These little sub-faults, or we've divided the fault up into one kilometre squares to model the slip on each of those squares and if you count down here, this earthquake would look roughly five or six kilometres deep, but that's where it started, what really matters in terms of the damage and shaking it produces is at what depth was most of the slip happening, and here you can see it was happening about three to five, or maybe a little more, 0 to five, 0 to six kilometres depth, because obviously being the Greendale fault the slip actually reached the surface, but don't think of it in terms of a six kilometre deep earthquake and then because of that more benign, it ruptured this whole thickness of crust and so it was a rupture between about five or six kilometres depth all the way to the surface, so a shallow crustal earthquake. This becomes very important for February the 22nd, also very shallow so both were very shallow earthquakes. Right, we'll try the next slide. Oh, this is just to show and perhaps Jarg will cover a bit more of this from the geological side, I don't really talk much about the surface faulting, I'm a Seismologist by training, I'm more interested in that map of fault slip at depth and the radiated seismic waves that produced. There's very interesting features in this though that Jarg will talk about later, so about 30 kilometres long in terms of the surface trace and reassuringly for seismologists, if we just go back a slide this maps reasonably well with our calculated slip from, in this case, precise GPS measurements of how the surrounding earth moved at a distance from the fault, so using that data and satellite data, satellite radar data, that's the kind of information you use to determine that date. Quite a complex problem, people are still working on it, yes, so next slide and the one after that. So let's look at the pattern of shaking, we've focused in on the city here and we measure shaking in terms of 1g or one times the acceleration of the earth's gravity. Now often people struggle a bit with this concept, so what might be helpful is to think in terms of g-force which you may be a bit more familiar with, so g-force is something that you would experience extreme g-force if you were in a Saturn V rocket being launched to the moon or in a jet fighter or a racing car driver, so that's the sort of concept if you want to think of earthquake shaking, imagine you're sitting in the car and you put your foot down and then you hit the brake, so you push back, and forward. So why is that because you were stationary, but the car's moving underneath you. Well an earthquake's doing the same thing, it's just powerful enough to move the ground underneath you, so that's why, and of course the thing the car is doing is accelerating and that's why we think in terms of g-force, so I guess, I'm no expert in this but in terms of forces on the body, five to 10 g is extremely unpleasant, and of course in these earthquakes we've got is approaching 2 g, so very, very high accelerations by international standards and of course you can then imagine what they do to buildings, so if you're driving your child say to the science fair and they've happened to build a nice thin meccano structure and you're driving the car and you put your foot down and then you slam on the brakes and they're holding this tight, you can imagine how the forces – how great the forces are on that structure and that's what earthquakes are doing to our buildings and that's what engineers have to design for. So when we look at these values higher than 1 g I guess from memory, out near the Darfield fault, the other thing that we'll come to in this talk today is how quickly earthquake shaking decreases with distance, just why again earthquake depth is important. If an earthquake's quite deep no one's close to it, if it's really shallow some people can be close to it, so you've got some vertical accelerations are here, a significant proportion of 1 g, more importantly usually for buildings are the horizontal accelerations so ones like this again, a significant proportion of 1 g, quite damaging shaking, so this is – these are severe levels of shaking experienced in Christchurch in September and some really high values in some places - next. So we're going to show, I'm going to show a number of plots like this, so I'll take a little bit of time to try and explain what it is. Each of the black squares there is a value from – it's an instrumental recording by a strong motion accelerograph, or seismograph basically so instrumental measure of shaking, and so our units essentially are g, the proportion of the g-force, so up here we've got 10 g, here we've got 1 g, so if you have 1 g of vertical things can get tossed in the air and now this is a funny scale, we called it logarithmic, for each change there's a factor of 10 difference. The range of values here is so large that we have to use this kind of scale to show it sensibly. So here .1 g starting to get significant level of shaking, up here 1 g, so, and here, this horizontal axis distance from the fault which again is where the depth's important, this is what I would call slant distance, so distance down to the fault surface from where the instrument was, so it's not just measured along the ground, it's actually measuring this slant distance to the fault –

JUSTICE COOPER:

Q. Which lant?

A. Slant.

Q. Slant, S-L-A-N-T?

A. Yes.

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EXAMINATION CONTINUES: MR MILLS

A. So here we have 1 g at a kilometre, just a kilometre from the fault, very high value, but we're down to, by the time we're out past say 10 kilometres, values are much lower. So when we want to provide or build a model that tells us how you should design buildings around the country we need to use empirical data from many earthquakes like this, put them into a model and give numbers to engineers that will inform how strong we build structures in different parts of the country. So we have to make mathematical relationships that represent these data. So you can see the data drop off with distance and so plotted in here, this solid red line, is actually our pre-existing model for New Zealand earthquakes supplemented I think a bit with some international data to improve the robustness at these very close distances to fault. The other thing to note, of course, we've got all these instrumental measures. They don't fall in a line. There's a lot of variability and that is the nature of ground shaking. It varies a lot from site to site and place to place. Our model has to try and capture that variability because when that is fed through to the building code and in the right form it affects the answers if you don't have the right measures of variability and so for those who know a little bit of statistics that's one standard deviation above, that's one standard deviation below or if your statistics are a little more shaky below this top you'd expect 84% of the data points to fall below this top line. So it's really trying to encapsulate the variability and often when we're dealing with things we might expect a lot of the data to be encompassed by plus or minus 2 of these line distances away so it's a not problem here with data falling outside the dash lines. That's probably reasonable fit to the data although you can see the shakings a bit low. To add a level of complexity that we'll have to grapple with over the next couple of days, we've actually in, in plotting those black squares there we've just selected out data at what we call a period of shaking of one second. So if you think back to the car and your child holding this structure going to the science fair, if you're driving along the road and you push the accelerator and half a second later you hit the brake and half a second after that you push the accelerator again you'll sort of, the building will be going through this in about one second and that's the data we've selected. You can imagine if you're driving along in the car and you're hitting the accelerator and brake far more frequently you'll get a much faster motion. If we'd happened to plot that motion here these black squares would be in a different place. In fact they actually come up to a somewhat higher level and fit this relationship better. So earthquakes and soil conditions vary and so you get different fits for these kinds of curves.

JUSTICE COOPER:

Q. The letters "SA" before the 1, 1S in brackets, what do they –
A. Spectral acceleration.
Q. I see.
A. So we're dealing with g-force in terms of acceleration –
Q. Yes.
A. – but spectral is bringing in this concept of shaking being able to happen at different periods.

EXAMINATION CONTINUES: MR MILLS

A. Right next slide. Right so anyone who's lived in Christchurch since September the 4th will be well aware of aftershocks so plot these here, the aftershocks up until 21st of February is the green circles, the size is according to the magnitude of the earthquake and also plotted on here is that fault model that we talked about earlier in terms of the sub-surface bits on that first diagram shown as yellow dash lines, the surface rupture here and this is where the rupture started, propagated across here down to here. Earthquake propagated here and so along this bit of the fault as we saw in that earlier diagram about five metres of slip one side of the fault compared to the other, here it stopped so the slip had to go to zero. What happens then is you create extra stressors in the earth where the fault stops and also because the slip you saw again from that first diagram, the slip wasn't uniform, the earth tries to even it out with little earthquakes to try and true things up if you like. They're the sort of early aftershocks that are often close to the fault line that ruptured and it's not unusual to get a lot of aftershocks where a fault that ruptures strongly in one direction suddenly terminates. What's probably more unusual is to get a step-over like this but you also see a few aftershocks even in relatively early times at the location of the February the 22nd earthquake.

COMMISSIONER CARTER:

Q. The, the length of the fault that you showed on a previous slide is 30 kilometres. That was the surface expression I suppose. How long is that red line. Is that the same length?
A. It should be.
Q. Roughly, okay. Thank you.
A. Yes, if we're being accurate.

EXAMINATION CONTINUES: MR MILLS

A. Also shown here because we're plotting through to February 2011 Boxing Day earthquake sequence, little cluster of activity right under central Christchurch. We'll have a look at that in a minute. That's probably all I need to say on that diagram. Various other faults shown in the diagram and Jarg will talk about them later on. Next slide. So this now, we're moving onto the Boxing Day earthquake and this might be an earthquake where various magnitudes have been mentioned but moment magnitude determination is 4.7 and I guess while we're, while I remember that calculation's probably accurate to about plus or minus .1. So it could be 4.6, it could be 4.8. That's the kind of accuracy to which we can calculate moment magnitude. When we're dealing with local magnitude it might be plus or minus .2 or in a bad case plus or minus .3. So that's the natural variability in trying to calculate these things.

COMMISSIONER CARTER:

Q. In energy terms a decimal point difference is equal to, in g terms, is three, three times the, the size of earthquake at 4.6 would be, 4.8 would be three times the, that's 2 you have, sorry, would be 2 out of 30, 1/15, 15.

A. Well the whole unit would be 30 times the unit so a 10^{th} of a unit is three times the energy.

Q. So even between 4.6 and 4.8 there's a huge difference in the energy released.

A. Yes.

EXAMINATION CONTINUES: MR WEBB

A. So this is just showing the spatial location zoomed in a bit of the Boxing Day sequence and a cross section north on the right-hand side of the cross section south on the left-hand side defining a bit of a dipping structure and Jarg again will talk to this when he talks about the crustal seismic work that's been done under the city since February. Next. So here's the pattern of shaking. Again some, some quite large values. Very concentrated on the central city. In other words very close to where the earthquake occurred and of course out in the countryside hardly, far, far less and relatively low values compared to these values over a lot of the city. So the thing to note, much smaller earthquake, affects a smaller area but if you’re very close to that fault line still very strong shaking – and next slide. Okay so now move onto I guess the disaster earthquake on the 22nd of February, MW6.2. In this figure both the June the 13 fault and the February 22nd fault are shown. Just ignore the June 13th fault for now. We’ll come back to that later and so the February the 22nd fault sloping up, so here’s CBD which was so badly affected and that fault is essentially, I'll show you in cross-section soon, sloping up almost pointing at the, at the CBD.

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Note also that in, in terms of again using satellite data and GPS data to invert for or define how much slip happened where on the fault plane. This slip did propagate fairly near to the surface although as yet no surface trace has been found. A lot of energy released between one and three kilometres depth. Very compact source in this case but only two metres of slip compared to Darfield earthquake which had maximum slip at depth of around the five metre mark according to these data. Other thing to note is the direction of slip and the rupture will have started at depth and across at the eastern end propagated up and across essentially aimed at the CBD so we’ll come later to why we thought the shaking was so strong but you can see some hints of it here again very shallow where the energy was released very close to the city but worse than that energy directed at the city from close range. Next slide please. So here’s aftershocks through ‘til June and those post-February the 22nd main shock or aftershock the large event shown in red and so very high concentration of aftershocks close to the fault plane. But you also see during the not September, February June period red dots over the whole aftershock zone so aftershocks still happening over the whole zone but this earthquake has in fact its own family of aftershocks happening very close to the fault plane and moving somewhat south of the fault plane, you can see still quite active here with quite significantly sized aftershocks, I guess they’re magnitude 5s in fact. And the next. And here’s the pattern of shaking. So this is incredible shaking really compared to those earlier and towards the end I'll show the four, the shaking on these diagrams in the four earthquakes so you can all readily compare it so extremely high levels of both horizontal and vertical, massive vertical movements at times over quite a large part of the city ranging from CBD and further east and south-east. I mean even values like this are quite significant proportion of 1 g which is normally regarded as quite severe shaking and the epicentre marked here but remember the fault perhaps running across about this point, yes next please. Okay so this is I guess the second of these shaking versus distance curves to focus on. So again we've got solid red line which is the line representing the, our model prediction for an earthquake of moment magnitude 6.2, I guess the outstanding feature or the really worrying feature is this bunch of very high values, sort of a little bit each side of 1 g these are I guess horizontal measurements, sideways movement of the ground, not up and down so very high values here at about less than eight kilometres from the fault. If we go back one slide please. So these basically these data are in here, perhaps including that point.

JUSTICE COOPER:

Q. So you're indicating the roughly the centre of this diagram?
A. Yes CBD and maybe the points a little, little to the east of that yeah.

EXAMINATION CONTINUES: MR MILLS

A. Next. So I guess we're quite concerned that the model is under-estimating this and part of what I'll go on to talk about and it will be part of discussion over the next day or so is steps we're taking to try and get a handle on these high levels of shaking, put them into the model and then inform changes to the loading standard and the way we build stuff. Interestingly though and this is can't, this may be useful later to just remember this out here the data actually falling a bit below the model so it's not like the model's too low at all distances, it's like you're, like to take that line and bend it but remember that line is derived from data from many earthquakes, I don't know the exact number 30 or 50 or something like that, you can't just because of one earthquake take the red line and change its slope it's got to – you've to try and get the best fit to all data, you can't just try and model the one earthquake so why these higher values that are making the fit so bad? And we'll talk more about that. Again remember this is spectral acceleration one second so the same as the earlier plot in terms of the frequency of the ground shaking that we're considering but yes very high values in here. Next slide. Okay, here's one step we've taken in the mean time to try and improve the fit of the model that was since we are changing the slope of the lines probably a bit warranted by the other earthquakes that are used to build the model one can raise the whole line and there are physical arguments for doing this that I will come back to in a minute so it's starting to go through the data better and this 84th percentile or plus one standard deviation in terms of the statistical measure is covering off the, some of the higher data points because it makes the fit worse back here but I guess we're really worried about the fit close in to the fault say within 10 kilometres that's going to be more important I think personally to get that right than to worry about lower levels of shaking further away. But this is work in progress and there may be other approaches to doing this but this was a first step was to increase this line so it be helpful if we can go back several slides to the pattern of fault slip. Right that's it. So a thing about this earthquake we also think it was true for the Darfield earthquake but particularly true for this earthquake this slip here given the size of the earthquake and the amount of slip is very, very concentrated so often earthquakes of this type of magnitude 6.2 you'd maybe expect a little less slip over a bigger area and still end up with the same moment magnitude. We've got enhanced or concentrated slip now if we now go forward again to where we were. That, a term for that is stress drop it's about the amount of stress relieved in the earth due to the earthquake so earthquakes are really relieving tectonic stresses in the earth they have to happen because we have stresses accumulating through the motion of plate, of the, the – on the plate boundaries throughout the world so the earthquake slip is relieving stresses and if you concentrate the slip and you have more slip then you're relieving extra stress so we say these earthquakes have high stress drop. They relieve a lot of stress given their magnitude and because they are relieving a lot of stress they're moving a lot, they're radiating more seismic energy, so – but when you put that into the model you expect to raise the level of shaking produced over all distances. You can see this isn't a perfect fix in terms of what we're trying to do so we can match these important data points in here better through doing this but it's not a perfect solution to what we want. Next. So I mentioned that we'd show the cross-section of the fault, a bit stylised but in about the right place I hope. Quite a bit of the fault movement you saw from that earlier diagram was pointed, it was, the, the rupture coming up and towards the CBD which is sort of indicated by these arrows here beaming in. So a number of things happen here.

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One of the things we think is probably very important here is the fact we've mentioned that the stress drop was high so there was a lot of slip given the size of the earthquake. We think a consequence of that is that also the slip spread over the area of the fault very, very quickly and we can actually work back from the seismic recordings to try and determine how quickly that slip did propagate if you like over the area that ruptured and a consequence of that is the rupture front was slipping almost as quickly as the seismic waves were leaving. So if you've got your fault here and you've got a rupture here and it's propagating in this direction up towards the CBD and the waves released here are only just keeping in front as it propagates all the energy tends to stack up and gives you a big pulse of energy in that direction, very little back over your shoulder. So that's effectively a Doppler effect that you hear in the note of an engine or whatever whether it's coming towards you or going away. The sound waves are stacking up if it's coming towards you or they're getting – which gives higher pitch and louder volume – or if it's going away you get the opposite effect. We call that for earthquakes, we call that directivity. So we think there is some directivity from the Darfield earthquake, the fault, the main bit of the rupture was oriented looking at Christchurch and the fault ruptured that way but here we seem to have much stronger directivity and we think it relates back to that higher stress drop. So there are some things we're pretty sure of here but as I said there's still work in progress but we are sure that the rupture spread over, well we're sure about the area that ruptured, that earlier diagram now is reasonably well resolved and we know that the rupture headed off in the direction of Christchurch and it was the rupture front spread very quickly, we think that creates the directivity pulse. It's a bit hard to show cleanly in the seismic records though. So there's still a bit of debate over that which leads nicely into the next thing to talk about here is how did the, this basin respond to the shaking being introduced by this earthquake because that complex shaking of the bowl of jelly if you like is obscuring perhaps the directivity thing that we might like to see in the records and would make the job of analysing this a lot easier.

JUSTICE COOPER ADDRESSES WITNESS - ADJOURNMENT

COURT ADJOURNS: 3.59 PM

COURT RESUMES: 4.12 PM

COMMISSIONER CARTER:

Q. Dr Webb, might I just ask you to give me some better understanding of the way the diagrams that showing the slip, the fault's location and the spread of the effects, could you go back to one of those diagrams, do I make myself clear, I'm just ...
A. Sure, so do you want a number –

EXAMINATION CONTINUES: MR MILLS

Q. Is it SEI GNS0010A.11?
A. Yes. 10A.4.
Q. 10A.4 is the 4th of September one.

COMMISSIONER CARTER:

Q. It doesn't matter what we're looking at, I just wanted to understand the diagram. If you could help me understand this drawing better, is the black line of the Greendale fault the surface trace of where it would be exhibited on the surface, yes.
A. Yes.
Q. Now is the coloured part shown below that, is that a vertical projection of where the trace is sloping out under the ground, or is it, do I have to read that by effectively turning the page at right angle, was that a vertical description measured in a vertical direction?
A. It's developed so that you can just look at it and get the impression of this fault down into the earth.
Q. So I have to disassociate the plan? If I picked a -
A. Yes.
Q. - particular location, say a couple of kilometres, we're looking at north of the – is that diagram, coloured diagram north or south of the Greendale fault?
A. Well our viewing angle is from the north-west I guess, so we're looking south-east.

Q. So is that coloured diagram, if I look at say the red colour and I look at the place on the map that would relate to where that red colour is, is that exactly where that colour is drawn –
A. No, so essentially this fault is very steeply dipping, so this is going down five kilometres directly below the Greendale fault.
Q. Okay.
A. For that example.
Q. So the relationship of the gray diagram underneath doesn’t have any purpose?
A. No, that's a plan view sitting on the top and it's been made transparent so you can see through the map view at the fault going down under the Greendale fault.
Q. And that fault is at an angle to the vertical rule, the horizontal –
A. Well –
Q. That's not a vertical –
A. – in that case it's close to a vertical fault.
Q. Close to a vertical fault?
A. But this one’s got some dip on it and you can see it bent a bit to show that.
Q. Okay, I think that helps me quite a lot, so I can in effect use the scale to measure down from the surface trace, which is shown as the Greendale fault, and that would show me the intensity as I proceed vertically down below the fault, okay. I think that's -

EXAMINATION CONTINUES: MR MILLS

Q. No, you need to say yes because the transcribers can't do nods.
A. Oh, and it was probably a no actually, just a slight correction on intensity –

JUSTICE COOPER:

Q. All the more reason to say something.

A. So it's the amount of slip remember which in turn will affect the intensity of the radiated seismic waves, so this is about five metres of slip from the surface at that depth.

COMMISSIONER CARTER:

Q. And now the other diagram that you showed us was one where the lines were sloping and you were –

A. So the same diagram but for February the 22nd?

EXAMINATION CONTINUES: MR MILLS

Q. No, 15 or 14, either of those.

COMMISSIONER CARTER:

Q. One of the spectral acceleration diagrams?

A. Oh. (Inaudible 16:17:21)

COMMISSIONER CARTER:

Q. No, no my interest is in whether these black dots are represented radially from the centre of intensity or are they measured, or are they – each of the black dots represents a particular measurement that's been made. Is that correct?

A. It could be I think largest horizontal component.

DR McVERRY ADDRESSES THE COMMISSION FROM THE BODY OF THE COURT

JUSTICE COOPER ADDRESSES COUNSEL

COMMISSIONER CARTER:

A. I think we're okay, this is so as I said, largest horizontal component, and as I said earlier, the measurement distance is from the instrument site to the nearest point on the fault surface.

Q. And that could be – if I used the fault line as an axis the position of the measurement could be along the line of the axis or at any other position, as long as it's 10, if I looked at the 10 kilometre numbers, there's probably what, four or five that look to be about 10 kilometres from – in your measurement, closest distance to the fault, so those could be 10 kilometres measured in a radial direction from that point. I'm very interested to understand this clearly for the reasons that I think we're going to be interested in this question of the release of the energy and the distance from the point as it comes up later in the discussions, so I just wanted to make sure I understand the way the diagram has been created.
A. So I guess as I understand the geometry, if you're not off-end of the fault, you're out sideways from the fault, the nearest point will actually be at a right angle to the fault, the closest point of fault.
Q. Okay.
A. To your instrument site. I guess if you're off end it gets a bit more complex because you've got to slope back to the nearest bit of end of fault.
Q. So no – I'm happy if I understand it, just in regard to the fault that you've indicated, so thank you for that.

COMMISSIONER FENWICK:

Q. Where the fault does not reach the surface, what's the measurement there, in the 22nd of February, the fault did not fault, there was no surface trace, so are you measuring to the top of the area that faulted, one kilometre down, or are you measuring to where you projected the fault line would be if you extended the plain?
A. So remember, it's in that case it will be slant distance to the top of the fault.
Q. Which would be about one kilometre down?
A. Yes.
Q. Thank you.
A.

JUSTICE COOPER:

Q. So when we adjourned you were at diagram .16?
A. Yes.
Q. And you were going to go on to tell us about the basin effects I think?

EXAMINATION CONTINUES: MR MILLS

A. That's right. So unfortunately there are number of basin effects that you can have which adds a little bit to the complexity, but we'll try and work through some of them, so we've talked remember a little bit about directivity, so Doppler effect, what seismic waves stacking up on each other to give you a big strong pulse, propagating up into here. Now in some ways seismic waves are a little bit like tennis balls, they will bounce off interfaces at the angle they went in, but that's not always the case and in a case like this where you've got waves coming up and this quite strong interface here, so this is stronger, this is stronger volcanic rock and these are softer gravels and sands and silts and so on –

JUSTICE COOPER:

Q. So at that last comment you're indicating the area below the legend, Christchurch?
A. Yes, the light blue colour.
Q. Yes, thank you.
A. Yes.
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EXAMINATION CONTINUES: MR MILLS

A. So the, the wave will come in, bounce off the surface. When it comes down here because of the angle it'll bounce back up rather than coming off down here so the energy gets trapped in the basin when waves enter and there's a dipping layer like that. So you can get a reverberation, a strong reverberation in the basin. If this was a saucer-shaped basin you could see waves would get trapped in there and oscillate back and forth. Of course over a matter of minutes they would attenuate away and that would be the end of it but you can think it would be far more benign if they came in and simply bounced off and went back down into the earth. So there's a tendency to trap the waves. That's one thing. Another thing is and I don't, sorry I don't have a particularly good map view of this but if waves are coming in for example from Darfield earthquake, bouncing off the Port Hills, other waves travelling a different path but perhaps more slowly are going directly say to the CBD and the bouncing ones and they coincide they can reinforce and give you much larger amplitudes and because they bounced off the edge of the basin we often refer to that as a basin-edge effect. So that's another kind of basin effect that you can have and there are potentially others. For example if you had an earthquake out to the left-hand side of this diagram which is, say, to the north the seismic waves may propagate in, trapped in the basin again and stack up as the basin shallowed out. Various effect you can get. Quite difficult to model accurately because you need to know the structure of the basin very well and you need to know the seismic velocities and the different materials. So that will take some time to resolve but with the more powerful computers we have these days you can model these things in three dimensions once you've built the right geological model. Try the next slide. Okay I might carry on to this, this, during the break there was one thing that we need to go back to but I can do that in a minute so we'll carry on with this slide. Terribly unfortunate scenario and as I alluded to earlier because the way shaking drops off so quickly with distance an earthquake very close to you, particularly a large earthquake, 6 plus, is a real problem. So proximity is a lot of the problem. Both Darfield and this earthquake quite shallow, a lot of energy released between say one and five kilometres depth. So those, those two things are sort of the first order simple things that's means you've got a problem. Then when we get into why things don't fit our model so well, I've talked a bit about the high stress drop, in other words all that slip, more slip than we'd expect on the fault surface over a small area, consequent spread of the rupture very quickly and a high directivity but then also in here we've got basin effects. Yeah I'll just, sorry I'm still just thinking of this thing we must come back to which is definition of aftershock so if I forget bring me back to it but carrying on – next slide please. Actually I'll skip ahead. If we go to – and the next one and the next one and the next one. Right. So this is this shaking versus distance plot but for June the 13th and an interesting thing here, again the same business of exceeding our model, a bunch of stations exceeding the model. If we go back one slide. But it's a different group of stations. So the, the, the fault that ruptured now runs along here. These stations are quite near to this and if we go forward again to where we just were. They are these stations. So they are a different set of stations from the ones in the CBD for the February the 22nd earthquake. I won't take us all the way back to the earlier figure but we're talking about basin-edge effect and the way waves can get trapped in the basin. Another thing we have which is another effect that can amplify motion is a local site effect. So this looks like a local site effect but we see exactly the same effect from two quite disparate sets of stations. So unless the underlying soil, near surface soil conditions are the same across them which may be a possibility this isn't obviously a site effect either but perhaps it could be. We'd need to know more about the details of the site. So I was just wanting to make that point. So now, sorry, we need to back track a bit, back to where we were. This one. That'll do. Thanks. This is really just to compare the shaking between the September the 4th 7.1 and February the 22nd which you can see a little discrepancy in the magnitude. So we're saying MW is 6.2 not 6.3 – that slide needs to be corrected – and firstly we look at the horizontal shaking which traditionally we'd say was important because buildings tend to be stronger vertically than horizontally but I don't want to stray into engineering issues. For the 6.3 because again of those factors like proximity, shallowness and so on, higher levels of, much higher levels of shaking than, than September the 4th for all these different seismograph or accelerograph sites in the city and again, sorry, the scale here again is a g-force scale not a spectral acceleration. No, I think this is straight PGA as in straight acceleration, unprocessed and you can look at code level which I guess Graham will talk more about this to tomorrow but just as a sort of introduction to it for the one in 500 likelihood event happening say in the, in the, in an annual basis, one in 500 chance, code level .3 g. So you can see the 6.3 exceeding code. Then if we look at the bottom histogram. Here we're looking, instead of looking at the horizontal motions that we were up here we're looking at the vertical motions and you can see a characteristic of the 6.3 are these very, very high vertical values. From I guess the seismological point of view it seems this is not exceptional in terms of what you'd expect if you're really close to a buried fault. So globally if you look at data I guess sometimes you do see these verti – high vertical motions very close to a fault. So why do we typically say vertical's less than horizontal. Well that's because generally we don't have instrumentation or perhaps even buildings very close to fault ruptures. When you look globally there's a real lack of near fault data. That situation's improving because these days globally there's far more instrumentation, far more earthquake instrumentation so your chances of being close to a fault rupture have improved over the past decade. Prior to that there was a real lack of data. So if you had more data perhaps we would often see quite high vertical motions when you're very close to faults oriented at the right angle to give you that effect. Next please. So moving on now to June the 13th which is this, what I'd call an orthogonal plain, so a plain at right angles to the other plain. Now we'll talk about some examples of this. This, this is not unknown. You can see the, the distribution of slip on the plain, peak slip is somewhat less now. So here in terms of Mw we're down to 6.0. So significantly smaller earthquake and you see the maximum slip correspondingly smaller as well. Slip directed horizontally, essentially horizontally towards the south and next. Right and so now the blue dots are aftershocks since June the 13th.

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Again quite intense, here's the dashed yellow line just in the ocean to the, to the east just off shore to the east is the rough location of that fault plane I showed you in the previous diagram and the star marking the, where the earthquake rupture started and so you see aftershocks in the vicinity of that plane but also in more recent times migrating further to the south-east and also continued aftershock activity in terms of blue dots over the whole aftershock area and next. So we've a bit about this so again very strong shaking, very, very strong shaking here in, particularly in the, to the east and the south-east, and then even I mean even some of these values still are a significant proportion of the horizontal g-force. Next. And so I guess I've briefly talked to this already as I mentioned the same problem of very high values above our model levels again the sort of eight kilometre distance but as I mentioned before different set of stations. Then a bit further out 10 to 50 kilometres shaking less than you'd expect, here we're again dealing with this one period, one hertz one second kind of shaking and just remembering quite high variability in ground motions which is what we always have to deal with. Next. So this is really a summary slide showing the shaking from the four events from September, December the Boxing Day one, February 22nd and June the 13th and I, when I put these together in one power point slide you have a tendency to think, "Oh well this is really quite low shaking in terms of the top left September the 4th" but of course it wasn't, it did significant damage as did Boxing Day but compared to February the 22nd it's way less so yeah, quite, I don't know what the right words are really, quite frightening I guess in terms of the shaking produced in these two earthquakes.

COMMISSIONER CARTER:

Q. Dr Webb how far under the gravel soils does the volcanic rock extend, does it extend on both sides of the Lyttelton Harbour do I interpret that?

A. They're probably best if we defer that and ask Jarg I don't feel able to deal with that question.

EXAMINATION CONTINUES: MR MILLS

A. Next slide. Okay so it's not quite thank you, you could take us back up to a seismicity plot, the one with the blue dots as well as the green so just back a couple of slides. I do want to talk briefly about the definition of an aftershock and unfortunately like magnitude scales there's a number of definitions. So that GNS Science working with a number of other organisations we've had, we have people who look at time dependent or time varying seismic hazard which is looking at the rate at which aftershocks might decrease. It also looks at the likelihood, the research also looks at the likelihood that large earthquakes may trigger other large earthquakes and so because of the nature of that problem those people have a definition of aftershock which is the one we've used for the Christchurch, applied for the Christchurch situation so I won't take you right back to the first slide that had the green dots but you remember there were green dots in here and so their definition of an aftershock really is something that is falling within sort of this initial aftershock zone and so it's got to be related in space and time so if it happens well reasonable number let's so loosely, reasonable number of aftershocks are happening and it's in the aftershock zone we'll call it an aftershock, according to that definition. And that's why this was termed an aftershock. Other people have other definitions. You can imagine for the Earthquake Commission where there's issues around when re-insurance kicks in or when the 100 k cap on a house kicks in you need a far more precise definition of that. They have their own definition and there are other science or direct science application that we're actually discussing with Norm Abrahamson on Friday. If you look at the characteristics in an aftershock that occurred on the Greendale Fault trying to even up the fault slip that actually, that aftershock it seems probably would radiate less energy than an earthquake in the same spot had that fault not ruptured because you've released a lot of stress so they tend to be benign aftershocks but you can imagine all these guys are probably as energetic as normal earthquakes so you can see there you'd want a special definition, very precise definition of an aftershock as something that occurred after a main fault lane had ruptured in the close proximity so there's at least three definitions of aftershocks, so that's really just to explain this issue. So then if you think, if you struggle with definitions I always find it helpful to step back a little and say, "Do we, do we understand the physics if you like of what's happening in the earth in terms of the aftershock process?" and that's often more helpful than worrying about definitions as, let's see if we can develop some basic understanding so hopefully I talked a little about that before, the fault ruptures and as I've just said there were bits on that rupture where you'd like a few aftershocks to help even out the slip that occurred, the fault suddenly terminated creating bit change and stress because you went from five metres of slip to none and you do perhaps potentially with the directivity a lot of damage to the rock and so you can expect aftershocks there but those changes in stress due to that five metre of stress relief here does affect the stresses in the surrounding region so you've released a lot of stress but off the end of the fault and this is very complex remember so it's actually quite a complex pattern, you do build up other stresses and as time goes on in an area where you've got stresses built up will you get a lot of aftershocks or a bit event or not? Well one of the things you might like to know is what was the stress out here say before we had this earthquake and how did it change? We can figure out how it changed but we don't, have no idea of what the stress was before. We don't, in this case, know there was the fault there and even if we had how strong is that fault? Was it near to failure or not?

JUSTICE COOPER:

Q. Dr Webb can I just I know it's difficult but when we're reading a transcript of this maybe in several weeks time we won't know what you did when you turned your indicator on and said, "Out here"?
A. Right.
Q. What you're referring to is the area covered in red and blue dots?
A. Yes. Roughly where the bulk -
Q. Can you and others following try to find some way of conveying in words what you're indicating with the pointer?
A. Right. Right.

EXAMINATION CONTINUES: MR MILLS

A. Okay, so to the east of say the termination of the Darfield or Greendale Fault rupture to the east perhaps where the February the 22nd rupture occurred we don't know even though we can determine stress changes in that region we don't know what the pre-existing stress was nor do we know the strength of the fault so you can see it's very, very difficult to make any prediction about the likelihood of that structure rupturing. To determine those things you really have to drill holes 10 kilometres deep into the earth which is extremely difficult to do and take stress measurements at depth. The other thing that might be happening that affects the strength of faults is how crustal fluids in the cracks in the rocks are moving and changing their pressure as a result of the stress changes. These again things we think that are important in terms of bringing perhaps, triggering earthquakes or bringing, allowing earthquake ruptures to happen but again they are things that are extremely difficult to measure.

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So these are some of the challenges we face but we do know that on some occasions, maybe two to four percent chance large earthquakes trigger other large earthquakes, large as in magnitude say 6½ plus earthquakes can on rare occasions trigger other large earthquakes over distances of tens of kilometres. So if you wanted to use that argument then clearly you'd say, well perhaps this was a candidate for triggering. It wasn't going to happen on February the 22nd. If this one hadn't happened, this wouldn't have happened. So I mean I guess it's intuitively obvious to most people these are all related but how well do we understand the relationships. It's what I mentioned, if you, we can figure out the stress change but it's hard to know about pre-existing stress or strength of fault. So that really is the best we can explain the, how this activity migrates in time. So I'll just add once this earthquake occurred of course it introduced the, once the February the 22nd earthquake occurred I mean that created its own stress changes and they will have affected the likelihood of the next rupture on June the 13th and so you build up what is a very complex pattern of stress change and you can only model those things if you know that pattern of fault slip which is about the first slide I showed of the Greendale fault. You need to understand that pattern of slip in order to predict the stress changes and we're still working, in fact, all these months later on refining those patterns. So step through, I think we're about there. Yes. So that's, yes, that's the end of the presentation. Thanks.

JUSTICE COOPER ADDRESSES MR MILLS – FURTHER QUESTIONS

MR MILLS:

No I was just going to say, initially I had thought I was going to but I had a discussion with Dr Webb before we started today and took him through the questions that I wanted to ask him which are merely to try to give more context, perhaps make it more comprehensive or some parts of it, and to build on it and it became clear that the questions didn't belong conveniently to any single GNS witness so – and I was going to talk to Your Honour about this later but the tentative proposal is that the panel session that we're talking about having tomorrow, that in effect any questions counsel might have would be also dealt with in some kind of ad hoc panel arrangement with the GNS people so that they can decide who's the best one to answer any given question that I might have or Mr Elliott might have or indeed you might have.

JUSTICE COOPER:

Q. Just in relation to what you've just been telling us about aftershocks. You have a number of earthquake events from the 4th of September and although they, you've differentiated them according to the fault which ruptured they're within an overall area which makes them close together. Is that a, I mean that's the fact isn't it and this – I'm just wondering about the word "aftershock." Would it be correct to say that once you had the 4th of September event then these other events could be called aftershock because they are likely to be related in a way which is more or less well understood. Is that a fair summary of the position?

A. It might be helpful to, something people perhaps get confused by is we sometimes talk about triggered events.
Q. Yes.
A. Now of course all aftershocks are triggered events. They wouldn't have occurred if you hadn't had the main shock or not, yes, they wouldn't. So –
Q. Are you saying that, I didn't think you were quite going that far but are you saying that we wouldn't have had the Boxing Day earthquake without the 4th of September earthquake?
A. That's right, yes.
Q. And you wouldn't have had the Boxing Day earthquake or the 22nd of February earthquake without the 4 September earthquake and so on?
A. That's right but there's, seismologists do talk about a different class of triggered event that might occur within decades and tens of kilometres away and outside the aftershock zone. That would be something that we might classify as a triggered event in a slightly different sense and that's simply due to the stress changes in the earth produced by that first large earthquake and so this other event probably would have happened eventually it would just brought forward in time.
Q. Yes.
A. So you can see how you'd distinguish that from aftershocks in the aftershock zone.
Q. Yes.
A. But in reality of course it's probably a continuum from one type of triggered event through to ordinary aftershocks.
Q. Yes but you're always looking backwards.
A. Yes. Well the other way to distinguish of course if you triggered an event that was bigger than 4th of September you might want to call it, all, all of this activity foreshocks.
Q. Well that's not a word that I've heard before.
A. No.
Q. But is that a word that seismologists sometimes use is it?

A. Some earthquakes do have foreshocks and, I mean if something larger occurred we wouldn't re-label them as foreshocks of course so that’s a bit of an extreme example.
Q. Yes.
A. But events happening reasonably close to where rupture eventually initiates and happening within a month or so before –
Q. Yes.
A. – probably would be called foreshocks.
Q. All right. Well then I wonder if to change the subject we could go back to the diagram which is, has the suffix 10A.18. That’s the one. Now I'm just wondering the basis upon which these various measurement sites have been laid out in this way. What’s the organisational principle which has the Heathcote Valley Primary School, for example, the first on the left and the Canterbury Aero Club the last on the right?
A. Right, sorry I can't answer that. It’s roughly in decreasing size of, mmm –
Q. I was just wondering whether the, the order of those sites is intended to convey anything.
A. No there’s nothing very strict about the order as far as I'm aware.
Q. It’s not moving from the south-east to the north-west or anything like that?
A. No, not that I'm aware of. I can check.
Q. Will somebody, would you like to just confer with one of your colleagues please.
A. Yes that might be useful.
Q. Go and have a chat.

WITNESS CONFERS WITH COLLEAGUE

A. A south-east to north-west pattern.
Q. Right.
A. Probably –
Q. Heathcote Valley being the south-east and –

A. Yes, high values in the south-east out to the north-west but of course you're talking about sort of rough, covering an area, whereas this is a linear plot so it won't be a perfect match to that.
Q. Well the level of shaking doesn't follow a constant pattern. That, that's what was behind my question. So it's a geo – these are laid out in the, in an order that reflects the physical location of the instruments?
A. Yes, that's right.

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Q. Right and then, tell me if others would be better to answer this question but I don't really have a good understanding of how many of these instruments are in place and I take it that this doesn't show, well I'm assuming that the list here, Heathcote Valley Primary School through to Canterbury Aero Club is not the complete, is not a complete list of the, of the instrument sites?
A. No and there's a couple of relevant things to that. Once ground starts to liquefy –
Q. Yes.
A. – the motions become quite different in their nature –
Q. Yes.
A. – so I would expect that sites that had liquefaction were excluded for that reason -
Q. Yes.
A. – and the other point is that after the September earthquake we installed a lot more instrumentation.
Q. Yes.
A. So for the February event there are more recordings and we only show here stations for which we've got recordings from both events.
Q. Well that would be all right providing that what was shown for February event was still representative. Do I take it somebody's formed that, that view?
A. Oh –
Q. If somebody is better able to respond to these questions I'm happy to defer to them but perhaps you could think about that overnight.

A. Right, okay, we'll do that.

COMMISSIONER CARTER:

Q. Just one question with respect to earthquake sequence, the cluster of earthquakes where you were talking about, talking about the trigger, the potential triggering of earthquakes from one to the other. Just looking elsewhere in the world is that helpful at all in understanding the, the triggering relationships between earthquake events?

A. Yes, a couple of examples. So if we go to 10G.1. So this is the Anatolian fault in Turkey and the fault's the black line running horizontally through the top frame of this diagram. It shows the period, the year 1939 and a large earthquake occurred on the segment of the fault with the deep purple colour and there's a little 1939 label near the centre of that and those deep colours show areas where stress was relieved as a result of the earthquake occurring but you can see that the earthquake has loaded up each end where you've got red colours and then in 1942 there was a smaller earthquake to the west, again labelled 1942, creating some more stressors and then in the third frame down, 1943, another large earthquake to the west of the 1939 and 1942 events in turn loading up the fault to the, to the west again. The thing to stress here though, this is a very well developed mature fault with a very high slip rate, very, very different from the Greendale fault. More akin perhaps to something like the Alpine fault in, in New Zealand and so in subsequent years, or time periods, ruptures stepped across in both directions. In fact by the time we get to the bottom frame, 1992, a very red area and this is work by, published work in international literature by Stein, et al published in 1997 and in 1999 the Izmit earthquake occurred, magnitude 7.4 at the eastern end of the bottom of the 1992 frame. So that's not really what we call an earthquake prediction but the earthquake, if you like, was brought forward in time due to these accumulated stressors. So that's probably the textbook example of stress triggering. I think I mentioned there are a couple of examples. You can also look at, if you want to think, rather than a particular spatial example, when you look at an earthquake catalogue, in other words the list of large earthquakes that have occurred in a region or a country you can look at the New Zealand catalogue and see a strong cluster of activity between 1929 and 1942 that covered quite an area of the country. Now some of those earthquakes probably triggered each other but it covers a very big area and so some of that could be coincidental. We probably will never really know the answer to that because the data are too poor. It's very hard to do these calculations of areas that are stressed or unstressed in earthquakes when there's not a clear cause of a fault and you don't have good information on the fault slip as I mentioned earlier. So certainly examples of clustering in the New Zealand catalogue with some of the earthquakes and so if you wanted to think about a particular region you could think about from Buller through to north-west Nelson where we know from archaeology that the faults slip very, very slowly and yet as I said from in fact 1929 right through to the, I guess the 1980s we had quite a few large earthquakes in that area so one would think that there was this kind of stress triggering, happening there. But just as a reality check for given earthquakes, given large earthquakes, how likely is it that they'll trigger other large earthquakes, well it could be as low as sort of a two to four percent chance as a, as a rough number.

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