Induced seismicity during EGS operation?

L. Rybach (GEOWATT AG, Zurich)

- Induced seismicity due to EGS stimulation is common and useful: it can depict reservoir development in space and time. The event magnitudes rarely exceed M=3.0.

- Possible, even larger events due to EGS operation (for heat and/or power production) cannot be excluded. Experience in high-enthalpy fields show that prolonged fluid withdrawal or injection can lead to noticeable ground shaking.

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Man-made seismicity (MMS)

Some level of MMS due to EGS operation must be expected;

Both fluid production and (re)injection can cause MMS, both in hydrocarbon and geothermal reservoirs;

The potential for noticeable MMS events at a given site depend on local conditions as well as on technicalities like fluid flow rate;

There is experience with MMS and there also expectations….

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Conceivable measures – DEEP HEAT MINING PROJECT Basel

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Procedures in case of perceived seismicity

PRELIMINARY WORKING PAPER

Stage		A phase is defined when at least one of the three criteria applies: Event			Measures						Communication		
		Magnitude M_L	Peak ground velocity cm/s	Public perception	Permanent measures	Interruption	Pumping regime	Pressure regime	Monitoring system	Resume operations	Project team	Authorities / Institutions	Public
1	"green"	< 2.0	< 2	none	permanent recording of injection pressure, draw down, pump rates, volumes, temperatures, regional seismicity, local microseismicity, surface vibrations near borehole	none	regular operation	regular operation	regular operation	-	standard reporting	standard reporting	-
2	"yellow"	> 2.0	2 - 3.4	few calls		none	reduction of the pump rate	pressure reduction	additional check of full operation of monitoring system	Resumption of operation after minimal 12 hour shut down period	report to PL, PE, GF	adhoc operations meeting	Communiqué on website
3		> 2.5		some calls		m	stop pumping	bleed off excess pressure	check data recording, inform SES	Integrated seismic and hydraulic data interpretation; adjust operation parameters	alarm PL, PE, GF	operations meeting with SES and Kantonsgeologe	Communiqué on website
4		> 3.0		many calls		until cleared	stop pumping	bleed off excess pressure	check data recording, alarm SES	Integrated seismic and hydraulic data interpretation; reduce operation parameters; evaluate alternative frac-methods (eg acid frac)	alarm PL, PE, GF; inform board	operations meeting with SES and Kantonsgeologe	press release to media
5	"red"	> 3.5	> 3.4	generally felt		until cleared	stop pumping	bleed off excess pressure	check data recording, alarm SES	Following review; board decision, permission by authorities	alarm PL, PE, GF; inform board	operations meeting with SES and Kantonsgeologe, Sicherheits-inspektorat	press conference and pressrelease to media

Haering (2006), 3rd IEA GIA Annex I Subtask D Workshop

For any EGS site, the monitoring of local seismicity by a suitable seismometer array, starting well before stimulation/production activities, is indispensable to provide reliable base-line information on the pre-EGS situation. Besides, technical and social issues must be carefully addressed during EGS planning and realization.

Should EGS reach its full potential the issue of MMS must be addressed to the point of public acceptance.

In such a situation it is advisable to look at existing experience, especially with geothermal reinjection.

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A quick summary of some experience with MMS

The Geysers (USA)

Larderello (Italy)

Berlin field (El Salvador)

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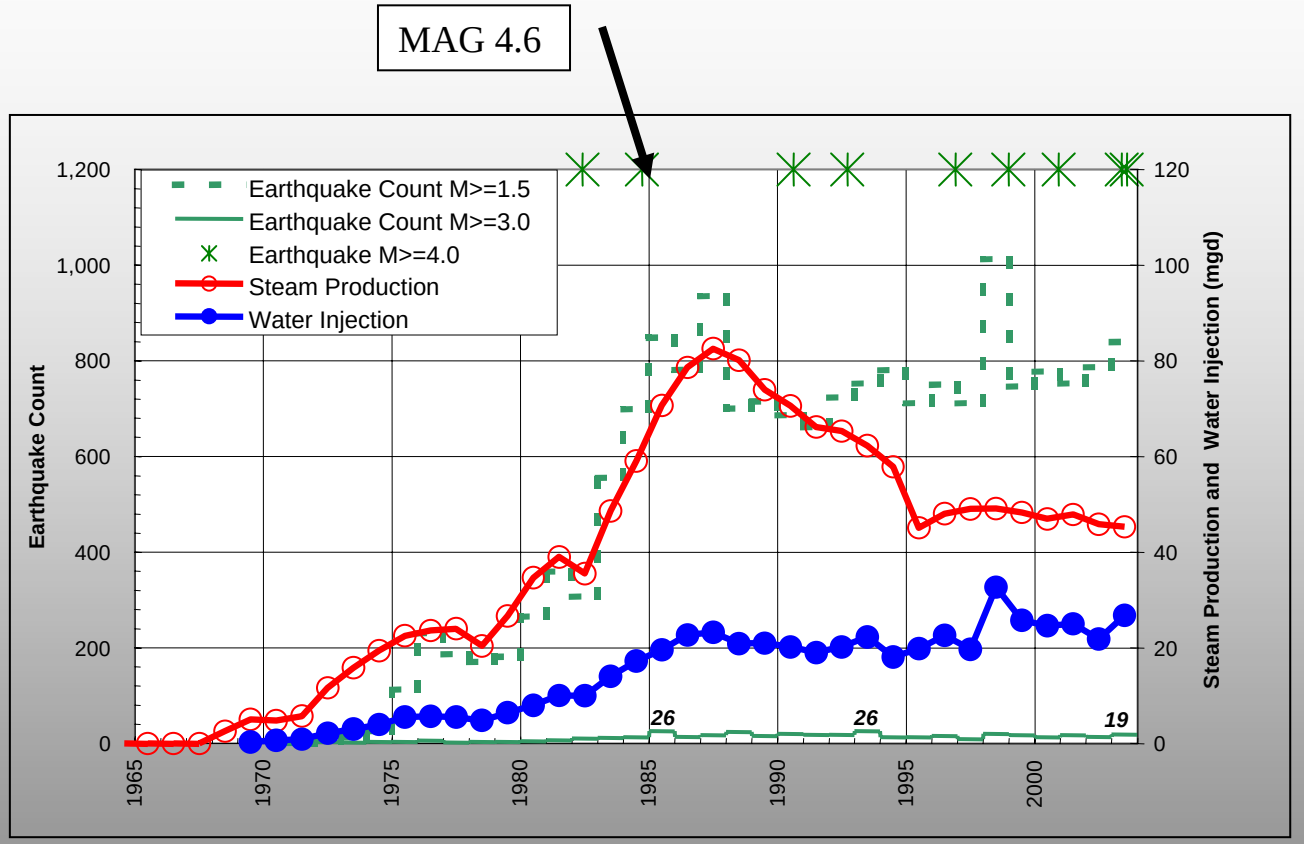
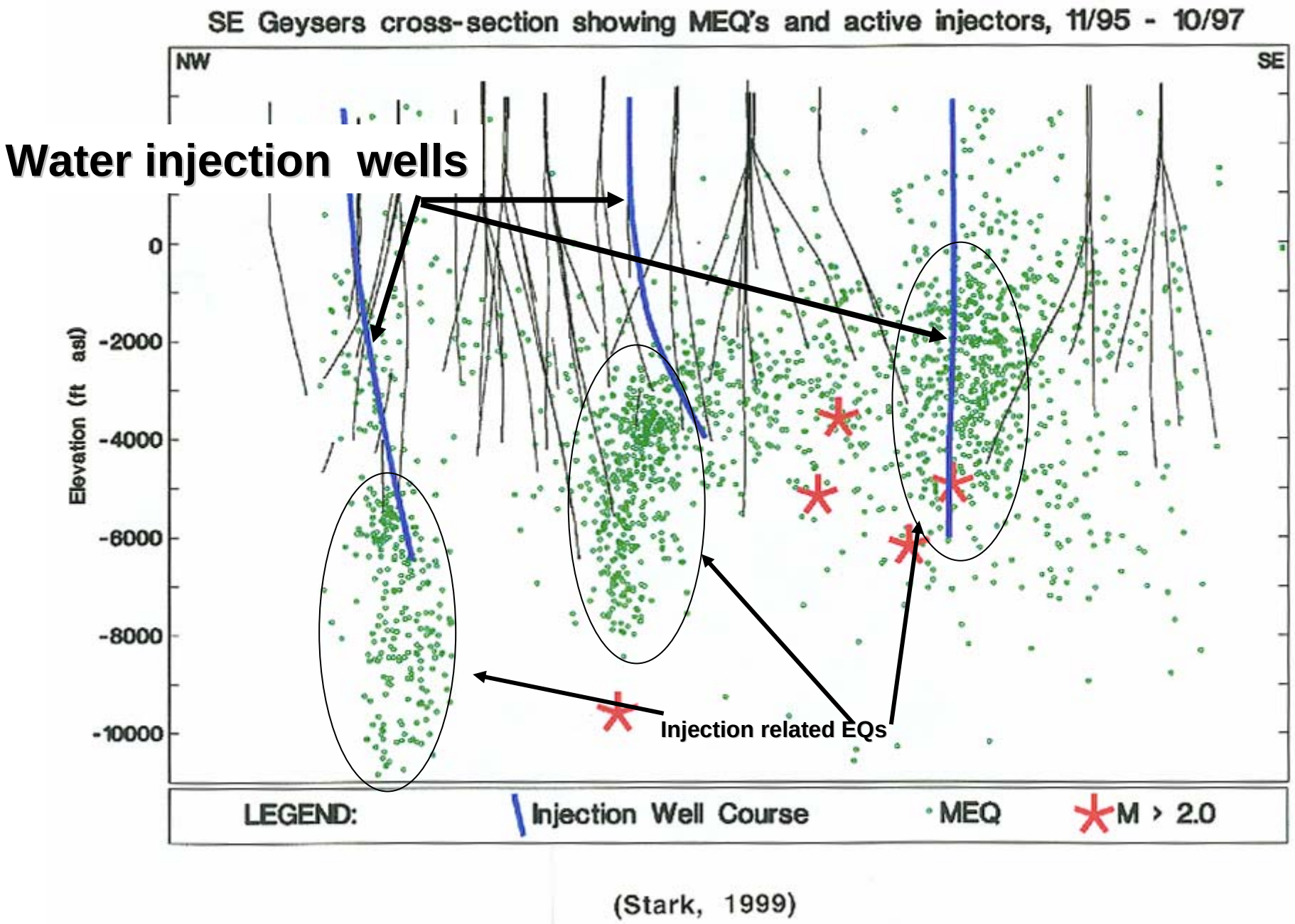
Historical Geysers Seismicity



Historical seismicity from 1965 to the present at The Geysers. Data are from the NCEDC. The largest event recorded was a Mag 4.6 in 1984. The Green dashed line shows the seismicity mag 1.5 and above, the solid green line shows the seismicity above 3.0.


SE Geysers cross-section showing MEQ's and active injectors, 11/95 - 10/97
NW
SE
Water injection wells
0
-2000
-4000
-6000
-8000
-10000
Elevation (ft asl)
Injection related EQs
LEGEND:
Injection Well Course
MEQ
M > 2.0

(Stark, 1999)

Experience at Larderello/Italy (Barbier 1997) shows that

- there is a correlation between reinjection and seismicity; increasing volumes of fluids do not lead to larger earthquakes, but to more frequent events;
- reinjection possibly has a positive effect, by releasing stress in numerous smaller events, which acts against stress accumulation for a large single event.

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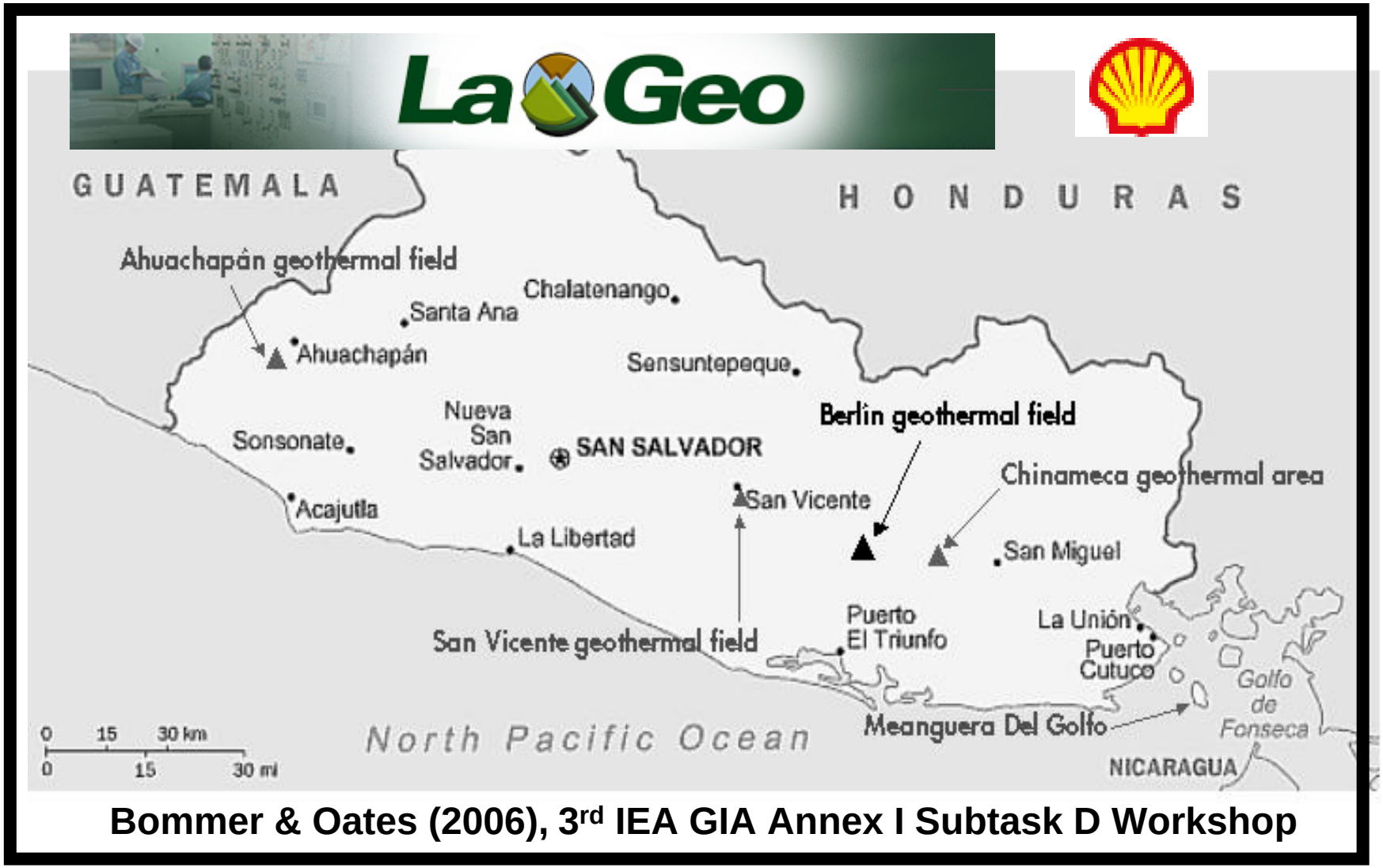
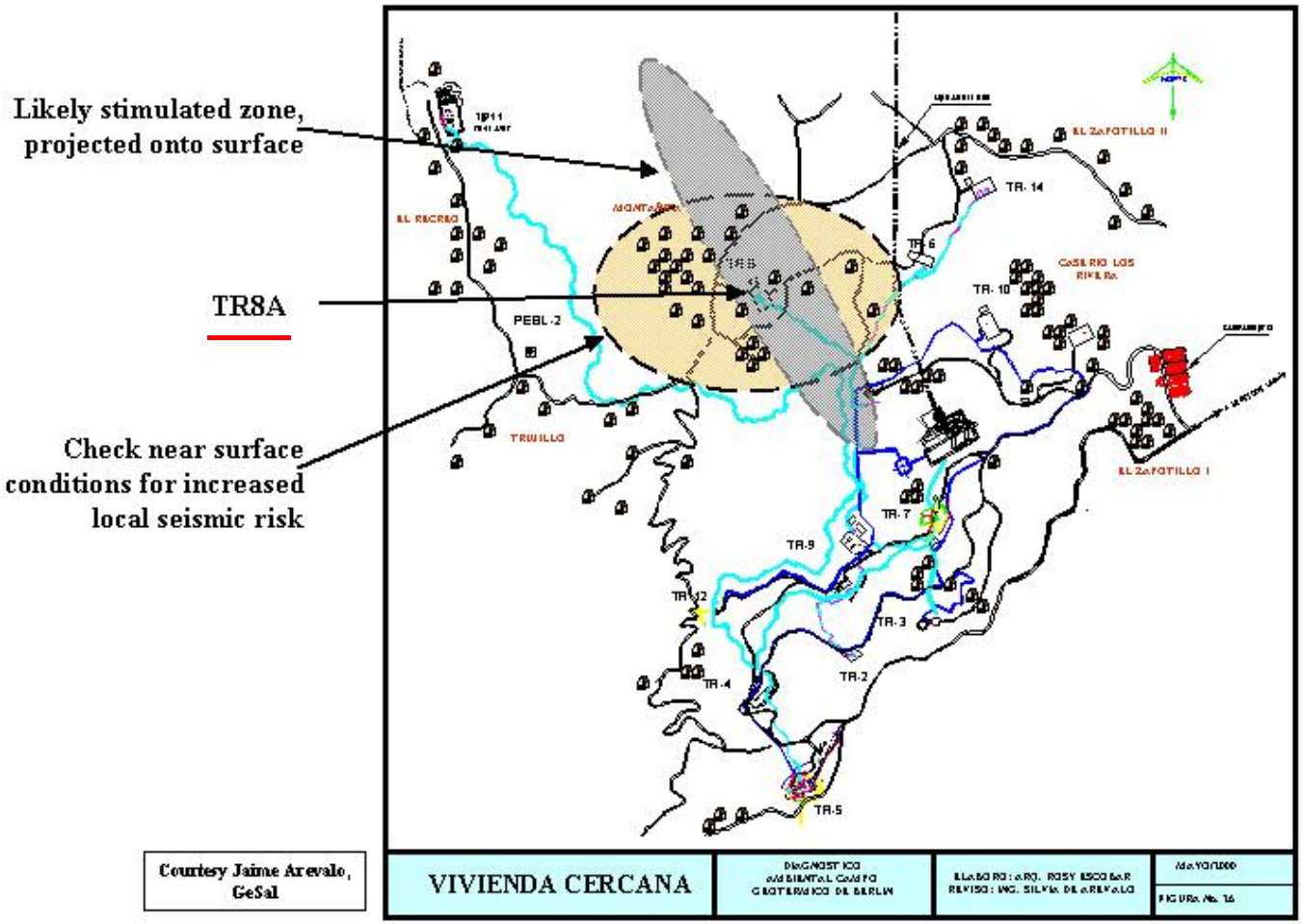
Experimental Project by Joint Venture between Shell International and LaGeo (El Salvador)



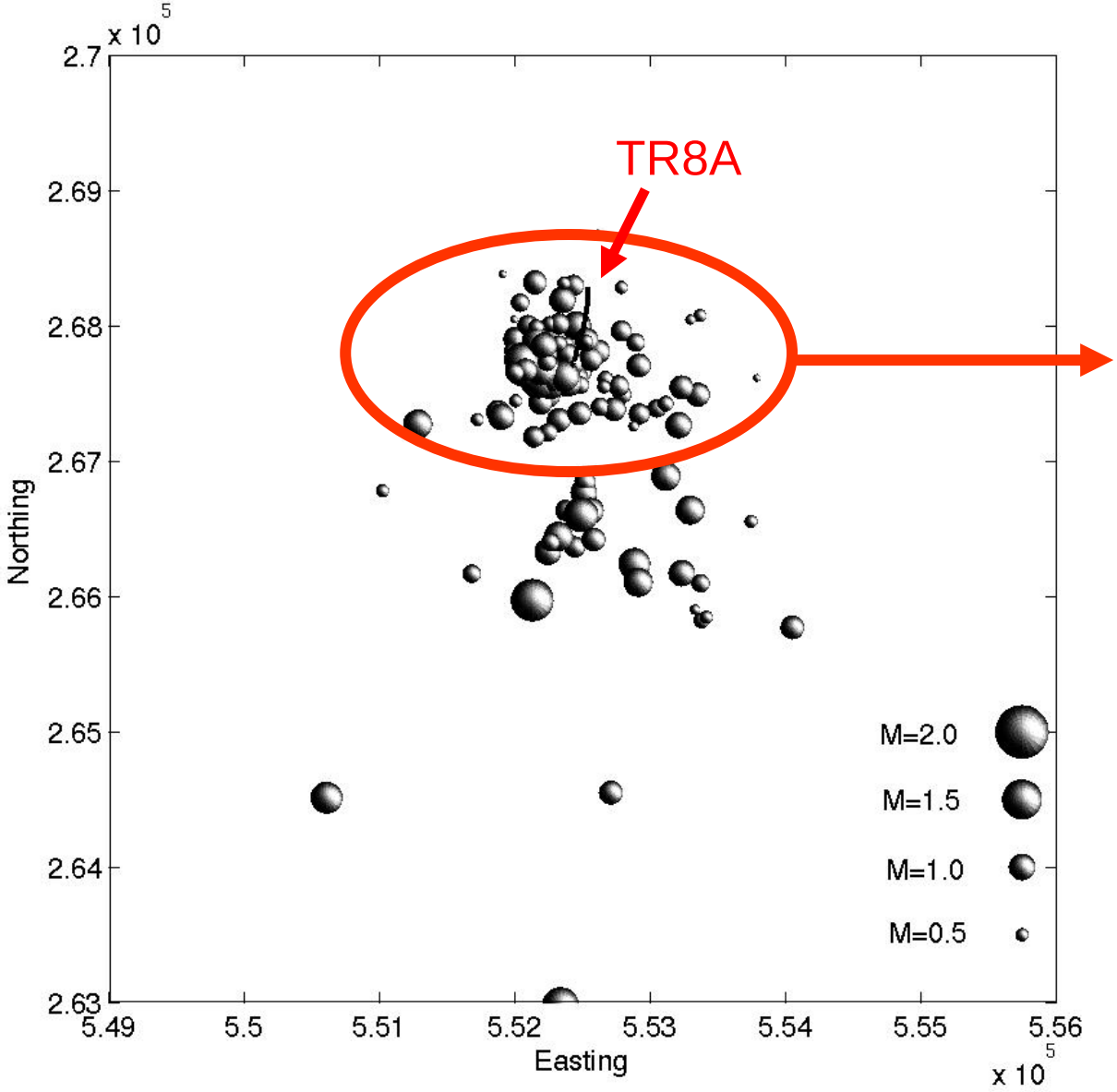
Bommer & Oates (2006), 3rd IEA GIA Annex I Subtask D Workshop

- **Objective: explore feasibility of commercial HFR energy generation**
- **Injections at TR8A – injector with low injectivity, non-productive**
- **High-pressure injection to stimulate rock fracture at depth of 1-2 km**



Bommer & Oates (2006), 3rd IEA GIA Annex I Subtask D Workshop

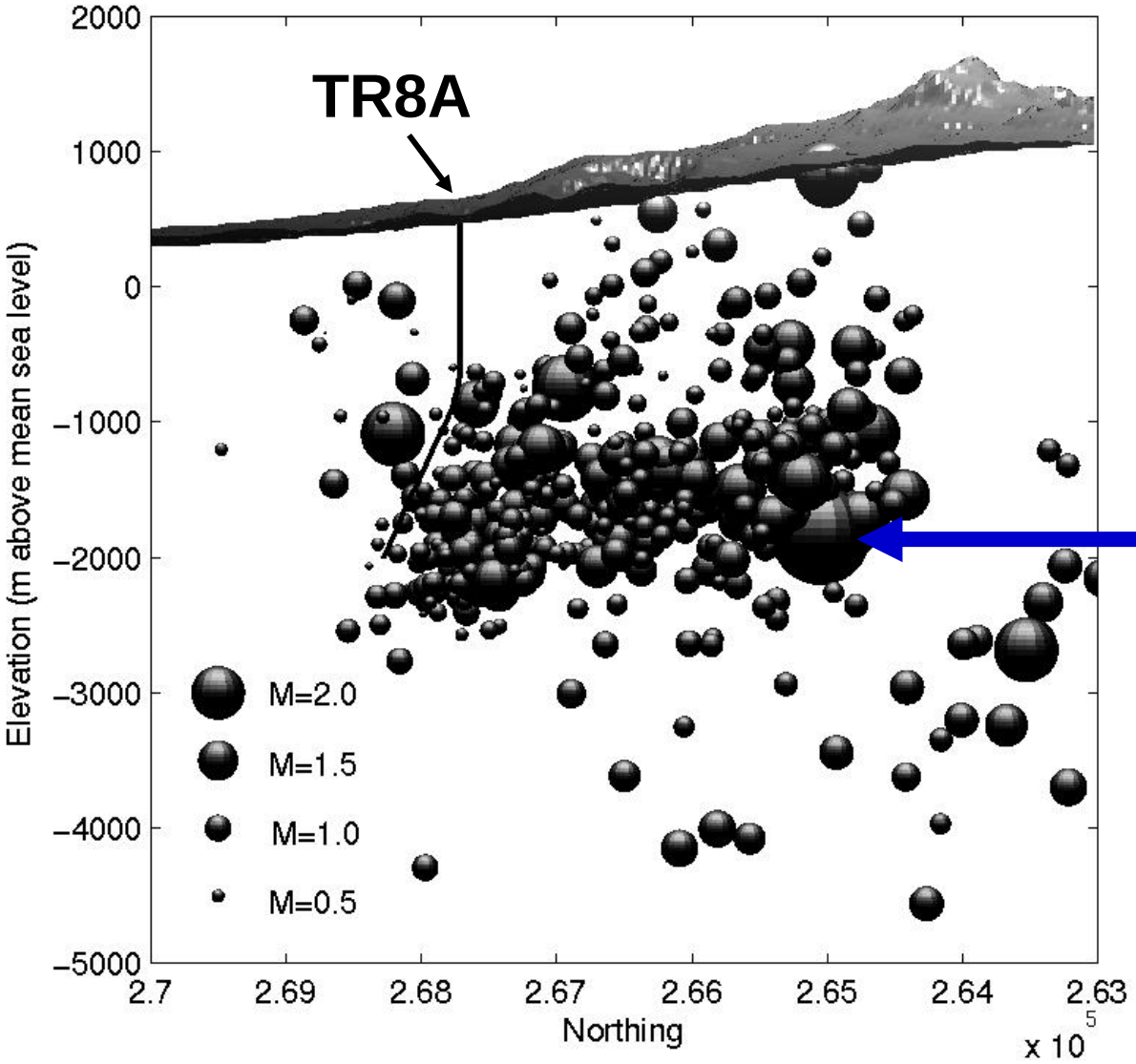
Observed seismicity during 3 injection phases (not intervals)



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

Bommer & Oates (2006), 3rd IEA GIA Annex I Subtask D Workshop

Observed seismicity during project (3 injection phases and intervals)



Largest event: M 4.4 on 16-9-03

During interval between injection phases and 3km south of TR8A – induced?

Bommer & Oates (2006), 3rd IEA GIA Annex I Subtask D Workshop

Technically the obvious goal is to get a handle on permissible levels of fluid injection, in terms of pressure, volume, flow rate, physical/chemical properties.

i.e. criteria and decision making is needed to decide whether to go on or to stop with injection.

For this it is advantageous to see whether there are ongoing activities relevant to the problem.

THERE IS ONE!

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SUGGESTION:

ENGINE should link to and cooperate with the

IEA Geothermal Implementing Agreement
Annex I Environmental Impacts of Geothermal Energy Development Subtask D

Access through http://www.iea-gia.org

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IEA Geothermal Implementing Agreement

Annex I Environmental Impacts of Geothermal Energy Development

Subtask D - Seismic Risk From Fluid Injection Into Enhanced Geothermal Systems

(Subtask Leaders: Dr. Ernie Majer, Lawrence Berkeley National Laboratory, Dr. Roy Baria)

The objective of this Subtask is to address the issue of the occurrence of significant induced seismic events in conjunction with EGS reservoir development or subsequent extraction of heat from underground.

These events have been large enough to be felt by populations living in the vicinity of current geothermal development sites. The objective is to investigate these events to obtain a better understanding of why they occur so that they can either be avoided or mitigated.

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Understanding requires considerable effort to assess and generate an appropriate source parameter model, testing of the model, and then calculating the source parameters in relation to the hydraulic injection history, stress field and the geological background.

An interaction between stress modeling, rock mechanics and source parameter calculation is essential. Once the mechanism of the events is understood, the injection process, the creation of an engineered geothermal reservoir, or the extraction of heat over a prolonged period may need to be modified to reduce or eliminate the occurrence of large events.

Subtask D results summary

- Have held three technical Workshops
  - Formed technical basis for understanding induced seismicity and a strategy for developing a protocol for designing "induced seismicity friendly" EGS projects
  - Working group of interested parties
  - Mechanisms for advancing research
- Products
  - Peer reviewed White Paper
    - Describing state of art and knowledge
    - Case histories
    - Future research necessary (mainly for reservoir management)
  - Protocol for the development of new geothermal sites and a good practice guide

IEA GIA Annex I
Subtask D Workshops

- 1st: Stanford, February 2005
- 2nd: GRC Assembly, September 2005
- 3rd: Stanford, February 2006

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Subtask D Schedule and Path forward

- Annotated outline of White Paper - March 15, 2006
- Case histories - June 1, 2006
- Draft White Paper - August 1, 2006
- Produce final White Paper - Sep 30, 2006
  - Submit to peer reviewed journal
- Protocol for managing induced seismicity
- Special Issues of Int. J. of Rock Mech. - Fall 2006
- Gather data and reports for website - ongoing
- Yearly meetings of technical group?

The protocol will be technical (i.e. identify and understand factors controlling seismicity, set limits for operations) and involve community interaction, with early and frequent communication with neighbouring communities an important aspect.

Seismic monitoring and a monitoring, mitigation and reporting plan are essential (event threshold of magnitude 1.5) components as is making data quickly available to the public.

Report on Annex I subtask D: Seismic Risk From Fluid Injection Into Enhanced Geothermal Systems

for the IEA/GIA ExCo meeting on 15th March 2006 at the IEA Headquarters in Paris, France.

Induced Seismicity Associated with Enhanced Geothermal Systems: State of Knowledge and Recommendations for Successful Mitigation

CONCLUSIONS AND RECOMMENDATION

Induced seismicity can be a relevant EGS issue

Means and measures are needed to avoid
stop & go of EGS operation

ENGINE should link to IEA GIA Annex I Subtask D

GEOWATT AG
SWISS GEOTHERMAL EXPERT GROUP
CH - 8050 Zürich

Prof. Dr. Dr.h.c. L. Rybach
GEOWATT AG Zurich
Dohlenweg 28
CH-8093 Zurich, Switzerland
rybach@geowatt.ch