AEES NEWSLETTER

December 2013

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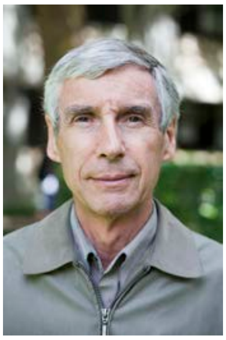
President's Report



It was a great honour to be elected President of AEES at the annual meeting in Hobart in November. I have been actively involved with AEES for only the past decade because I have been working overseas, so for those who do not know me I would like to introduce myself. I was born in Armidale, NSW, Australia and received my B.Sc. degree in Geophysics from the University of New England. Before going to Canada for my M.Sc. and Ph.D. degrees in Geophysics at the University of British Columbia in Vancouver, I spent two years as a high school teacher in Wewak and half a year at Unitech in Lae, PNG. I spent two years as a Visiting Research Fellow at the Earthquake Research Institute, University of Tokyo, and have been involved with Japanese colleagues in engineering seismology research for my whole career.

I am Chief Geoscientist at Risk Frontiers, Macquarie University, where I construct earthquake loss models and do related research for the insurance industry and other clients. I have been Principal Seismologist for URS Corporation for over 30 years, doing research and development on earthquake source and strong ground motion prediction models, and I have applied this knowledge in the design and analysis of major buildings, bridges, dams and power generation facilities in many countries, including Australia, New Zealand, the United States and Japan. I am currently involved (with Gary Gibson) in updating the seismic guidelines for ANCOLD (the Australian National Committee on Large Dams).

As in past years I found the AEES Annual Meeting in Hobart to be very stimulating and enjoyable. Our Society includes people having the many and varied vocations, backgrounds, interests and technical capabilities that are needed to mitigate earthquakes, which I regard as the most complex and difficult of all of the natural hazards to address. Foremost among our roles is our participation in disaster response, most recently in the Canterbury, NZ earthquake sequence. This reminds us that we need to be ready to respond to similar situations in Australia and in our neighbouring countries, and use them as important learning opportunities for our own professional practice.

I am very pleased that Peter McBean has accepted the position of Vice President of AEES, and will follow me as the next President, because I would like practicing professionals in the areas of seismic hazards and earthquake engineering to have more participation in AEES. Researchers need to understand the practical problems being encountered by these professionals, who in turn can gain a deeper understanding of earthquake engineering through communication with researchers. We all need to support the training of professionals working within Australia and in neighbouring countries. Many of our members would like to see enhancements in our building code to include displacement-based design and the consideration of performance objectives at annual probabilities lower than 1/475. To meet our societal goals, our Society equally needs the participation of people involved in public policy, emergency response, insurance, and many other facets of society.

I would like to thank Sharon Anderson, Adam Pascale, Kevin McCue, Hong Hao and all the others whose excellent planning work made the 2013 Annual Meeting in Hobart such a success. The 2004 Annual Meeting will be held at a very special venue near Melbourne. I would like you to encourage friends or other people you know who are practicing professionals to attend that meeting. I know these professionals are very busy but you can assure them that our meeting provides great scope for social and leisure activities as well as learning about earthquake engineering, and they will return home reinvigorated and refreshed. Meanwhile, I would like to wish you much merriment during the holiday season and all the best for the coming year.

Paul Somerville, AEES President

Paleo-liquefaction Christchurch NZ

Evidence of historical liquefaction has been found in Dr Mark Quigley's Avonside house back yard in Christchurch.

He and his Master's student Sarah Bastin dug a trench about 2 metres deep through the liquefied sediments where the paved barbecue area used to be. They found a patch of "palaeo-liquefaction" that is cut by near-vertical feeder dykes through which liquefied sand and water flowed to the surface in the September 2010 and February, June and December quakes, 2011.

The historical deposit has a mottled appearance with streaky orange lines caused by fluctuations in ground water level over time and distinguishing it from the recent liquefaction. They hope to date charcoal fragments found in the patch to find out when the causative earthquake occurred. Dr Quigley said it could be hundreds or thousands of years old.

Dr Mark Quigley and Masters student Sarah Bastin in a trench in the backyard of Quigley's red-zoned Avonside property. Photo: DEAN KOZANIC/FAIRFAX NZ

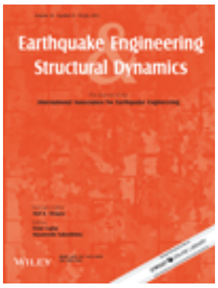
However, even when it was dated, it might still be difficult to fix it to a single event. It might have occurred as a result of a magnitude 8.0 earthquake quake on the Alpine Fault, or a smaller more local earthquake.

"The really important and unresolved question this might help us determine is, would an Alpine Fault earthquake cause liquefaction in Christchurch?" Quigley said.

Bastin said this was the first evidence of historical liquefaction in Christchurch, although it had been found at Greenpark, near Lincoln.

They plan to dig more trenches around the city's eastern suburbs to find other historical liquefaction deposits.

Earthquake Engineering & Structural Dynamics



Edited By: Anil K. Chopra, Peter Fajfar, Masayoshi Nakashima

EARLY VIEW ARTICLES ARE NOW AVAILABLE ON WILEY ONLINE LIBRARY

This is the journal of the International Association for Earthquake Engineering to which AEES is affiliated.

Bougainville Earthquake M7

A magnitude 7 earthquake occurred at 9.31 pm ESST, 10:31 UTC, on 16th October off the coast of Bougainville Island, Papua New Guinea, its focal depth 50km.

The shaking would have been felt strongly throughout Bougainville and in the northern Solomon Islands. Undoubtedly there were landslides and a small tsunami on the west coast of Bougainville, as well as liquefaction in the mine tailings along the Java River. Unfortunately we will probably never know.

Man-made earthquakes in the US

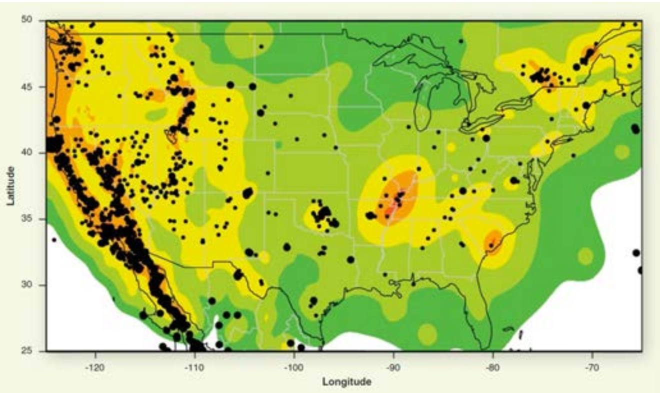
by William Ellsworth, Jessica Robertson, and Christopher Hook

The number of earthquakes within the central and eastern United States has increased dramatically over the past few years. More than 300 earthquakes above magnitude 3.0 occurred in the three years from 2010-2012, compared with an average rate of 21 events per year observed from 1967-2000.

This increase in earthquakes prompts two important questions: Are they natural, or man-made? And what should be done in the future as we address the causes and consequences of these events to reduce associated risks? USGS scientists have been analyzing the changes in the rate of earthquakes as well as the likely causes, and they have some answers.

USGS scientists have found that at some locations the increase in seismicity coincides with the injection of wastewater in deep disposal wells.

Much of this wastewater is a byproduct of oil and gas production and is routinely disposed of by injection into wells specifically designed and approved for this purpose.



Seismicity of the coterminous United States and surrounding regions, 2009–2012.
Black dots denote earthquakes with a magnitude ≥ 3.0; larger dots denote events with a magnitude ≥ 4.0.
Background colors indicate earthquake hazard levels from the U.S. National Seismic Hazard Map (NSHM).
Learn more about the NSHM at:
http://earthquake.usgs.gov/hazards/?source=sitenav

Review Article on Injection-Induced Earthquakes
U.S. Geological Survey geophysicist William Ellsworth reviewed the issue of injection-induced earthquakes in a recent study published in the journal Science. The article focused on the injection of fluids into deep wells as a common practice for disposal of wastewater, and discusses recent events and key scientific challenges for assessing this hazard and moving forward to reduce associated risks.

What is Induced Seismicity?

Although it may seem like science fiction, man-made earthquakes have been a reality for decades. It has long been understood that earthquakes can be induced by impoundment of water in reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and injection of fluids into underground formations.

What is Wastewater Disposal?

Water that is salty or polluted by chemicals needs to be disposed of in a manner that prevents it from contaminating freshwater sources. Often, it is most economical to geologically sequester such wastewaters by injecting them underground, deep below any aquifers that provide drinking water.

Wastewater can result from a variety of processes related to energy production. For example, water is usually present in rock formations containing oil and gas and therefore will be co-produced during oil and gas production. Wastewater can also occur as flow back from hydraulic fracturing operations that involve injecting water under high pressure into a rock formation to stimulate the movement of oil and gas to a well for production.

When wastewater disposal takes place near faults, and underground conditions are right, earthquakes may be more likely to occur, Ellsworth's research showed. Specifically, an earthquake can be triggered by the well-understood mechanism of raising the water pressure inside a fault. If the pressure increases enough, the fault may fail, releasing stored tectonic stress in the form of an earthquake. Even faults that have not moved in millions of years can be made to slip and cause an earthquake if conditions underground are right.

While the disposal process has the potential to trigger earthquakes, not every wastewater disposal well produces earthquakes. In fact, very few of the more than 30,000 wells designed for this purpose appear to cause earthquakes.

Hydraulic Fracturing

Many questions have been raised about whether hydraulic fracturing - commonly known as "fracking" - is responsible for the recent increase of earthquakes. USGS's studies suggest that the actual hydraulic fracturing process is only very rarely the direct cause of felt earthquakes. While hydraulic fracturing works by making thousands of extremely small "microearthquakes," they are rarely felt and are too small to cause structural damage. As noted previously, wastewater associated with hydraulic fracturing has been linked to some, but not all, of the induced earthquakes.

Photo Damage in Central Oklahoma from a ML5.6 earthquake on 6 Nov 2011. Photo: Brian Sherrod, USGS.

Unknowns and Questions

USGS scientists are dedicated to gaining a better understanding of the geological conditions and industrial practices associated with induced earthquakes, and to determining how seismic risk can be managed.

One risk-management approach highlighted in Ellsworth's article involves the setting of seismic activity thresholds for safe operation. Under this "traffic-light" system, if seismic activity exceeds preset thresholds, reductions in injection would be made. If seismicity continued or escalated, operations could be suspended.

The current regulatory framework for wastewater disposal wells was designed to protect drinking water sources from contamination and does not address earthquake safety. Ellsworth noted that one consequence is that both the quantity and timeliness of information on injection volumes and pressures reported to the regulatory agencies is far from ideal for managing earthquake risk from injection activities.

Thus, improvements in the collection and reporting of injection data to regulatory agencies would provide much-needed information on conditions potentially associated with induced seismicity. In particular, said Ellsworth, daily reporting of injection volumes, and peak and average injection pressures would be a step in the right direction, as would measurement of the pre-injection water pressure and tectonic stress.

Importance of Understanding Hazards and Risks

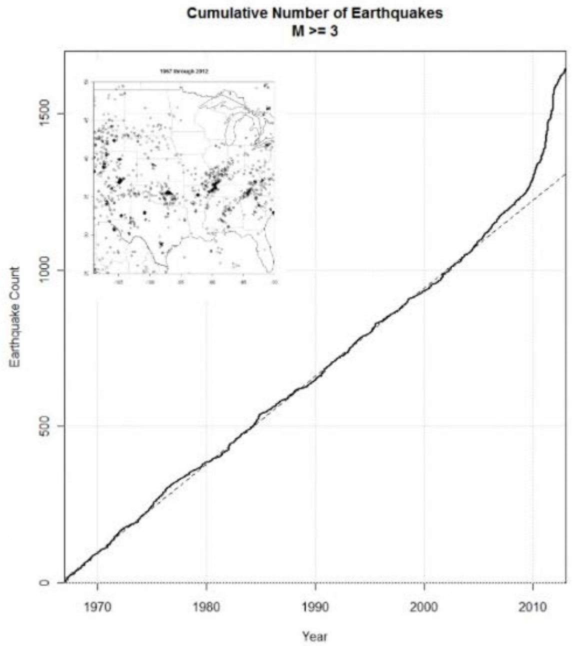
There is a growing interest in understanding the risks associated with injection-induced earthquakes, especially in the areas of the country where damaging earthquakes are rare.

For example, wastewater disposal appears to have induced the magnitude-5.6 earthquake that struck rural central Oklahoma in 2011, leading to a few injuries and damage to more than a dozen homes. Damage from an earthquake of this magnitude would be even worse if it were to happen in a more densely populated area.

The USGS and Oklahoma Geological Survey (OGS) have conducted research quantifying the changes in earthquake rate in the Oklahoma City region, assessing and evaluating possible links between these earthquakes and wastewater disposal related to oil and gas production activities in the region.

Studies show one to three magnitude 3.0 earthquakes or larger occurred yearly from 1975 to 2008, while the average grew to around 40 earthquakes per year from 2009 to mid-2013.

"We've statistically analyzed the recent earthquake rate changes and found that they do not seem to be due to typical, random fluctuations in natural seismicity rates," said Bill Leith, USGS seismologist. "These results suggest that significant changes in both the background rate of events and earthquake triggering properties needed to have occurred in order to explain the increases in seismicity. This is in contrast to what is typically observed when modeling natural earthquake swarms."



Cumulative count of earthquakes with a magnitude ≥ 3.0 in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes per year, with an increase in the rate of earthquake events starting around 2009.

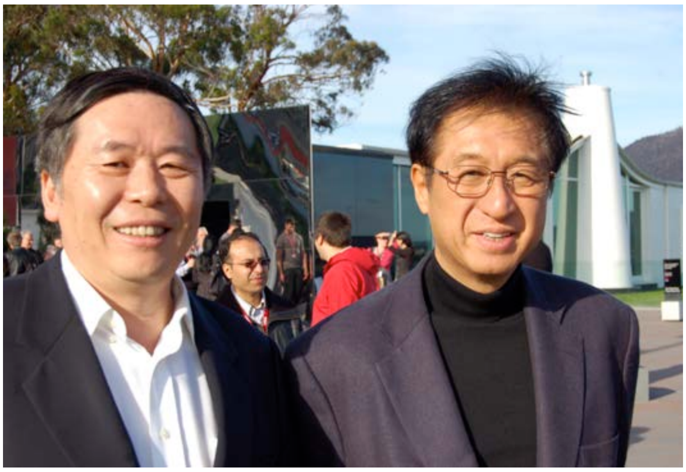
The OK analysis suggests that a contributing factor to the increase in earthquakes triggers may be from injection-induced seismicity from activities such as wastewater disposal. The OGS has examined the behavior of the seismicity through the state assessing the optimal fault orientations and stresses within the region of increased seismicity, particularly the unique behavior of the swarm just east of Oklahoma City.

Start with Science

As the use of injection for disposal of wastewater increases, the importance of knowing the associated risks also grows. To meet these challenges, the USGS hopes to increase research efforts to understand the causes and effects of injection-induced earthquakes.

2013 Hobart – one of our best conferences to date

When Professor Hong Hao suggested Tasmania as the venue for the 2013 Earthquake Engineering conference I had some doubts, perhaps it was too far for many students, practicing engineers and retired seismologists. Fortunately I was wrong.



Professors Hong Hao and Kazuhiko Kasai at MONA

Sharon Anderson organised an excellent program, the venue was perfect, the dinner functions exciting, the outings most impressive. All it needed was registrants and this year they did show up, ~75 people registered not a single local Tasmanian amongst them. They came because the program was so interesting with a good balance of keynotes, oral presentations and posters – or was it MONA?

Dr Paul Somerville (President AEES), Dr Jason Ingham Uni of Auckland, Prof Mike Griffith and wife Liddy

Ultimately the format is what makes the scientific part of the program so attractive, the mix of engineering, seismology, hazard, planning and geotechnical presentations, the chance to exchange ideas and discuss progress in a single stream.

There is not room to mention every speaker; the keynotes were excellent: Professor Kasai from Japan was riveting with his discussion of shake table testing and damping models, Charles Clifton was insightful in his deliberations on lessons from the Canterbury earthquake sequence, EA President Dr Kanga spoke about risk assessment and Dr Somerville about the different thought processes necessary to accommodate risk mitigation at a high hazard site in New Zealand compared with a low hazard site in Australia.

David Love and Peter McBean (vice-President AEES)

Dr George Walker

It was very rewarding to see so many young members of AEES but also founding members including George Walker, Mike Griffith, Gary Gibson, David Love and Russell Cuthbertson.

AEES members at Russell Falls on route to Gordon Dam

The AGM saw the election of a new Executive; Dr Paul Somerville took over from Prof Hong Hao whose 3 year term was up but Prof Hong Hao has agreed to act as immediate past President and is still the IAEE rep. Sharon organised a small gift in gratitude for a job very well done. Dr Helen Goldsworthy took over as Secretary in Paul's shuffle and Adam Pascale added the role of Treasurer to that of Webmaster.

We look forward to seeing you next year at a venue near Melbourne, Sharon is already onto it.

Kevin McCue

New California Early Warning System

California will be the first state to get an earthquake early warning system, thanks to a bill signed Sept. 24. And the state's effort should be a model for a national system, one earthquake scientist argues.

Scientists in California have successfully run a test version of the system for two years. Now it's time to set up a similar earthquake warning system along the West Coast, said Richard Allen, director of the Berkeley Seismological Laboratory.

"Earthquakes are a real risk for us on the West Coast, but they come around very infrequently, so they are easy to ignore," Allen told LiveScience. "Earthquake early warning is a proven technology. If we were to have an earthquake next week, [legislators] would be all over building one because it really doesn't cost very much. Are we really going to sit on our hands and wait until we have the next earthquake, or are we going to take the steps to do it now?"

The California system will cost about $80 million to build and run for five years, but the bill does not provide funding. Instead, the law directs the state's Office of Emergency Services to identify sources of funding by January 2016 and develop standards for the statewide warning system.

Extending the warning system to Oregon and Washington would cost $120 million, Allen estimates in an editorial published today (Oct. 2) in the journal Nature. Though California shakes more often than its northern neighbors, both Oregon and Washington are at risk of a massive magnitude-9.0 earthquake from the Cascadia subduction zone, which also lies offshore of Northern California. The fault's last known earthquake was Jan. 26, 1700. The temblor sparked a tsunami that traveled to Japan and drowned trees along the U.S. West Coast.

Much of that money would be spent on hardware: A dense network of modern earthquake sensors, or seismometers, that would accurately detect and report quakes.

After setting up enough seismometers, the next big hurdle in building a warning system is the software. The key is avoiding false alerts, such as an Aug. 8 error in Japan that shut down the nation's bullet trains.

How it works

Earthquake early warning systems are designed to detect the first strong pulse coming from an earthquake, which carries information about its size. This shock wave travels faster than the slower waves that do most of the shaking damage during a quake. The farther you are from the quake's epicenter, the more warning you get.

Photo: View looking southeast along the surface trace of the San Andreas fault in the Carrizo Plain, north of Wallace Creek. Elkhorn Rd. meets the fault near the top of the photo. Credit: Scott Haefner, USGS

In California, the warning may be a minute, or there may be no warning at all. That's because some of the state's biggest cities are built on top of its most hazardous faults. The most famous, the San Andreas Fault, is somewhat distant from Los Angeles and San Francisco. Residents would get several seconds of warning. But much of San Francisco's urban infrastructure sits on top of the Hayward fault, which has a 31 percent chance of a magnitude-6.7 or greater earthquake in the next 30 years.

"We need to build a system that absolutely minimizes the delay in getting the warning out," Allen said.

Japan's earthquake early warning system often provides several seconds to a minute of warning because its greatest seismic hazard is miles offshore: A subduction zone similar to the Cascadia fault line. In Japan, private companies provide phone alerts, radios and other custom applications of the publicly available warnings.

Allen hopes that public-private partnerships similar to Japan's will emerge once the California warning system launches. He said the Berkeley lab is testing an Android app to provide rapid notification of new earthquakes.

The good news is that rolling out California's system will be easy if the funding ever comes through. Though the U.S. operates on a hodge-podge of seismometer networks, they all "talk" via the same software system. The California earthquake alert also collects information from the same software, making it simple to expand the system.

"There is no reason we couldn't roll it out across the nation," Allen said.

NZ Schools Strengthened

http://www.voxy.co.nz/politics/research-reduces-earthquake-strengthening-costs-schools/5/171365

Associate Education Minister Nikki Kaye says ground-breaking research released today by the Ministry of Education has found timber-framed classrooms are extremely resilient to earthquakes.

"This is good news for the education budget because we will not have to spend hundreds of millions of dollars on earthquake strengthening these buildings," Ms Kaye says.

"The research has confirmed these buildings are safe and resilient in quakes. This means that we can focus on modernising buildings to provide better learning environments.

"The Ministry advises me that timber-framed structures account for up to 90 per cent of school classroom and administration buildings.

"Timber-framed school buildings performed very well in the Canterbury earthquakes, with no major structural damage caused by ground shaking. Building damage there was caused by liquefaction, rather than shaking.

"The Ministry advises me that this led to commissioning research to find out definitively whether wooden school buildings needed earthquake upgrading, or whether they were already strong enough.

"This research confirmed that timber-framed buildings are low risk and don't pose a significant life safety hazard in quakes. But it showed that previous models which engineers worked with didn't accurately quantify this.

"As a result of the research engineers are conservatively assessing that the Ministry's one and two-storey timber-framed buildings are twice as strong as previously thought.

"In terms of school buildings which are not timber-framed, outside of greater Christchurch the Ministry is looking more closely at a small group of 1900 out of a total 35,700 buildings to make more detailed engineering assessments.

"These include unreinforced masonry, multiple storey and heavy construction buildings and buildings with a large open area. Based on the individual assessments, they will be prioritised for strengthening work if required.

"In greater Christchurch the Ministry has been assessing approximately 2600 buildings as required by the Canterbury Earthquake Recovery Authority (CERA). A majority of these buildings are timber framed and CERA has agreed to a streamlined approach to the evaluation of timber framed school buildings.

"This research may have wider implications for the nation's wooden buildings, meaning they are significantly more resilient than engineering calculations had previously suggested."

The research - Report on Structural Testing of a Standard Classroom Block in Carterton in June 2013 can be found at: http://www.minedu.govt.nz/DestructiveTesting

http://www.minedu.govt.nz/NZEducation/EducationPolicies/Schools/PropertyToolBox/StateSchools/Design/EarthquakeResilience/DestructiveTesting.aspx

To gather more evidence of the performance of timber framed buildings, the Ministry commissioned the destructive testing of a single storey timber framed classroom block at South End School in Carterton. The testing was undertaken on 15 and 16 June 2013 by the Building Research Association of New Zealand (BRANZ) and was overseen by the Ministry's Engineering Strategy Group (ESG).

The test was performed on two classrooms that formed part of a four-classroom "Avalon" block. This block was selected because it is a common building type that occurs in a number of primary schools in many regions and was scheduled for demolition. Avalon blocks feature extensive glazed facades and clerestory windows, aspects which are also present in a number of other standard classroom designs.

Anchors were fixed to each end of the building and force applied in increasing increments to pull the building in each direction. This was designed to place the building under stresses it would experience during an earthquake.

The whole of building test has confirmed observations from the Canterbury earthquakes about the resilience of timber framed buildings. While failure of some windows occurred at between six and seven times the calculated capacity of the structure, the building continued on to withstand an even higher level of loading without showing any signs of imminent collapse.

Both the longitudinal and transverse tests have also confirmed the view held by many engineers that timber framed buildings constructed prior to modern seismic codes have an inherent lateral resistance and ductility beyond that which can be readily calculated. Timber framed buildings constructed under modern seismic code requirements are expected to have earthquake resilience that meets or exceeds current building code requirements.

BRANZ has published a technical report on the testing, which is incorporated into the Ministry's overall report on the testing.

The Ministry is considering whether other types of school buildings could usefully be tested, in order to enhance the applicability of the test outcomes and to provide further evidence of the resilience of single and two storey timber buildings.

Evidence for a Paleoearthquake Triggering Mechanism

Massive Sensitive Clay Landslide, Quyon Valley, Southwestern Quebec, Canada

Gregory R. Brooks

Natural Resources Canada, Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8, Canada

Abstract

A landslide debris field covering ~ 31 km^2, the presence of large sediment blocks up to hundreds of meters long, and the exposure of deposits of a single landslide along the incised course of the Quyon River are evidence of a massive failure of sensitive Champlain Sea glaciomarine sediments along the lower Quyon Valley, southwestern Quebec, Canada. Seventeen radiocarbon ages indicate that the failure occurred between 980 and 1060 cal yr BP. Twenty-four additional radiocarbon ages reveal that nine landslides within a 65-km belt in the Quyon–Ottawa area also occurred at approximately this time. In combination, the contemporaneous occurrence of ten landslides between 980 and 1060 cal yr BP, the setting or morphology of five of the other failures, and the close proximity of two of the failures to the Quyon Valley landslide provide circumstantial evidence of a paleoearthquake-triggering mechanism.

The paleoearthquake is estimated to be M_w ~ 6.1 or larger, with the epicenter within the West Quebec Seismic Zone. A common earthquake-triggering mechanism for the three largest landslides in eastern Canada suggests a close link between massive failures of sensitive glaciomarine sediments and the regional seismicity.

AEES Contact Details

PO Box 4014, McKinnon P.O. VIC 3204

Email: sandersonsec@bigpond.com

Phone: 0414 492 210

Website: www.aees.org.au

Future Conferences

March 21-23 2014 – Auckland NZ.

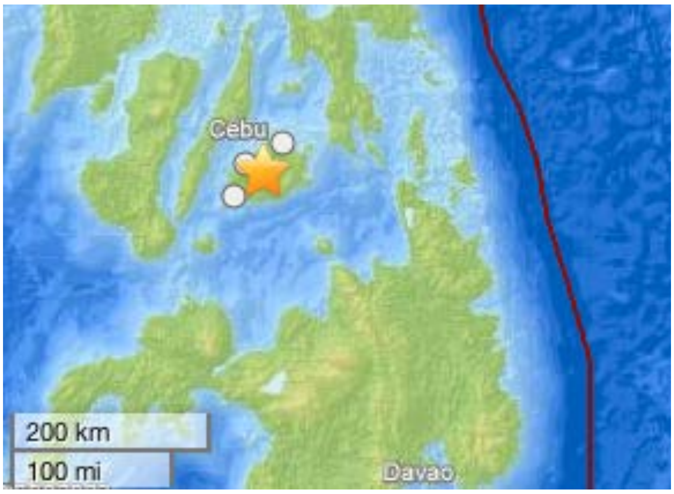
New Zealand Society for Earthquake Engineering 2014 Conference

http://confer.co.nz/nzsee2014/

November 2014 - AEES Annual Conference, to be held in Victoria. http://www.aees.org.au

Earthquake on Bohol Island, Philippines Magnitude 7.1

October 15, 2013



The earthquake occurred as the result of shallow reverse faulting on a moderately inclined fault dipping either to the northwest, or to the southeast. The depth of the event indicates it ruptured a fault within the crust of the Sunda plate, rather than on the deeper subduction zone plate boundary interface. At the latitude of this earthquake, the Philippine Sea plate moves towards the west-northwest with respect to the Sunda plate at a rate of approximately 10 cm/yr, subducting beneath the Philippine Islands several hundred kilometers to the east of the October 15 earthquake at the Philippine Trench.

The Philippine Islands straddle a region of complex tectonics at the intersection of three major tectonic plates (the Philippine Sea, Sunda and Eurasia plates). The region within 500 km of the October 15 earthquake has hosted 19 events of M6 or greater, a dozen of which have been shallow (0-70 km). One of these, a M 6.8 earthquake 70 km to the east of the October 15, 2013 event in 1990, caused several casualties.

Dramatic pictures of a 3m high fault scarp caused during the magnitude 7.1 earthquake have emerged as the government worked to effect repairs in the island of Bohol. Maria Isabel Abigania, a geologist at the Philippine Institute of Volcanology and Seismology, told AFP. "Our people have walked five kilometres so far and not found the end of this wall," she said, as experts from the institute surveyed the damage.

Ground rupture in Brgy. Anonang, Inabanga, Bohol
15 October 2013 Magnitude 7.2 Bohol Earthquake

"So far we have not gotten any reports of people getting swallowed up in these cracks. The fault runs along a less-populated area." A photograph on the institute's website showed part of the rock wall grotesquely rising on farmland behind an unscathed bamboo hut (see above). Another house was shown lodged in a crack of the Earth, while a big hole on the ground opened up at a banana farm.

Renato Solidum, head of the institute, said the ground fissures from the quake, which killed 198 people on Bohol and two nearby islands, were among the largest recorded since the government agency began keeping quake records in 1987. "Most of our other quake records show a lateral (sideways) tearing of the earth, though we've also had coral reefs rising from the sea," he said, citing a 6.7-magnitude earthquake that hit the central island of Negros last year.

The earthquake on Tuesday morning, toppled bridges, tearing down centuries-old churches and triggering landslides that engulfed entire homes. Ten churches, many of them dating back to centuries of Spanish colonial rule of the Philippines, were destroyed or badly damaged in Bohol and the neighboring island province of Cebu. Loon's limestone Our Lady of Light Church was reduced to piles of crushed rock.

Many houses were destroyed or severely damaged including the one pictured below which lost its soft ground storey. Four major roads and 13 bridges were destroyed or damaged on Bohol, seven bridges in Cebu.

Several major power lines suffered outages.

Photo The main concrete road to Buenavista on Bohol seems to have been destroyed by landslide or mass soil movement.

The National Disaster Risk Reduction and Management Council (NDRRMC) said that more than 3 million people from Bohol, Cebu and Siquijor were affected by the earthquake. The towns of Loon and Maribojoc in Bohol, near the epicenter of the quake, were isolated after bridges collapsed and landslides rendered roads impassable, the council said. Reynaldo Balido, spokesman for the NDRRMC, said more bodies were found under the rubble of collapsed buildings, including a hospital in Bohol. First responders retrieved two bodies from the rubble of Cong. Nicasio P. Castillo Sr. Memorial Hospital in Bohol, he said.

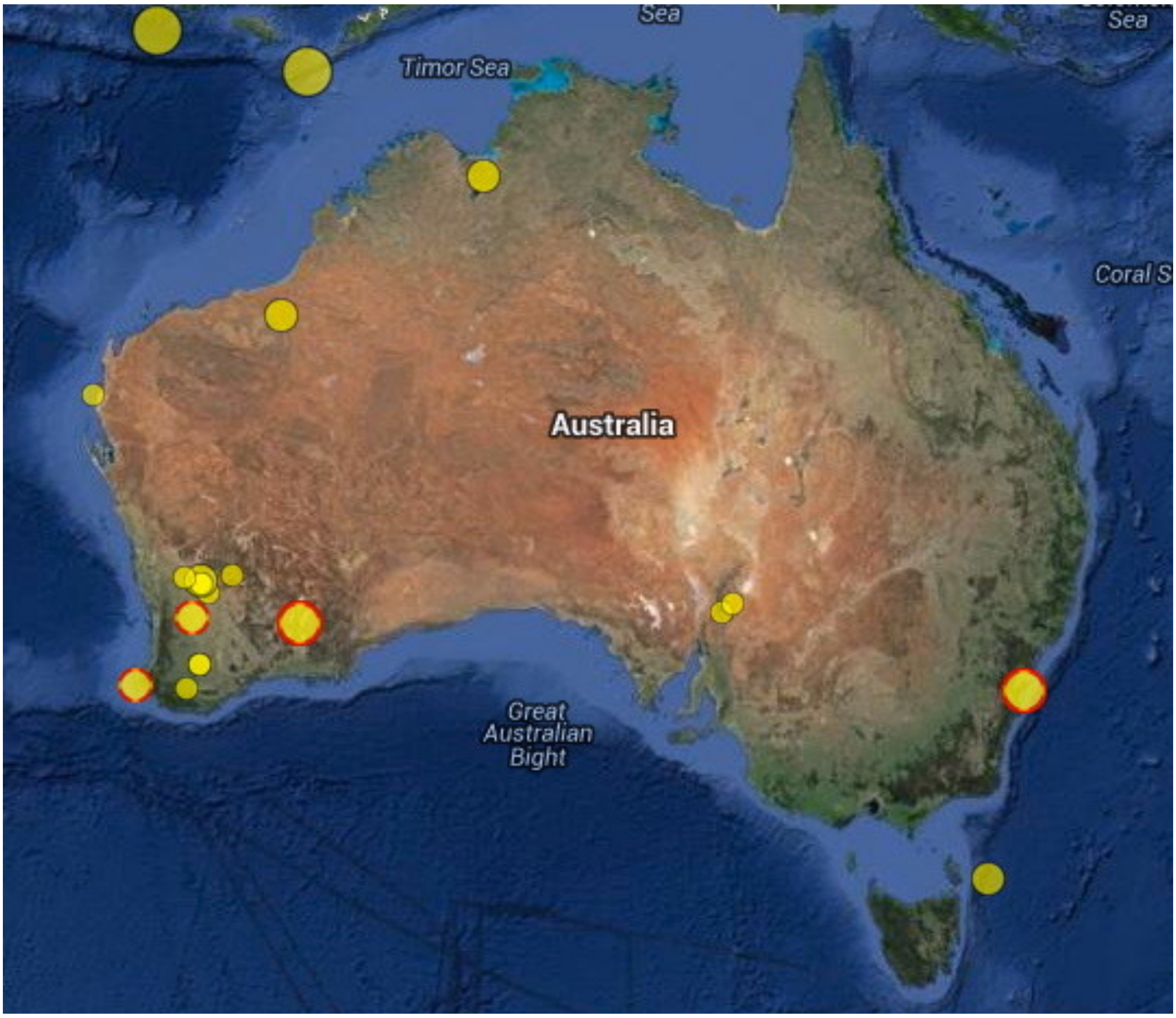
Damaged two-storey house with first floor pressed under the second floor in Maribojoc, Bohol 15 October 2013 Magnitude 7.2 Bohol Earthquake

Australian Earthquakes 01 Sep to 30 Nov 2013

In contrast to the previous quarter, earthquake-wise the last 3 months have been quiet in Australia. The three largest events were of magnitude 3.7, all three in WA. A swarm was in progress near Koorda WA and several earthquakes occurred near Appin NSW. Earthquakes were recorded in all states and territories except Queensland and the ACT, though for some reason the Sale earthquake on 5th November has not plotted.

Table Earthquakes in the Australian region, magnitude 2.5 or greater, located by Geoscience Australia, ES&S and PIRSA. Focal depths are mainly notional, set by the analyst, hence 0, 5 or 10km. The range of measured magnitudes is ±0.2.

UTC Date	UTC Time	Latitude	Longitude	Depth km	ML	Approximate location
05/09/13	17:59:31	-30.96	117.94	2	2.5	SW Mukinbudin WA
06/09/13	19:08:26	-40.41	149.48	0	3.0	E Flinders Is, Tas
06/09/13	11:19:21	-31.66	138.67	0	2.5	Flinders Ranges, SA.
10/09/13	23:48:01	-30.34	118.88	13	2.7	SW Mt Jackson, WA.
12/09/13	14:35:00	-31.33	139.17	10	2.7	Flinders Ranges, SA.
13/09/13	11:58:52	-20.99	120.93	2	**3.7**	Pilbara, WA.
18/09/13	18:36:20	-30.64	117.63	3	2.6	NE of Koorda, WA.
18/09/13	18:02:59	-30.64	117.63	2	2.6	NE of Koorda, WA.
18/09/13	17:58:02	-30.66	117.61	2	2.5	NE of Koorda, WA.
18/09/13	17:31:08	-30.66	117.61	7	2.7	NE of Koorda, WA.
18/09/13	15:47:12	-30.66	117.61	2	2.6	NE of Koorda, WA.
21/09/13	13:41:01	-33.94	114.74	10	2.6	W Margaret River WA.
22/09/13	19:28:58	-33.46	117.62	5	2.5	N of Katanning, WA.
28/09/13	17:02:51	-34.26	117.06	0	2.7	N of Rocky Gully, WA.
28/09/13	04:00:32	-15.61	129.12	0	3.4	NE of Kununurra, NT.
30/09/13	21:14:03	-31.90	121.50	12	**3.7**	Near Norseman, WA.
01/10/13	07:12:00	-33.45	117.57	6	2.6	N of Katanning, WA.
04/10/13	20:03:00	-30.62	117.66	0	3.4	NE of Koorda, WA.
04/10/13	13:35:40	-23.88	113.31	10	2.9	NW Carnarvon WA
07/10/13	20:15:41	-34.17	150.76	0	3.5	Appin, NSW.
09/10/13	03:34:05	-30.64	117.69	10	2.6	NE of Koorda, WA.
10/10/13	20:57:22	-30.47	117.01	10	2.6	NW of Burakin, WA.
10/10/13	01:13:17	-31.67	117.06	3	2.5	Meckering, WA.
11/10/13	11:38:04	-29.27	137.29	10	2.7	Lake Eyre, SA.
14/10/13	15:54:33	-24.05	130.83	0	3.4	SE Lake Mackay, NT.
18/10/13	05:54:01	-30.24	138.61	0	2.7	W of Beverley, SA.
20/10/13	07:52:19	-35.20	123.70	10	3.1	SE Esperance WA
22/10/13	22:29:08	-33.56	138.54	10	2.6	Near Spalding, SA.
22/10/13	07:16:14	-29.64	137.58	10	2.8	W of Marree, SA.
23/10/13	19:52:10	-17.09	120.23	30	3.0	Rowley Shoals, WA.
24/10/13	15:59:42	-32.88	151.31	14	2.5	Pelton, NSW.
24/10/13	12:49:39	-34.18	150.79	8	3.1	Appin, NSW.
26/10/13	10:32:13	-30.21	138.59	6	3.0	NE of Leigh Creek, SA.
27/10/13	00:56:17	-30.15	138.76	6	2.5	NE of Leigh Creek, SA.
29/10/13	07:06:23	-31.97	138.64	10	2.5	SE of Hawker, SA.
30/10/13	22:25:38	-27.79	120.75	0	**3.7**	Near Leinster, WA.
03/11/13	02:51:57	-36.40	149.94	2	3.5	Cobargo, NSW.
05/11/13	16:48:44	-30.65	117.60	12	2.6	NE of Koorda, WA.
05/11/13	10:18:33	-38.32	147.27	3	2.5	SE of Sale, Vic.
12/11/13	08:58:22	-31.35	138.67	10	2.5	Flinders Ranges, SA.
13/11/13	02:42:05	-34.18	150.77	0	2.9	Appin, NSW.
18/11/13	17:43:55	-16.61	128.66	0	3.0	Lake Argyle, WA.
22/11/13	16:59:54	-31.03	138.36	16	2.9	NW Parachilna SA
22/11/13	08:20:31	-35.35	150.93	4	2.7	E Ulladulla NSW
24/11/13	19:25:51	-34.15	150.78	9	2.6	Appin, NSW.
25/11/13	15:39:53	-19.31	124.53	10	3.3	SW Fitzroy Crossing WA



Plotted epicentres as listed in table above from Geoscience Australia.