Tectonics, tsunami and active faults on Omaezaki: hazards for Hamaoka Nuclear Power Plant (M1 Mid-Congress excursion)

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I was looking forward to this field trip. Coming from Christchurch we are not unaccustomed to tectonic activity, so I was curious to visit a country which not only utilised nuclear power, but was also seismically active. What were the challenges in this? A group of 40 INQUA delegates from over 20 countries assembled at the Convention Centre and it soon became apparent that this was more than just a "let's-look-at-some-tsunami-deposits" trip. The wider responsibility of science to society was the purpose of the M1 excursion. The organiser of the excursion, Dr Yugo Ono (who unfortunately was not able to attend personally due to family illness), had stated that he passionately believed that all nuclear power plants (NPP) in Japan should be closed. Moreover, he believed it was the responsibility of Japanese Quaternary researchers to show the Hamaoka Nuclear Power Plant (NPP) to INQUA participants and to discuss its risk and safety from the (objective) viewpoint of Quaternary science.

As we drove through the Urban fringe of Nagoya in our air conditioned, fossil fuelled coach, this wider remit prompted a philosophical moment in my mind: what *do* we use our science for? Sure, it is to publish our research; to feed that curiosity inside us all. But we also have a wider responsibility to society: to promulgate our ideas and research for the benefit of all. But sometimes the dissemination of our ideas can be frustrating: the battle to make the real science visible in a sea of alternative advocacy. There is a danger that the real science issues get drowned out. Often with a paucity of scientific literacy and the proliferation of selectively filtered information through the media, the public struggle to grasp the scientific issues and hence the relevance of science to society and their lives. Dr Ono urged us to consider our roles as scientists in decision making and outlined four idealised roles that are summarised in Table 1. In particular, advocating for a move from a linear model "pure scientist" to a stakeholder model: in particular the "honest broker of policy alternatives" (Table 1).

Table 1. Four idealised roles of scientists in decision making (after Ono (pers comm.) and Pielke (2007).

	VIEW OF SCIENCE	
	LINEAR MODEL	**STAKEHOLDER MODEL**
VIEW OF DEMOCRACY	**Pure scientist** Studies the science only for scientific interest.	**Issue advocate** Intervenes actively in the issues; with a focus of insistence and a narrowing of perspectives.
	Science arbiter Offers data to scientific committees or Government if asked.	**Honest broker of policy alternatives** Scientists who wish to intervene actively in the issues, but not bound to a single insistence. Shows balanced options (both positive and negative) and objective scientific data to society to help widen their perspectives. Allows the public to judge the issues on the facts.

Thus we started our journey, through the science/society nexus and the equally enchanting landscapes of Aichi Prefecture. The planned trip was to drive east from Nagoya to first visit tsunami deposits and uplifted marine terraces close to the Hamaoka NPP. This power plant sits at the junction of 4 tectonic plates (Pacific, Philippine, Eurasian and North American). As a result, this NPP is widely regarded as the most dangerous in Japan. Reassuring.

In 36 degrees Celsius and 80% humidity, we first visited the locations of historic tsunami deposits in the Otagawa river lowland, a strand plain facing the Enshu-nada coast. Always good to set down some unequivocal scientific markers in the landscape, upon which to build the tectonic story. Here, the 1498 Mejo Tsunami deposit was clearly visible as laminated fine sand and silt deposits 20 cm thick, intercalated with the flood plain deposits. The laminated tsunami deposit indicated the repeated occurrence of the sediment flows; tsunami run up and return flows. The tsunami deposit is also very fine grained, and located about 2.5 km inland from the 1498 Mejo coastline. Current ripples in the deposits indicate landward water currents, allowing differentiation from the river flood deposits (Fujiwara, 2014). Three older tsunami deposits are now below the water table, and these represent tsunami events in the 7th, 9th and 11th centuries. Evidently, tsunami events are frequent in this part of the world.

We next moved to view some of the community/local government responses to the tsunami hazard. Recognising that tsunamis are a regular occurrence, the local authorities have been quick to construct appropriate refuge structures. Heisei no *inochi-yama* is a recently built flood evacuation mound, constructed after the 2011 Tohoku-oki tsunami (*Inochi* = lifesaving and *yama* = mound) (Figure 1). Located 1.3 km inland from the coastline, it is an oval shaped mound, the top of which is 10 m asl and can hold approximately 1300 evacuees (Figure 2). Also visible were many steel tsunami evacuation towers. We also saw the Nakashinden *Inochi-yama*, a smaller evacuation mound, built in the Edo era (17th – 19th Centuries). It is now tucked away somewhat incongruously, behind suburban houses. Clearly, this is a community used to living with tsunami inundation. The scientific evidence in the landscape was clear: tsunamis have happened in the past and are expected to happen in the future. Fact.

And so onto the Hamaoka NPP. To aid our understanding of the societal impact of the NPP we had with us Aileen Smith, of Green Action. Aileen is a passionate environmental advocate; her first environmental advocacy work was being involved with the Minamata disaster back in the late 1960's. In addition, there is currently a lawsuit against the Hamaoka NPP, seeking the permanent decommissioning of the reactors. The lawyer representing the plaintiffs, Mr Yuki Kaido, was also in attendance to fill us in on the wider societal impacts of the NPP.

Figure 1. Heisi no *inochi-yama*, a tsunami evacuation mound built in 2012. (Photo credit: Carol Smith)

Figure 2. View from the top of the Heisi no *inochi-yama*: designed to accommodate 1,300 people. Squeeze up everyone! (Photo credit: Carol Smith)

The location of the Hamaoka NPP is a geologically challenging one. It is located within a syncline, sandwiched between the Atsemi upwarping to the NW and the Ebshu-Nada flexure to the SE. The Hamaoka NPP commenced operation in 1976, but the extent of the tectonic setting was (apparently) not fully appreciated at that time. There are 5 reactors, with two currently being decommissioned (following hydrogen explosions in 2006) and the remaining 3 being offline for safety checks and remedial seismic strengthening. Following the 2011 Tohoku-oki Tsunami and the inundation of the Fukushima Dai-ichi NPP (490 km to the north), all NPP's were closed in Japan to allow for safety checks. All the reactors except the most recent one, are BWR (boiling water reactors – the same technology as at the Fukushima Dai-ichi NPP). Once at the Hamaoka NPP, we were shepherded up to the observation tower, where we had a panoramic view (from 62 m asl) of the compound and the surrounding landscape. Cameras were strictly prohibited, with vigilant security guards present to ensure compliance. A quick Google search afterwards demonstrated the futile nature of their request (for example http://fukushimaupdate.com/safety-screening-sought-for-hamaoka-reactor/). From this vantage point, we learnt of the two major seismic risks to the NPP.

Firstly, earthquake. The subduction of the Philippine plate under the Pacific plate results in the Nanki-Sugura trough offshore. Significant local earthquakes in the past associated with this system have included the M8.4 Ansei-Tokai (1854) and the M8.4 Hamaoka To-nanki (1944). Historically, there have also been earthquakes centred north of Hamaoka NPP at Odawara (1633, 1782 and 1853) and the 1923 Great Kanto Earthquake in Yokohama. The outer edge of the continental shelf has been deformed by the active Enshu-nada and Kumano-nada flexure. An inferred active fault related to this flexure could generate a significant earthquake at the plate boundary. Of equal concern is a fault line under the NPP itself.

Secondly, tsunami. The NPP is built on a reclaimed back beach of the Niino River, behind a fore dune and is at 6-8 m asl. This part of the coastline consists of late Pleistocene fluvial and marine terraces and more recent Holocene marine terraces, clearly demonstrating evidence of recurring millennium scale seismic uplift events. The marine terraces are covered by thick aeolian sand deposits. We observed construction of a 22 m high tsunami wall, anchored into the friable mudstone of the Plio-Pleistocene Kakegawa Group. The coastal sea wall defences on the beach designed to disperse energy were indeed impressive. But having just observed the sequence of tsunami deposits on the Otagawa River and appreciating the tectonic setting, the tsunami risk at this site is clearly significant. A projected tsunami wave height of 19m has been modelled, based on a possible local source region of a M9.1 Tokai earthquake. While there is only a 3% probability of a tsunami >19m high, the fore dunes in front of the wall offer a run up "ramp" that would likely result in a wave coming close to overtopping the wall.

Combining these seismic risks, we were told that the concern here is of a *genpatsu-shinsai* – or domino-effect NPP disaster (a phrase coined by Prof. Ishibashi in 1997). This is where a major earthquake causes a severe accident at a NPP, near a major population centre, resulting in an uncontrollable release of radiation and significant local and global economic and societal consequences. 860,000 people live within 30 km radius of the Hamaoka NPP and major transport arterial routes are nearby. Evacuation of the area would be challenging, despite the man made "refugia" or *inochi-yama* and evacuation towers we saw earlier in the day.

Further evidence of this flexure zone caused by the tectonic setting was seen at the last stop of the trip– the uplifted MIS5a marine terrace at Omaezaki Cape. Here, the Enshu-nada flexure stretches NE and continues to the Makino-hara flexure, which has tilted the MIS5e-d surfaces. The MIS5e-d geomorphic surface is presently covered by immaculately clipped tea gardens, and formed of thick marine deposits including sands and gravels deposited during a regression, following a peak of marine transgression of the MIS5e. The Makino-hara surface is intensively tilted and uplifted to the SE, reaching >160m asl in the NW to around 40m asl in the SE. This is in fact the highest MIS5e surface on the Japanese mainland.

This evidence in the landscape begs the question – why build a NPP in such a high risk area? The answer partly lies in the fact that each electricity company in Japan is required to generate electricity from within their own geographical region. Hamaoka must have ticked a number of boxes, apart from that for avoiding seismic risk. Ironically, following the closure of all NPP for safety checks in 2011, Japan has been generating nuclear-free electricity for close to 2 years (with the first recommissioned NPP coming back on stream in August 2015). But at the cost of fossil fuel – generated electricity.

Figure 3. Aileen Smith outlining the challenges of locating a NPP within a seismically active landscape (Photo credit: Carol Smith)

So, where does this leave electricity power generation in Japan and the role of Quaternary Science? With our "pure scientist" hat on, we observed during the trip some impressive and objective evidence of seismic signatures in the landscape in the form of tsunami deposits and tectonic uplift. Plus some power-generating infrastructure at risk of damage. Now viewing this through the "honest broker" lens, clearly the message from the seismic signatures does not sit conformably with the NPP infrastructure, and the community must be made aware of both the positive and negative aspects of the NPP.

And therein lies the challenge: the science message is clear, but it sits within a social-eco-political setting and decision making process. For the wider community to judge properly the issues involved also requires a level of understanding and scientific literacy: free from unbiased, selectively filtered information. How often have we heard that? Perhaps there is some merit in adopting the "honest broker" approach in our current science/policy debates around climate change.

With thanks to Prof Yugo Ono, Prof. Hirakawa (Hokkaido University) and Dr. Osamu Fujiwara (Geological Survey of Japan) for guiding us through this complex landscape where Quaternary science meets society. Aileen Smith and Yuki Kaido who offered us highly informative views and a valuable insight into the societal impacts of NPP's.

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