Control of induced seismic hazard associated with the hydraulic stimulation of a hot fractured rock geothermal reservoir

Steve Oates, Julian Bommer et al

Acknowledgements:

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Thanks to ISS International who supplied, installed & helped maintain the seismic system.

Talk based on material presented in the Engineering Geology paper:

Control of hazard due to seismicity induced by a hot fractured rock geothermal project

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Outline

- Background: the area and recent earthquakes
- The traffic light – conceptual framework
- Seismic catalogue and hydraulic data
- What is the difference between Geothermal and Oil & Gas stimulations?
- Conclusions

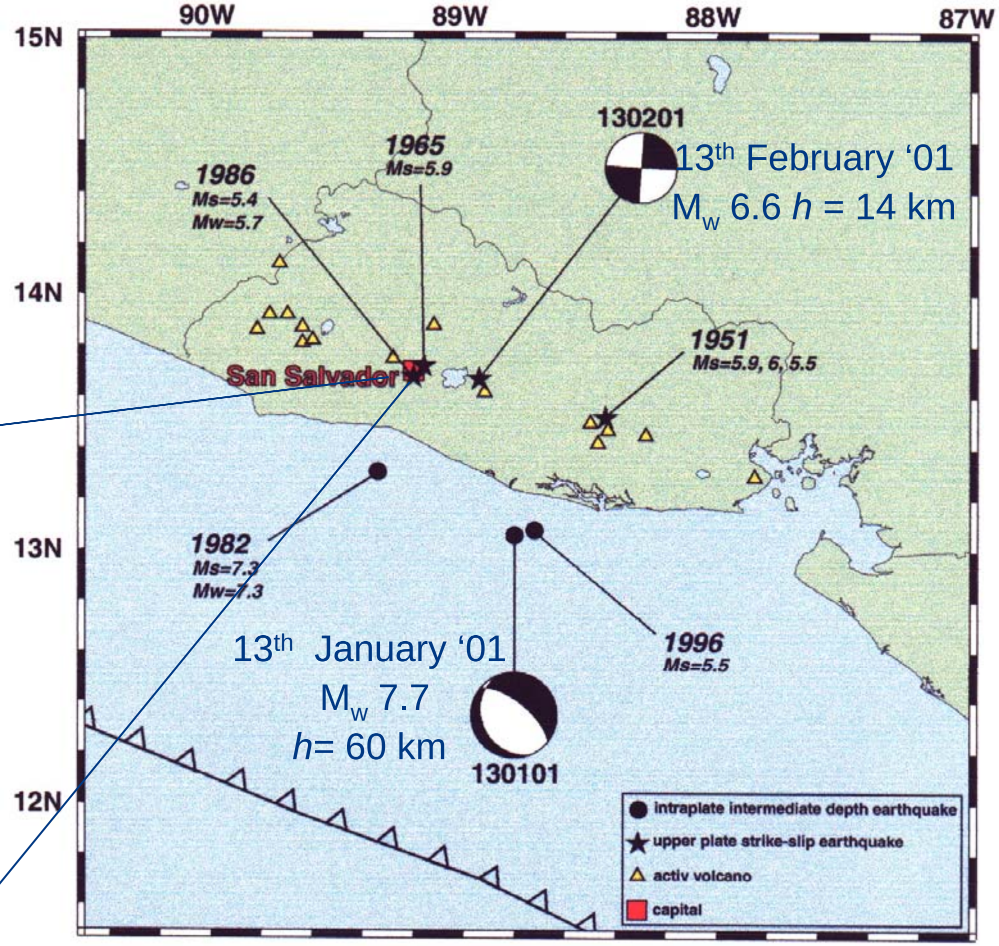
El Salvador and the Berlín Geothermal field


Volcán Chichontepeque

Faulting in recent volcanic deposits along a road cutting near San Martín

An area of high natural seismicity and high risk

Landslide at Santa Tecla triggered by 13/01/01 event



Recent major earthquakes in El Salvador.

Damage to vulnerable buildings due to 2001 events

Adobe (sun dried clay brick)

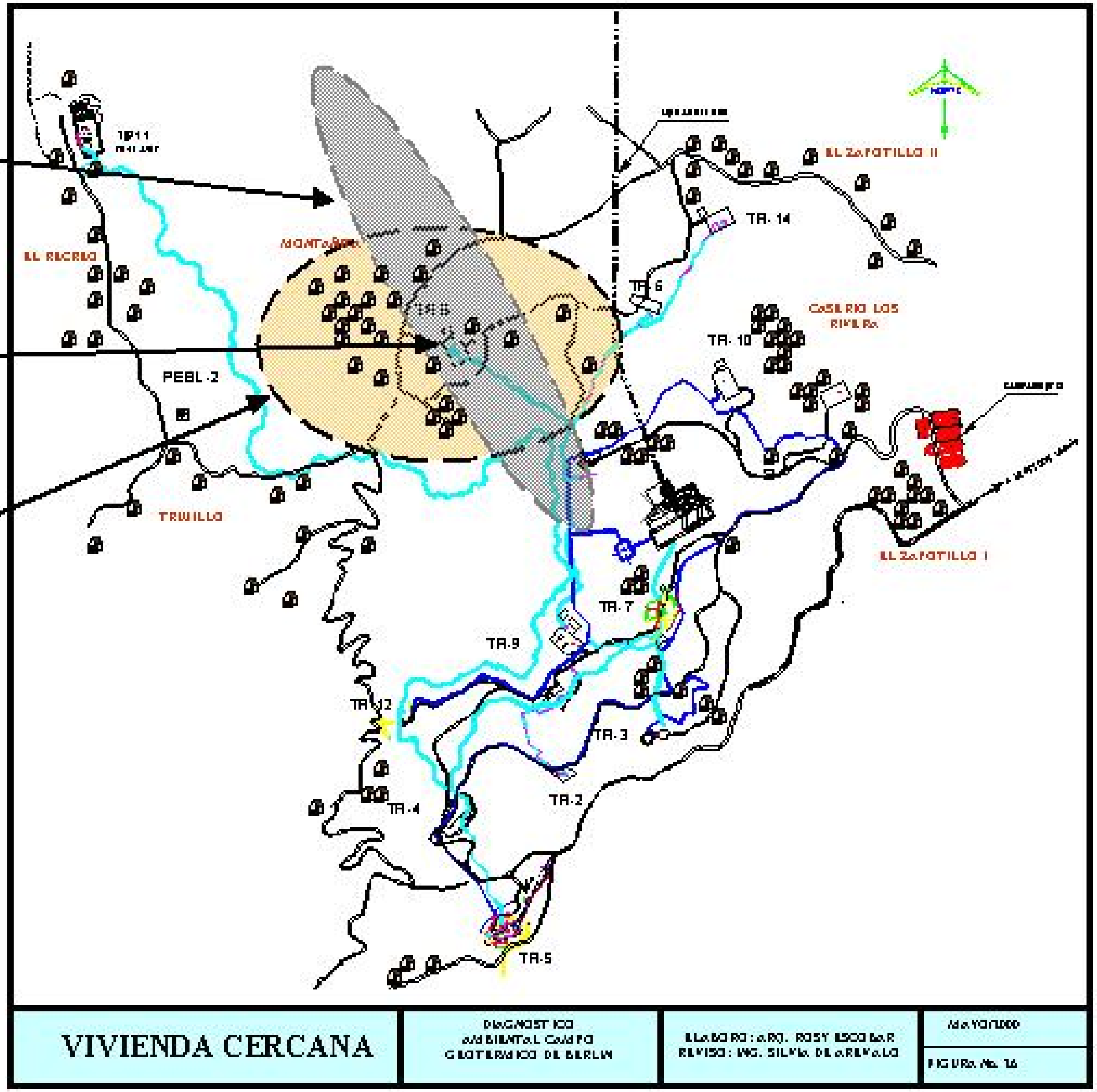
Bahareque (wattle and daub)

Hydraulic injection operations in a populated area

Likely stimulated zone, projected onto surface

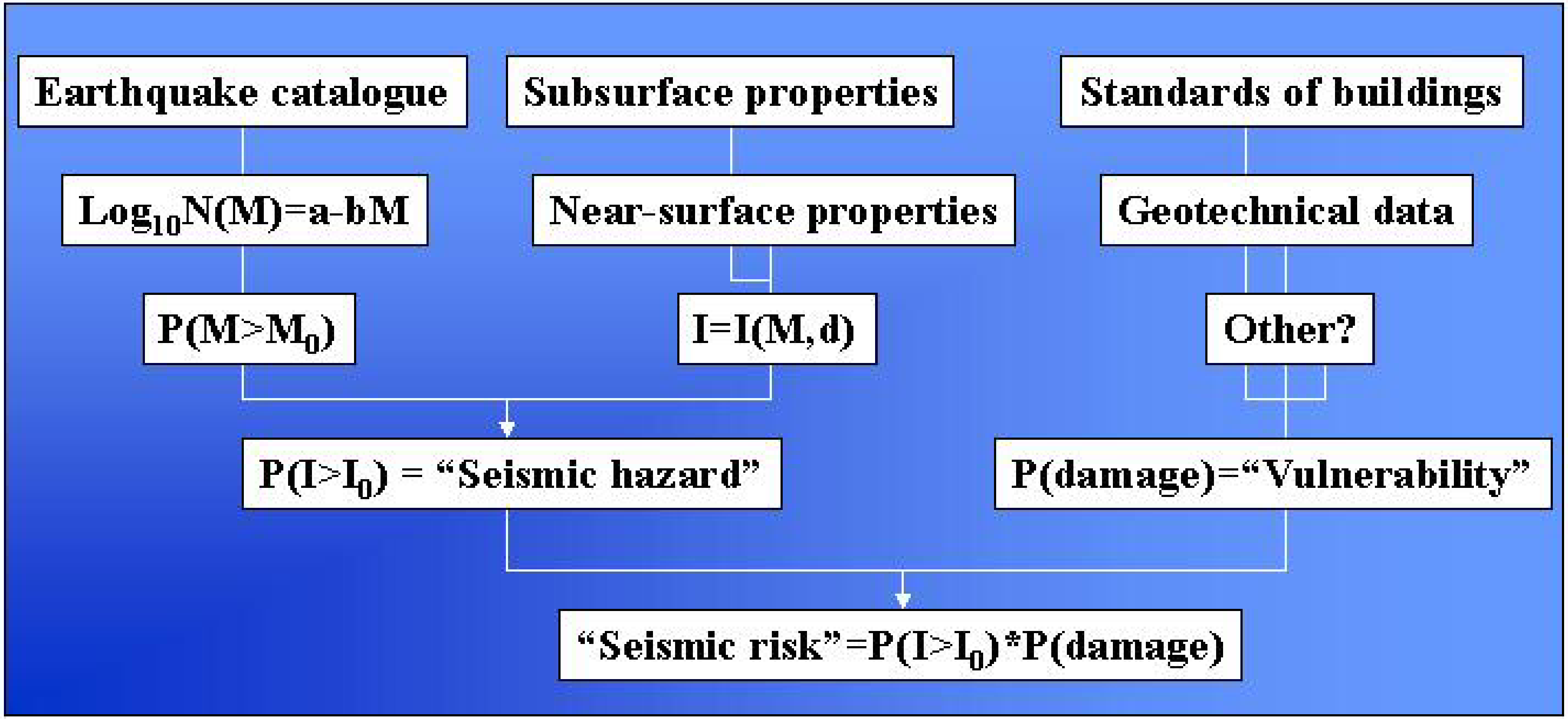
TR8A

Check near surface conditions for increased local seismic risk



Significant number of low quality dwellings in the area around well TR8A.

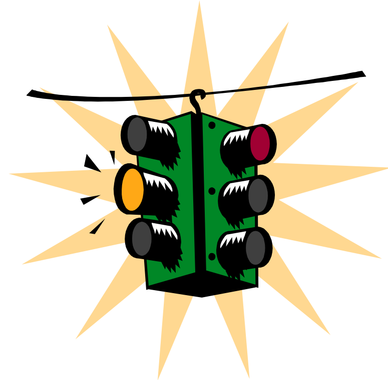
Summary of seismic hazard analysis (after Udías)



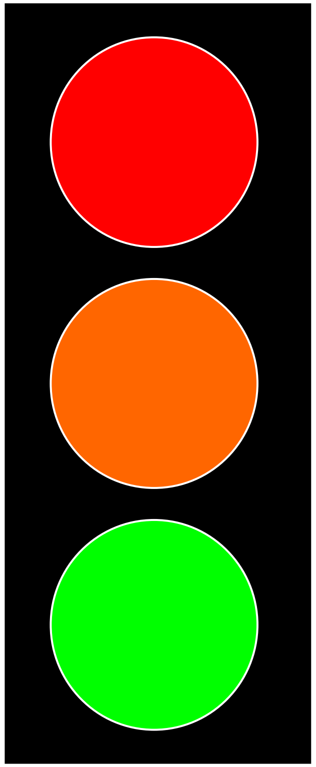
Based on discussion in Udías, "Principles of Seismology".

Conceptual framework

Control of the injection process



A clearly defined control strategy based on pre-defined thresholds of intensity of induced ground movements and frequency of occurrence.



•Red. The fracc is going out of bounds or seismicity is exceeding acceptable levels. STOP or reduce pump rate and reassess.

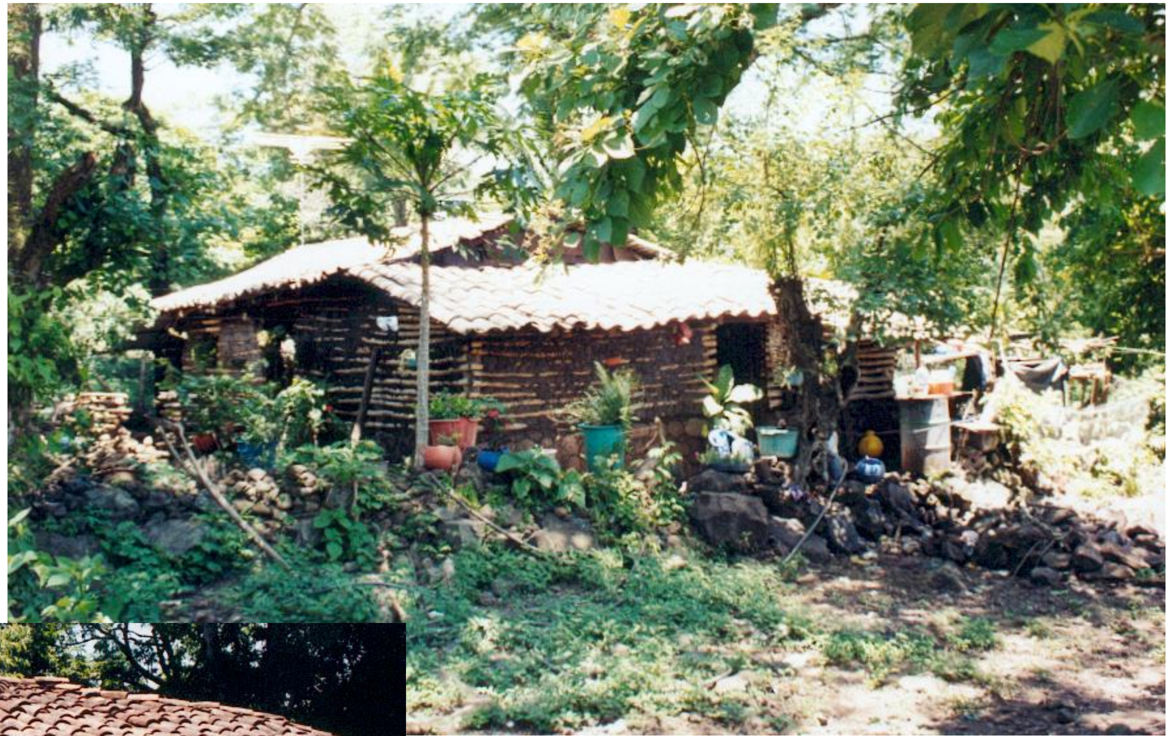
•Orange. The fracc is growing away from planned direction or level of seismicity is higher than expected. CAUTION – be ready to stop.

•Green. Fracc growth and levels of seismicity within planned bounds. GO – continue and maintain regular reporting.

The elements of the traffic light system

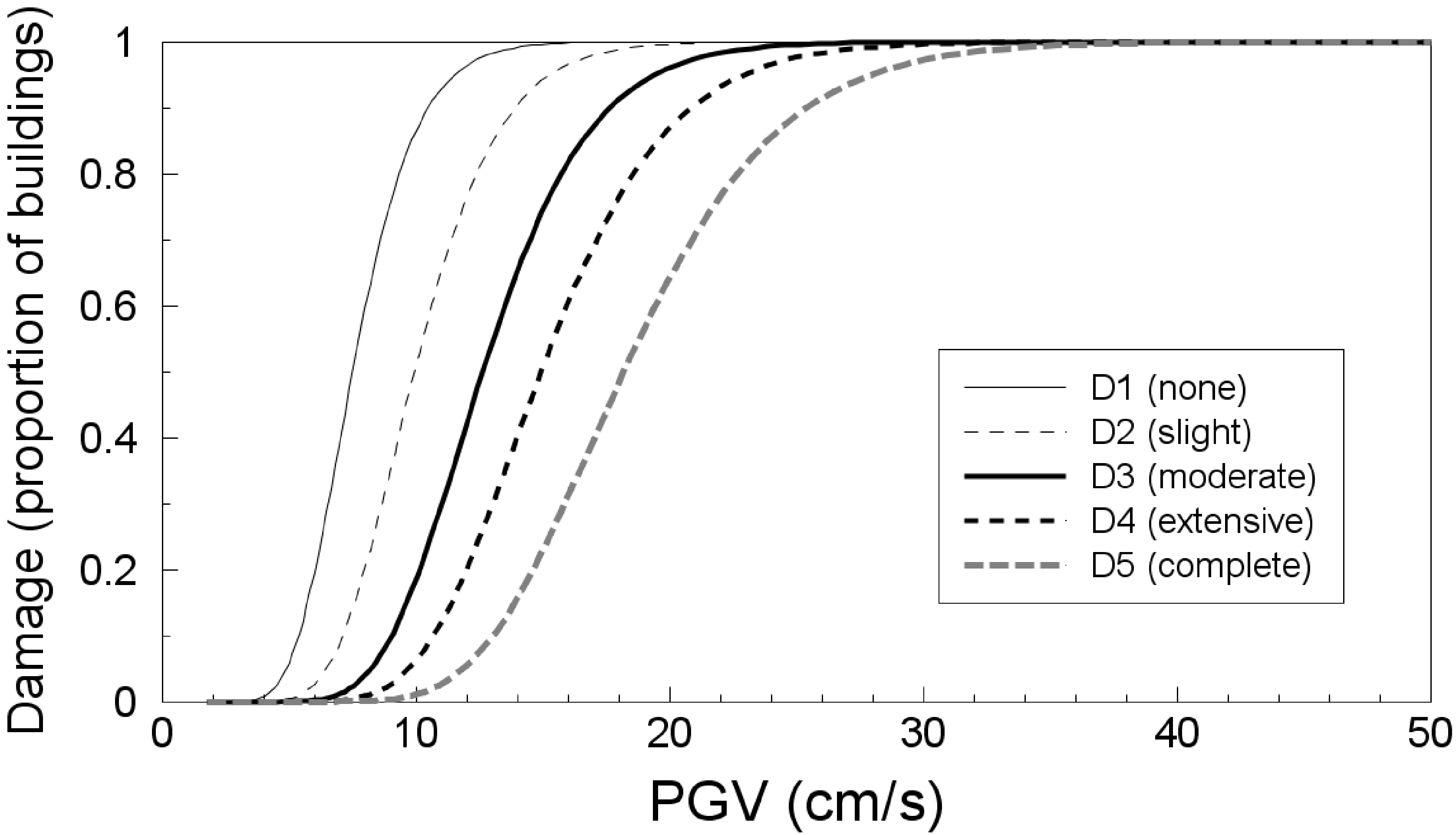
1. Incorporates basic elements of seismic hazard analysis
   - Analysis of background seismicity
   - Derivation of PGV attenuation relation from analogue data
   - Vulnerability estimates based on survey of local buildings
2. Constructed in terms of PGV (more indicative of damage potential than PGA)
3. PGV-equivalent magnitude derived for each event
4. Near real-time data processing – events mapped onto pseudo Gutenberg-Richter plot.
5. PGV thresholds on pseudo Gutenberg Richter plot derived from:
   - Guidelines for induced vibrations (eg. blasting, traffic, pile-driving)
   - Correlations between PGV and Modified Mercalli Intensity
   - Vulnerability curves for local housing
6. Accelerographs at 3 key locations – used to update PGV attenuation relation

Hydraulic injection operations in a populated area



Bahareque housing near TR8A.
Note the typical heavy roof on a weak framework.

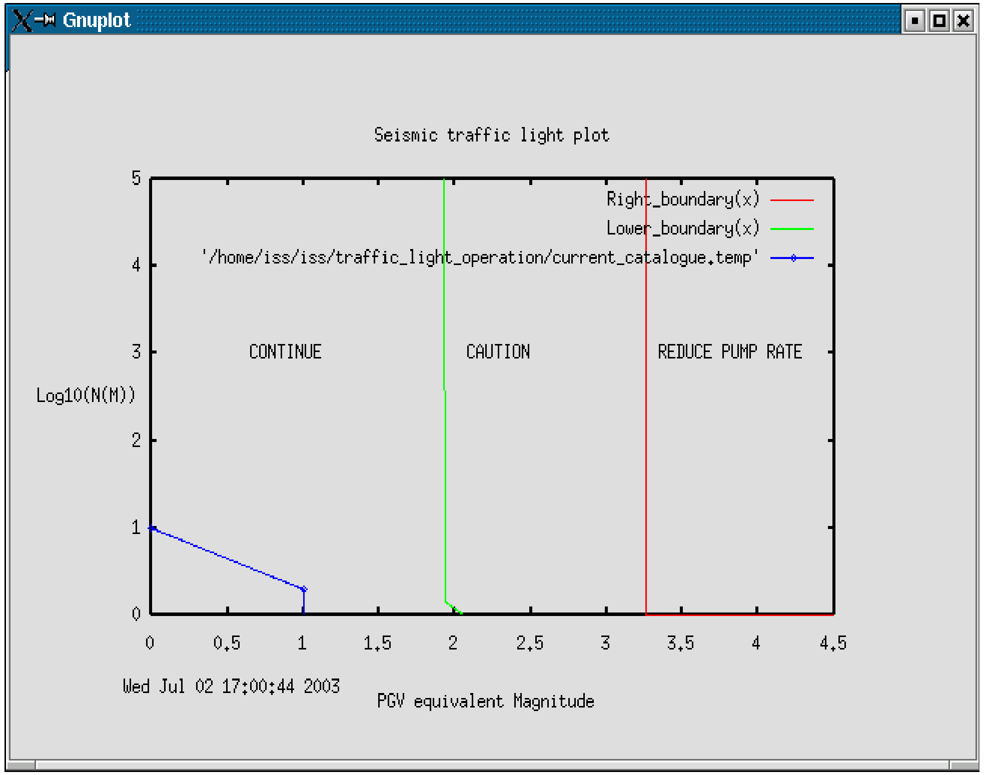
Vulnerability curves for local housing stock



The traffic light plot & PGV-equivalent magnitude

Attenuation relation for PGV:
$\log_{10} PGV = a + b\,M - c \log_{10} R$

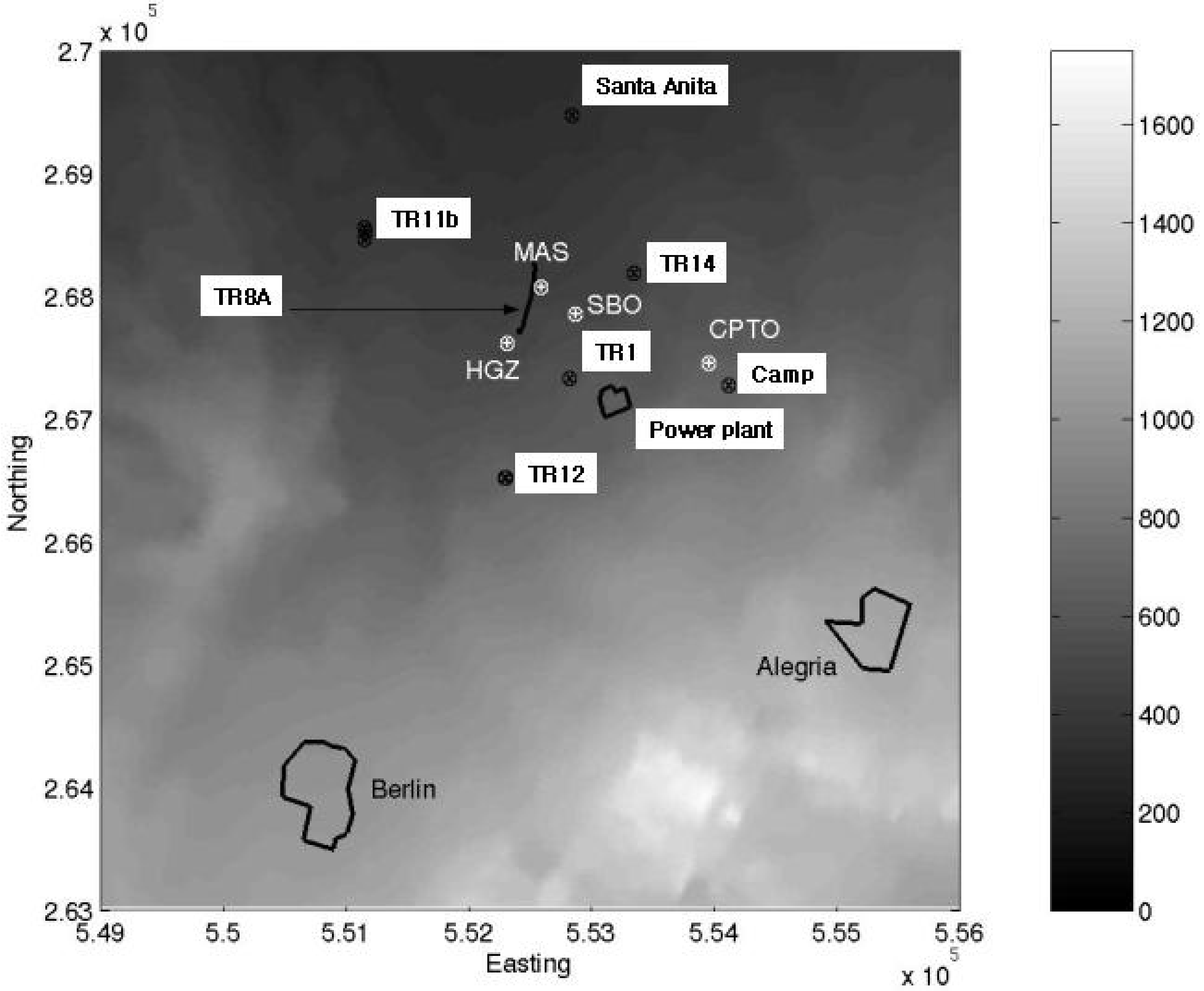
PGV-equivalent magnitude then defined with respect to a reference depth:
$M_{equiv} = M + (c/b) \log_{10} (D_{ref} / D)$



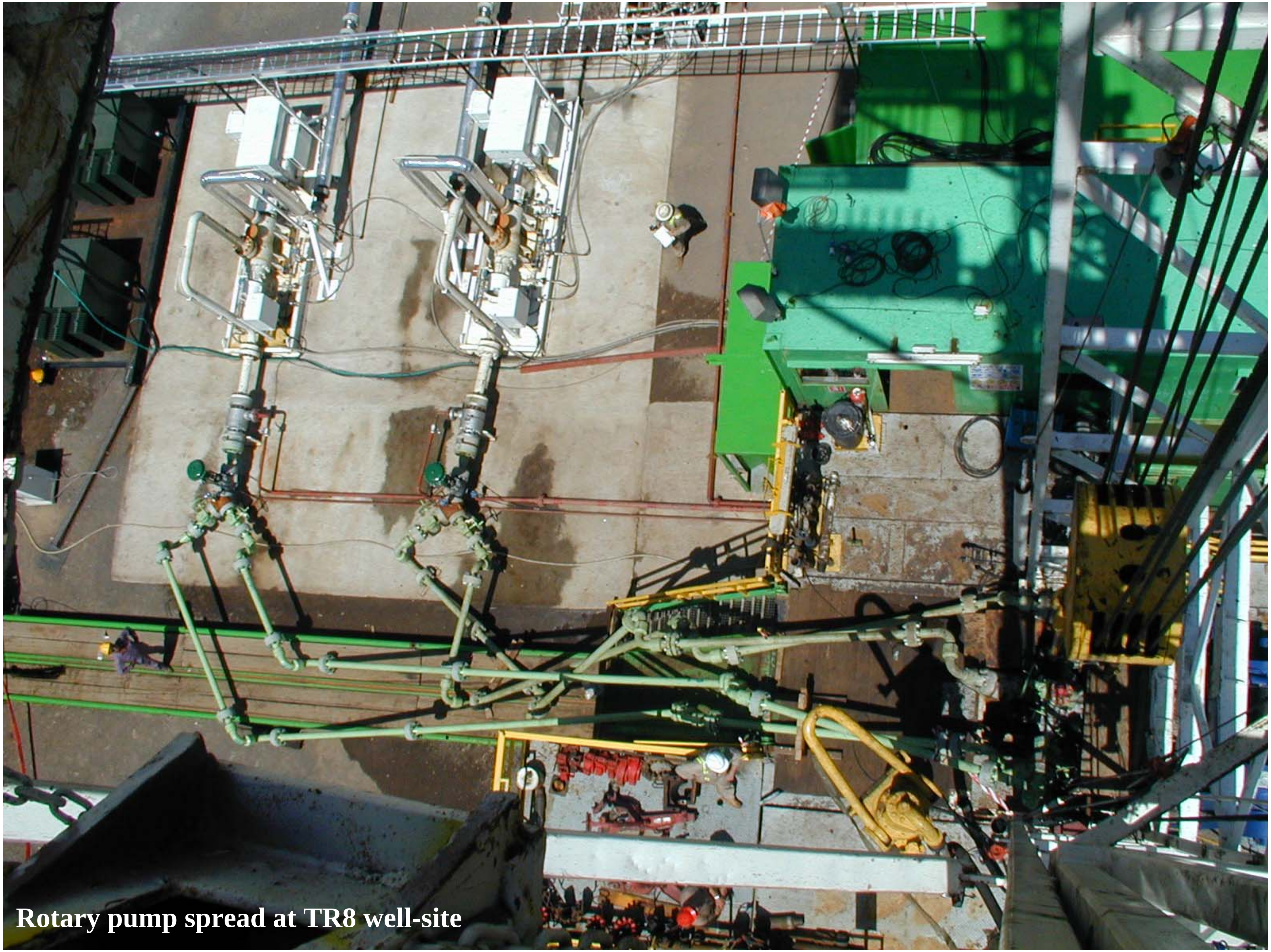
Traffic light operation:
The following steps executed automatically (using *cron* facility)

- Event hypocentre and magnitude determined in (near) real-time
- PGV at epicentre estimated using attenuation relation
- PGV-equivalent magnitude calculated for a depth of 2km
- Data point added to traffic light plot (pseudo Gutenberg-Richter plot with thresholds) displayed on screen in pump control room

Map showing layout of monitoring array



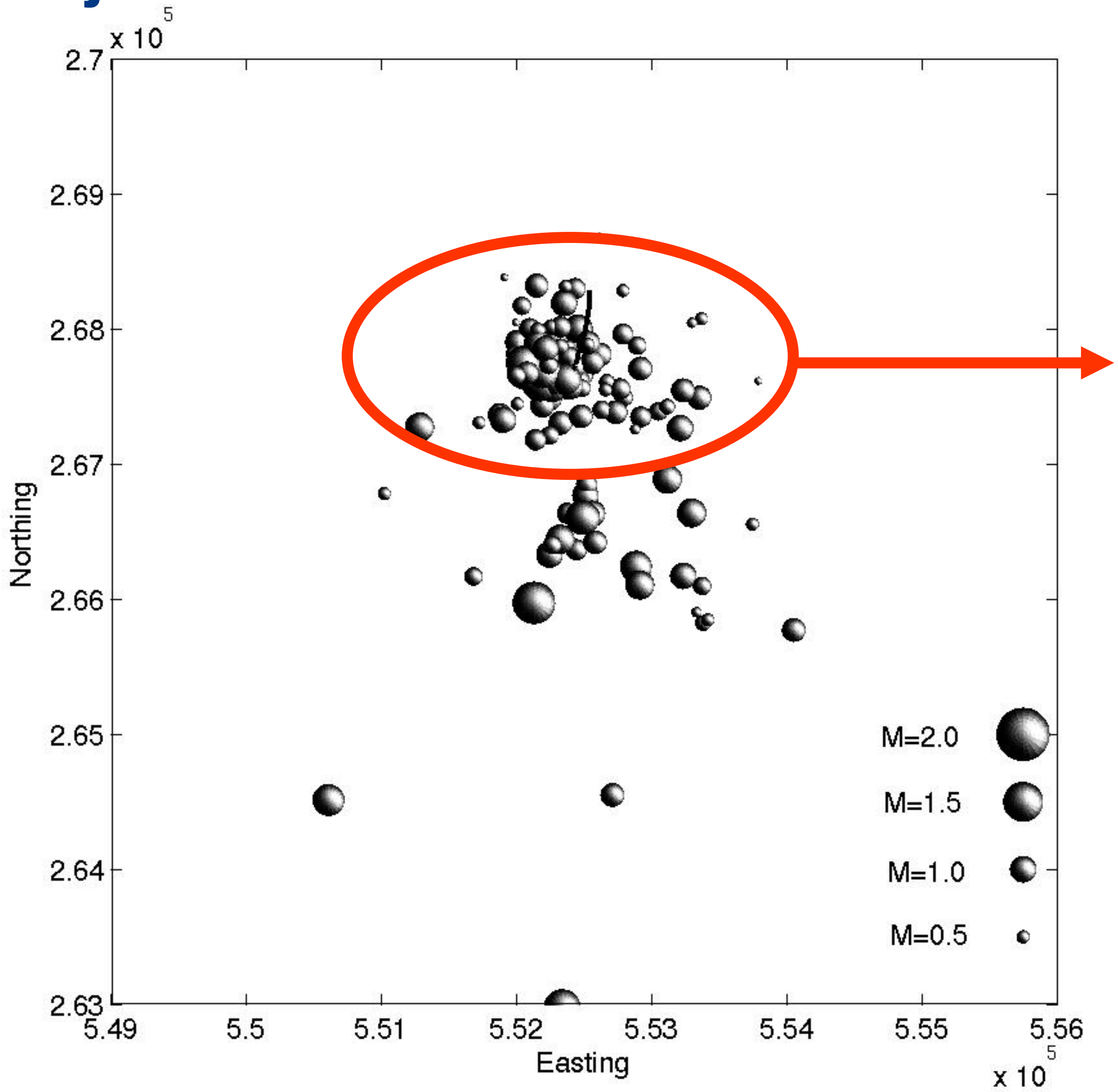
Black symbols – stations of the ISS network
White symbols – ETNA accelerograph stations
Grey scale gives ground elevation in m above mean sea level



Rotary pump spread at TR8 well-site

Data acquired

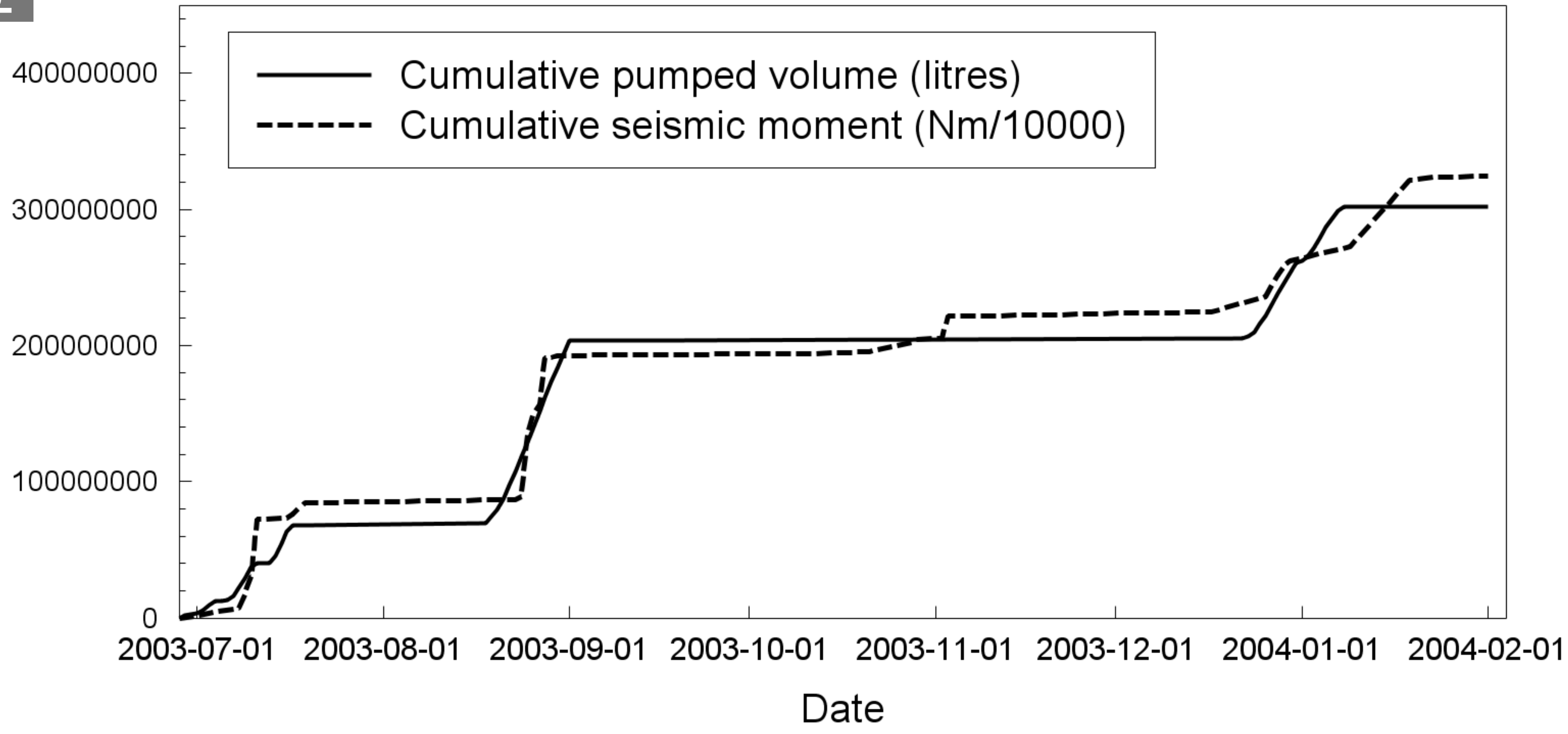
Map view of event locations from periods of injection



Considering only the events in the immediate vicinity of TR8A…..

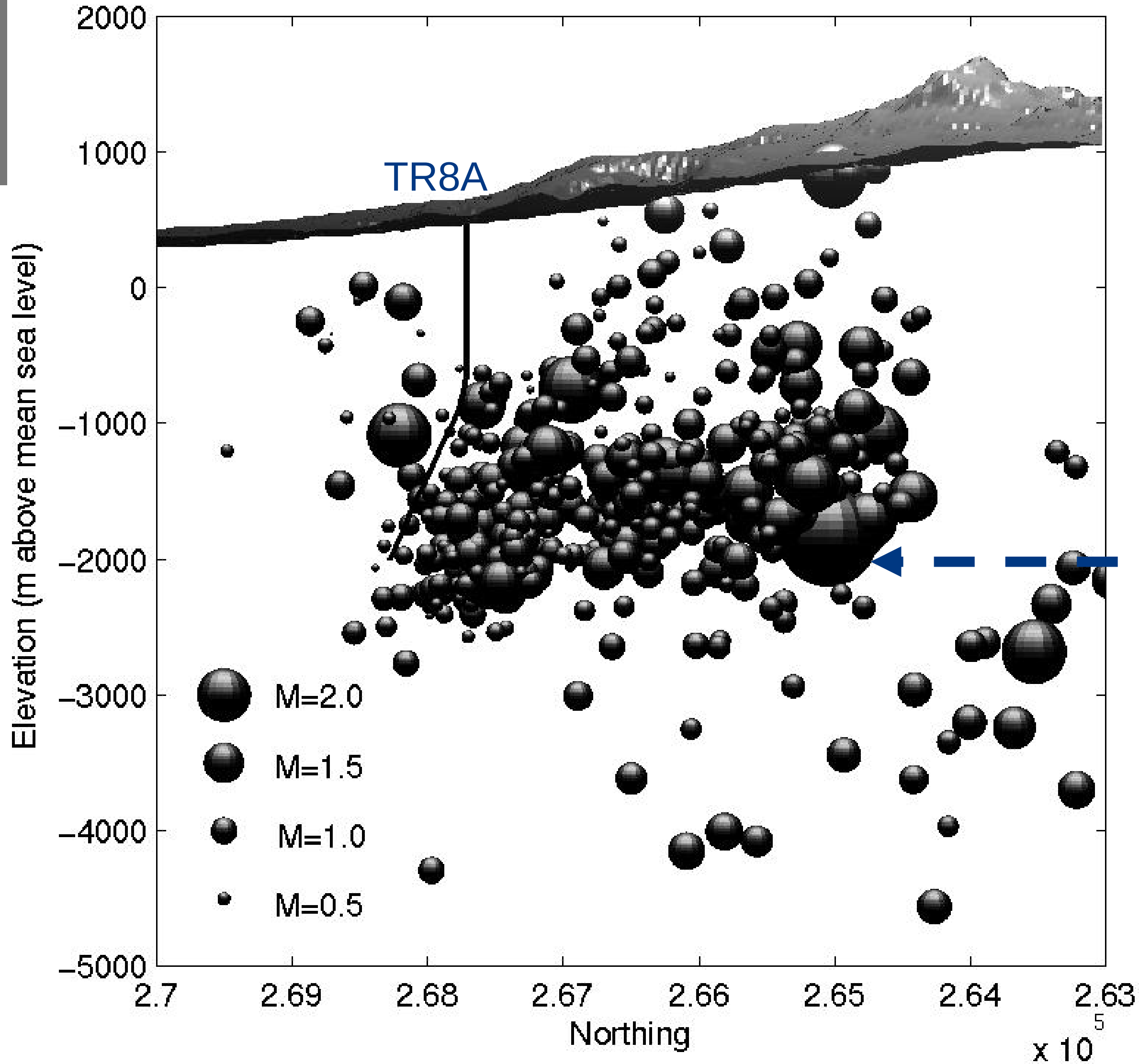
Data acquired

Cumulative moment against pumped volume



McGarr plot taking only the events in the neighbourhood of TR8A.

Complete seismic catalogue for project



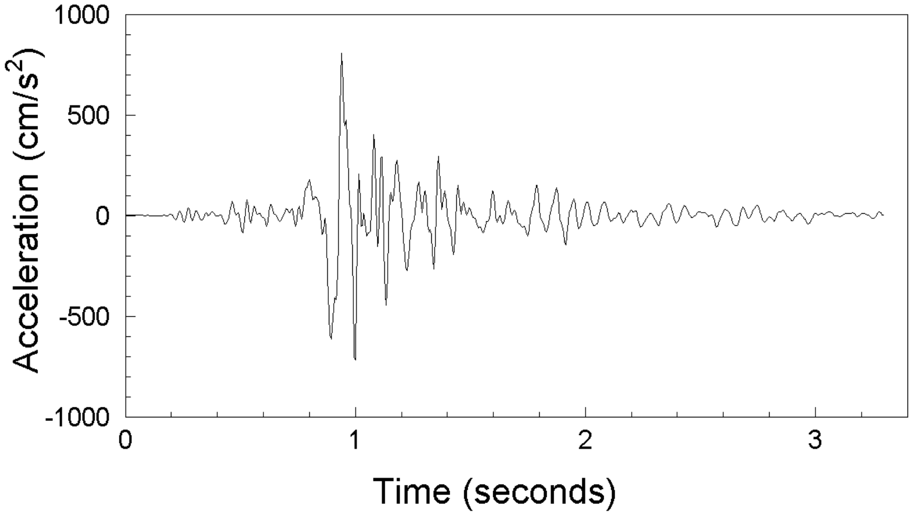
Largest event: M 4.4 on 16-9-03

Occurred during interval between injection phases, 3km south of TR8A on other side of geothermal field production zone – is it possible to say whether it was coincidental or induced?

Section view showing all event hypocentres 30th October 2002 – 12th February 2004

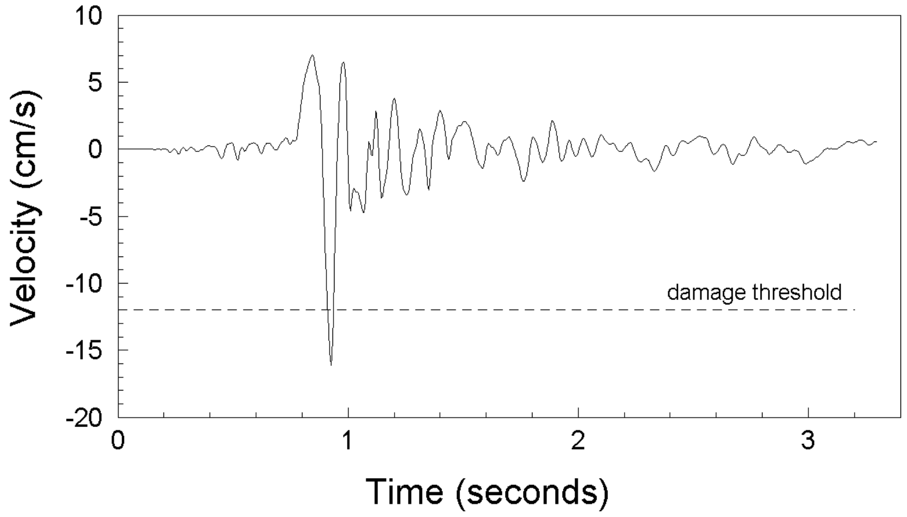
The large event of September 16

Strong-motion accelerograph recorded at MAS during 16 September event



PGV damage ***threshold*** exceeded ….

….but no reports or observations of damage (lower PGV values observed at SBO & HGZ)



Comparing typical HDR and oil&gas projects

…. for discussion

	HFR Geothermal	Oil and gas
Rock type	Hard	Soft
Stress regime	Unstable	Stable
Permeability	Low	High
Seismic activity (background)	High	Low
Hydraulic fracturing	Long T, high V	Short T, low V
Felt seismicity during hydro-fracs?	Yes	No**?**
Felt seismicity during production?	No**?**	Yes
Long term disposal/re-injection	Yes	Yes
Primary risks	Induced seismicity during stimulation or circulation	Compaction during production or breach of cap-rock during injection
Risk management options	Active control of injection (acid frac, traffic lights,…) then manage as community issue	Full project risk analysis (+active control of injection) then manage as community issue

Conclusions

•A workable and rational system for monitoring and controlling hazard due to induced seismicity – being adopted by other projects (eg. Basel)

•Thresholds designed conservatively and vindicated by observations and recorded motions

•Induced seismicity lower than expected so system not fully tested.

•Approach does not address the problem of post shut-in events.

•Induced seismicity a more immediate hazard for geothermal projects….

•…. but better chance of controlling hazard than in oil and gas projects

Learnings & outstanding issues

•Must develop techniques for addressing the post shut-in events

•Requires good quality real-time processing: autopickers must be improved

•Need good coverage and location accuracy

•Integrate accelerographs as remote stations in the monitoring array

Aiden Bernie with the pump system he designed and installed