Swiss Centre of Competence
for Deep Geothermal Energy
for power and heat production

GEO ENERGIE SUISSE

Understanding the Pohang EGS reservoir and the need for advanced traffic light systems

3rd Induced Seismicity Workshop Schatzalp
Davos 6th March 2019

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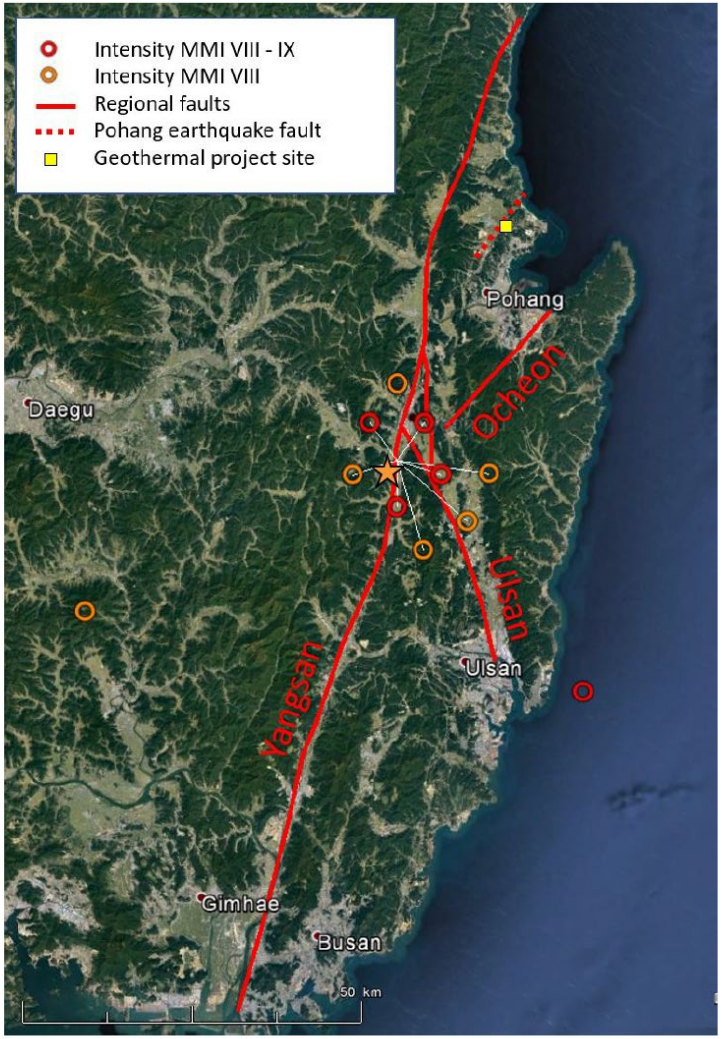
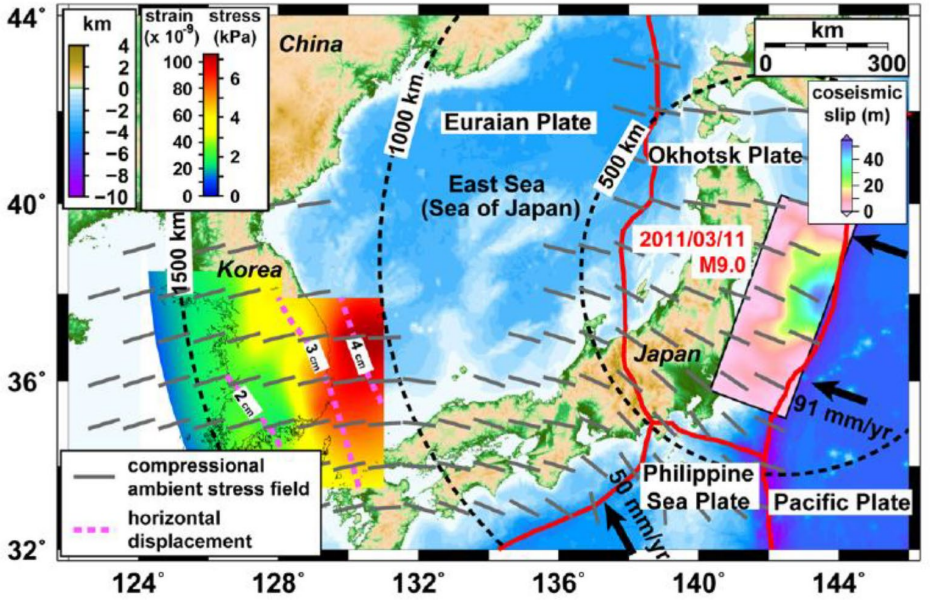
DESTRESS
Demonstration of soft stimulation treatments of geothermal reservoirs

aet ebl EOS HOLDING ewb ewz Die Energie GVM Gasverbund Mittelland AG IWB

Seismotectonic situation South-East Korea: many active faults in the region of the EGS site





Hong, Tae-Kyung, Junhyung Lee, Seongjun Park & Woohan Kim, 2018, Time-advanced occurrence of moderate-size earthquakes in a stable intraplate region after a megathrust earthquake and their seismic properties, Nature Scientific Reports, 8:13331 | DOI:10.1038/s41598-018-31600-5.

Figure 19: The Pohang EGS location is situated within the area of influence of active fault systems, in between the active Yangsan and the Ocheon fault. Thus, it is plausible that the Pohang region in between these faults is active as well.

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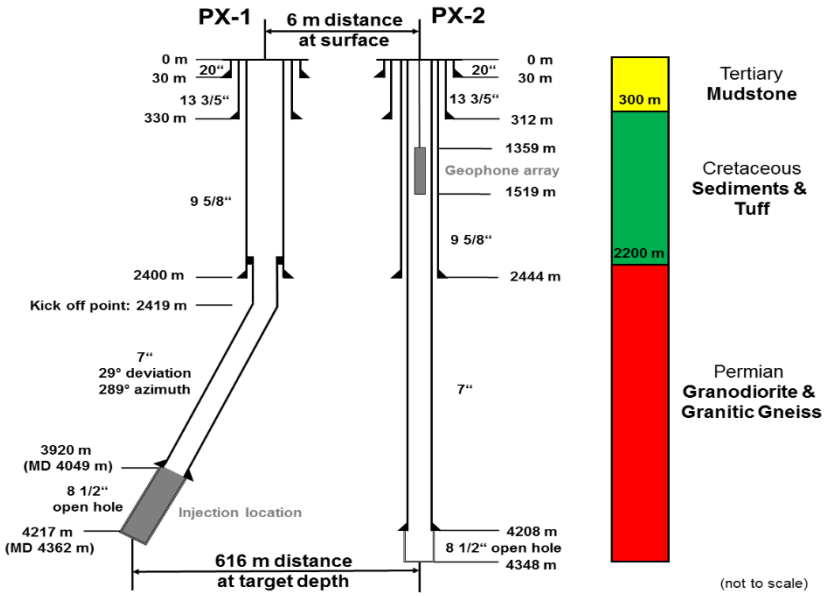
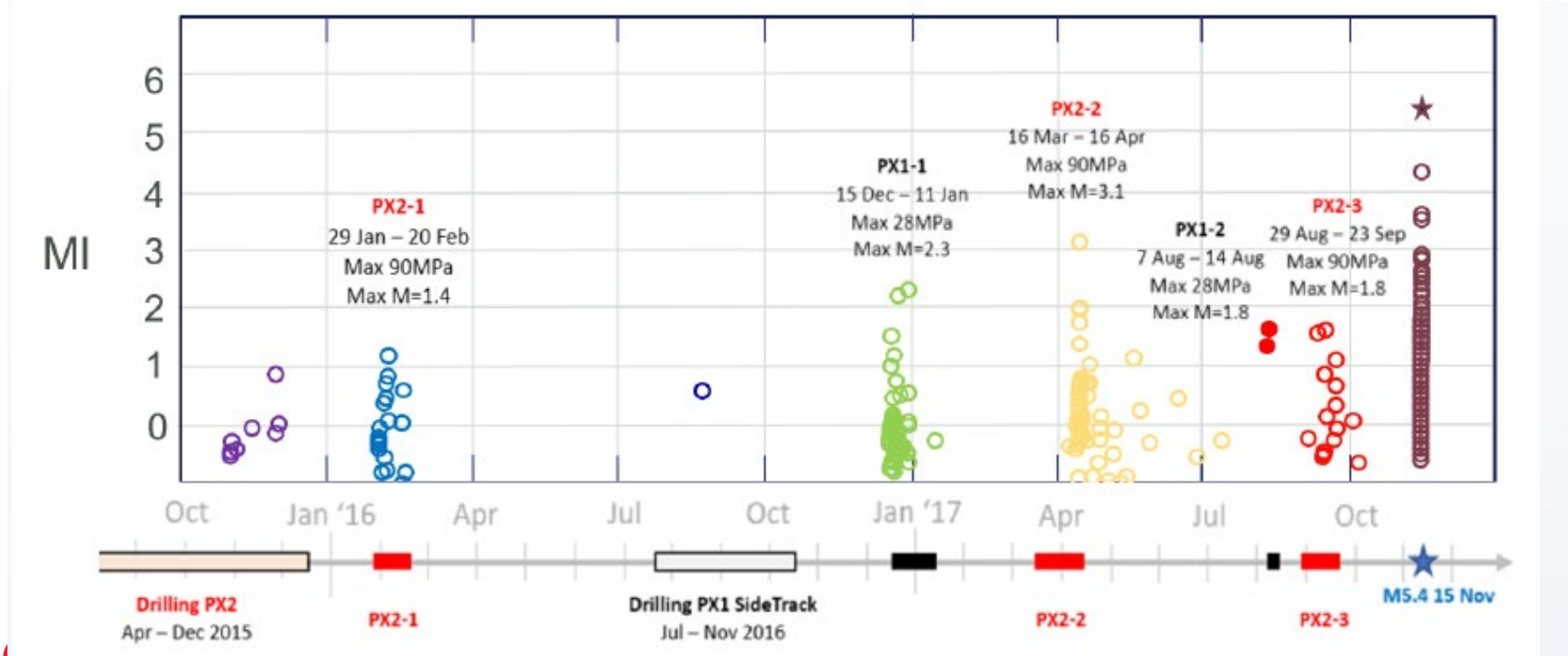
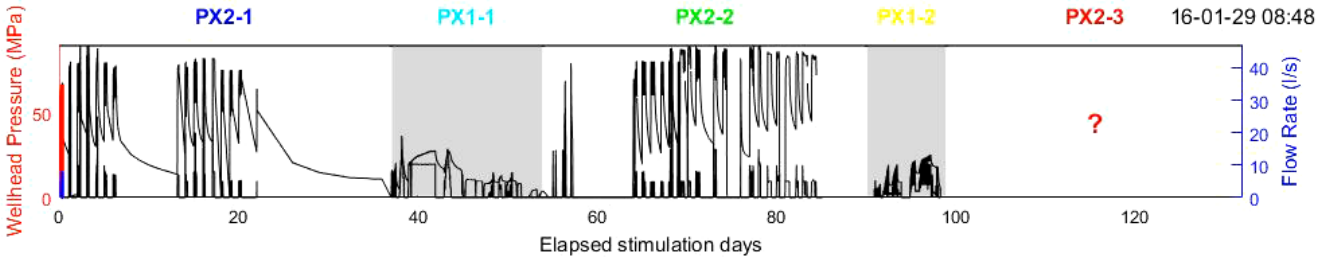
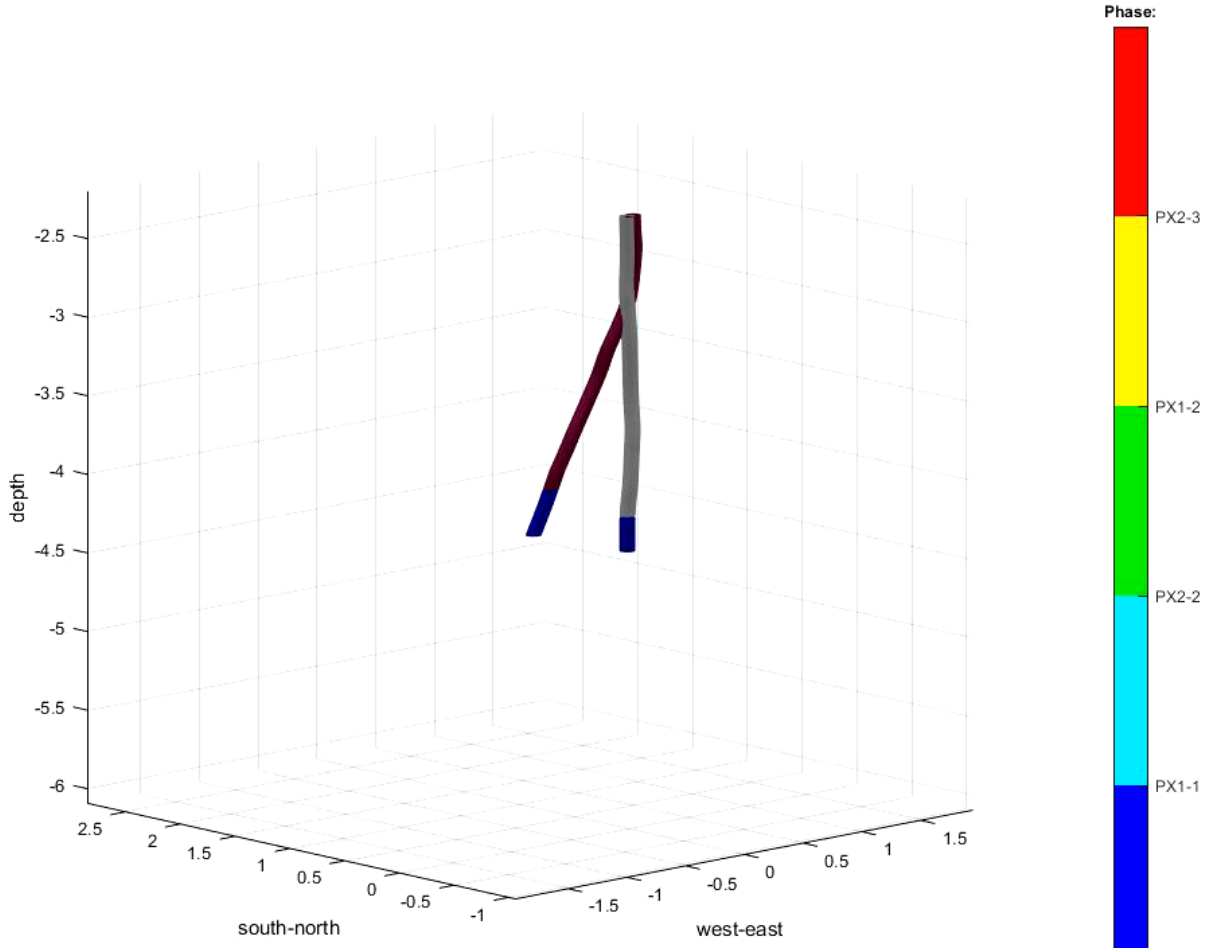
Overview

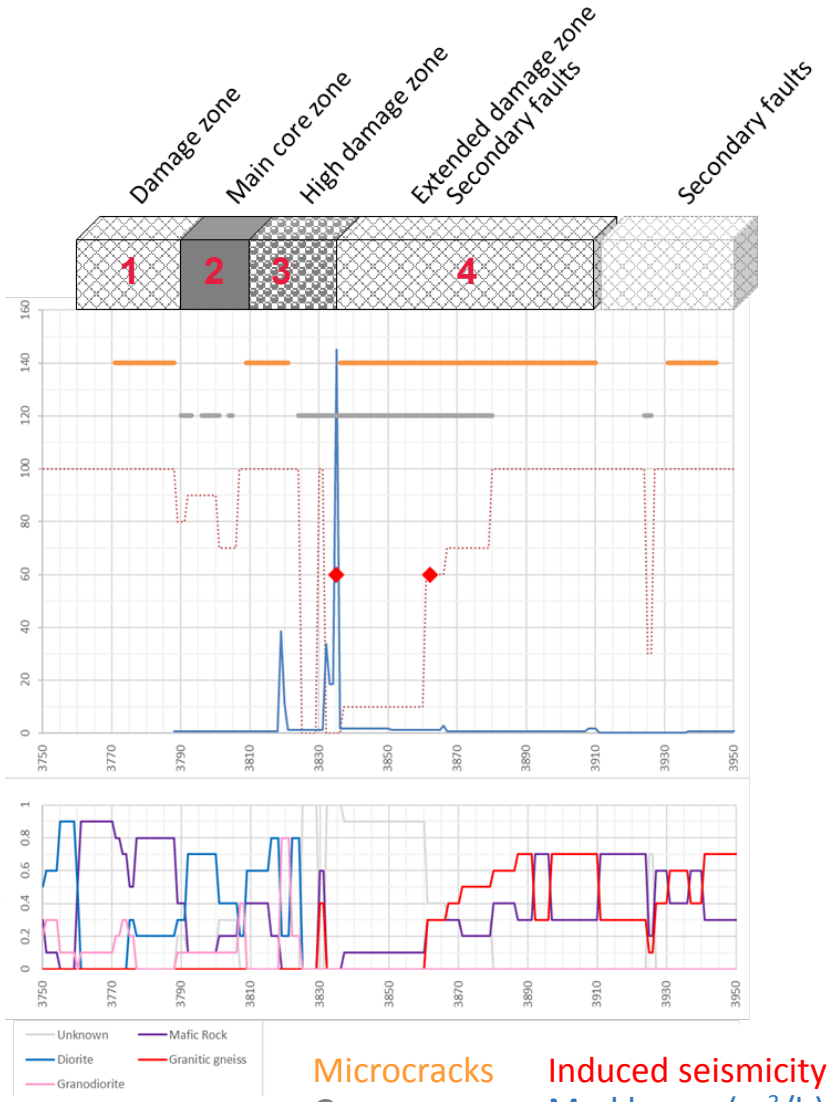

PX-1
6 m distance at surface
PX-2
0 m
30 m
20"
13 3/5"
330 m
9 5/8"
2400 m
Kick off point: 2419 m
7"
29° deviation
289° azimuth
3920 m
(MD 4049 m)
8 1/2"
open hole
4217 m
(MD 4362 m)
Injection location
616 m distance at target depth
20"
0 m
30 m
13 3/5"
312 m
1359 m
Geophone array
1519 m
9 5/8"
2444 m
7"
4208 m
8 1/2" open hole
4348 m
300 m
2200 m
Tertiary
Mudstone
Cretaceous
Sediments & Tuff
Permian
Granodiorite & Granitic Gneiss
(not to scale)


MI
6
5
4
3
2
1
0
PX2-1
29 Jan – 20 Feb
Max 90MPa
Max M=1.4
PX1-1
15 Dec – 11 Jan
Max 28MPa
Max M=2.3
PX2-2
16 Mar – 16 Apr
Max 90MPa
Max M=3.1
PX1-2
7 Aug – 14 Aug
Max 28MPa
Max M=1.8
PX2-3
29 Aug – 23 Sep
Max 90MPa
Max M=1.8
Oct
Jan '16
Apr
Jul
Oct
Jan '17
Apr
Jul
Oct
Drilling PX2
Apr – Dec 2015
PX2-1
Drilling PX1 SideTrack
Jul – Nov 2016
PX2-2
PX2-3
M5.4 15 Nov

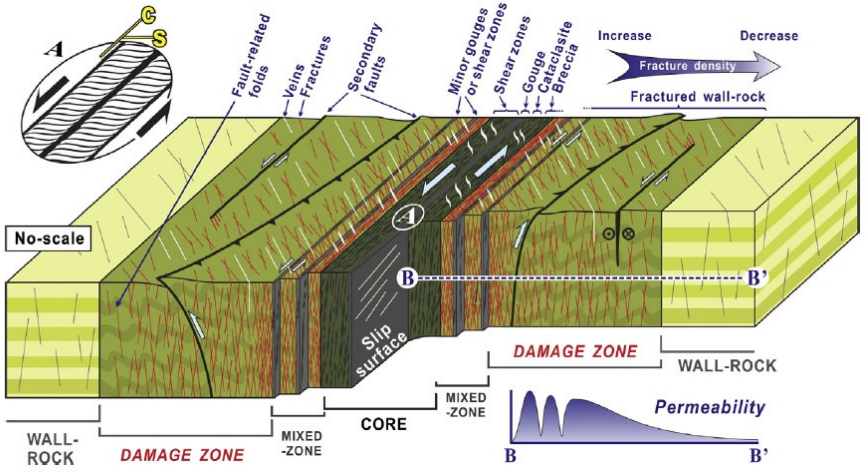

PX2-1
PX1-1
PX2-2
PX1-2
PX2-3
16-01-29 08:48
Wellhead Pressure (MPa)
50
0
?
40
30
20
10
0
Flow Rate (l/s)
0
20
40
60
80
100
120
Elapsed stimulation days


depth
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
2.5
2
1.5
1
0.5
0
-0.5
-1
south-north
-1.5
-1
-0.5
0
0.5
1
1.5
west-east
Phase:
PX2-3
PX1-2
PX2-2
PX1-1
PX2-1

Conceptual fault model PX-2, 3750-3950 m



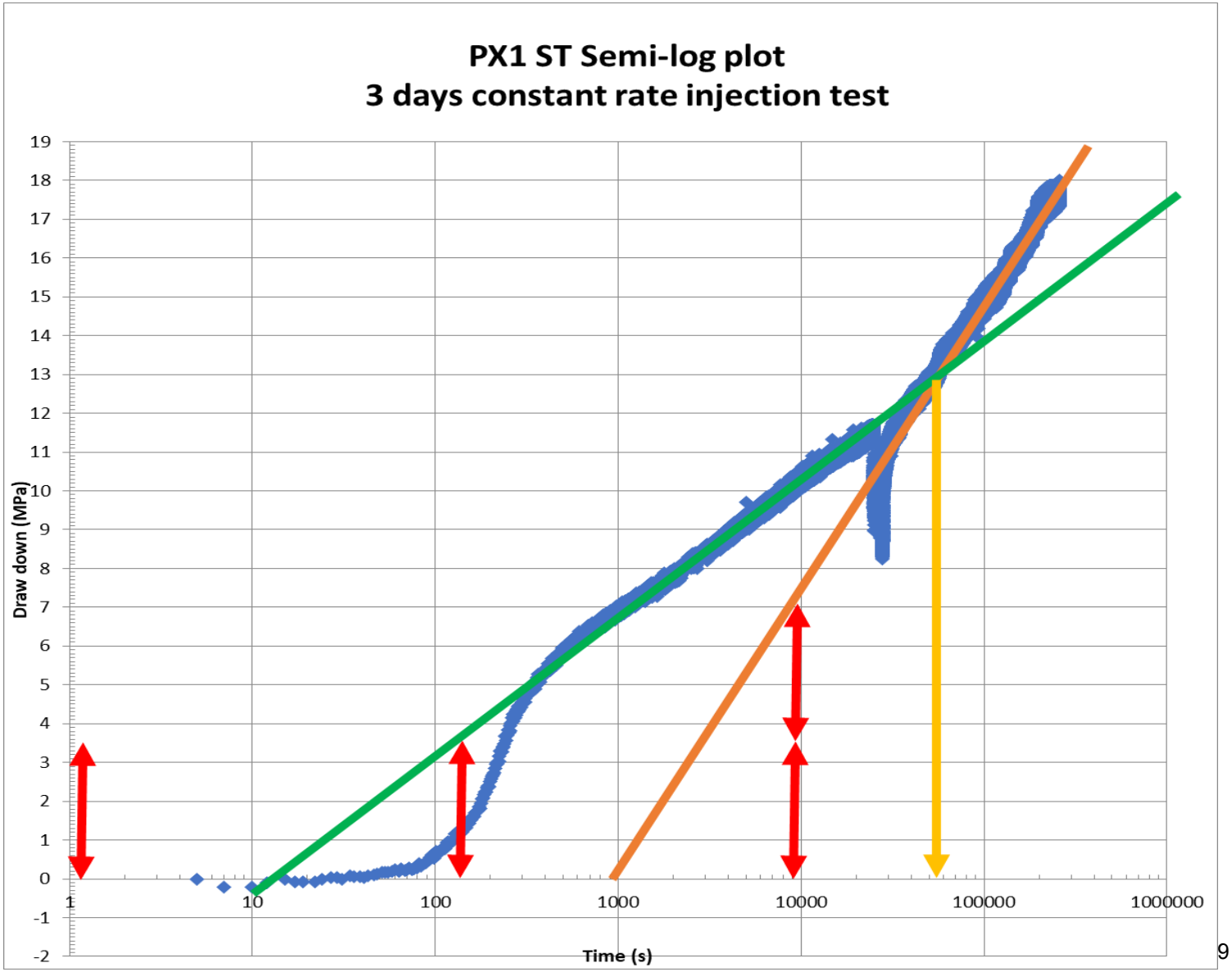
1. 3760 – 3790 m: damage zone attested by the presence of hydrothermal alteration followed by a high density of “microcracks”
2. 3790 – 3810 m: core zone attested by the presence of fault gouge making up to 40% of the cuttings.
3. 3810 – 3835 m: highly damage zone attested by silicified mafic rocks with “microcracks” and by massive mud losses associated with induced seismicity (according to Kim et al. 2018, fig. 4). The temperature measured at 3820 m is anomalously high and could indicate a water inflow.
4. 3835 – 3910 m: damage zone attested by silicified mafic rocks with “microcracks” and hydrothermal alteration.

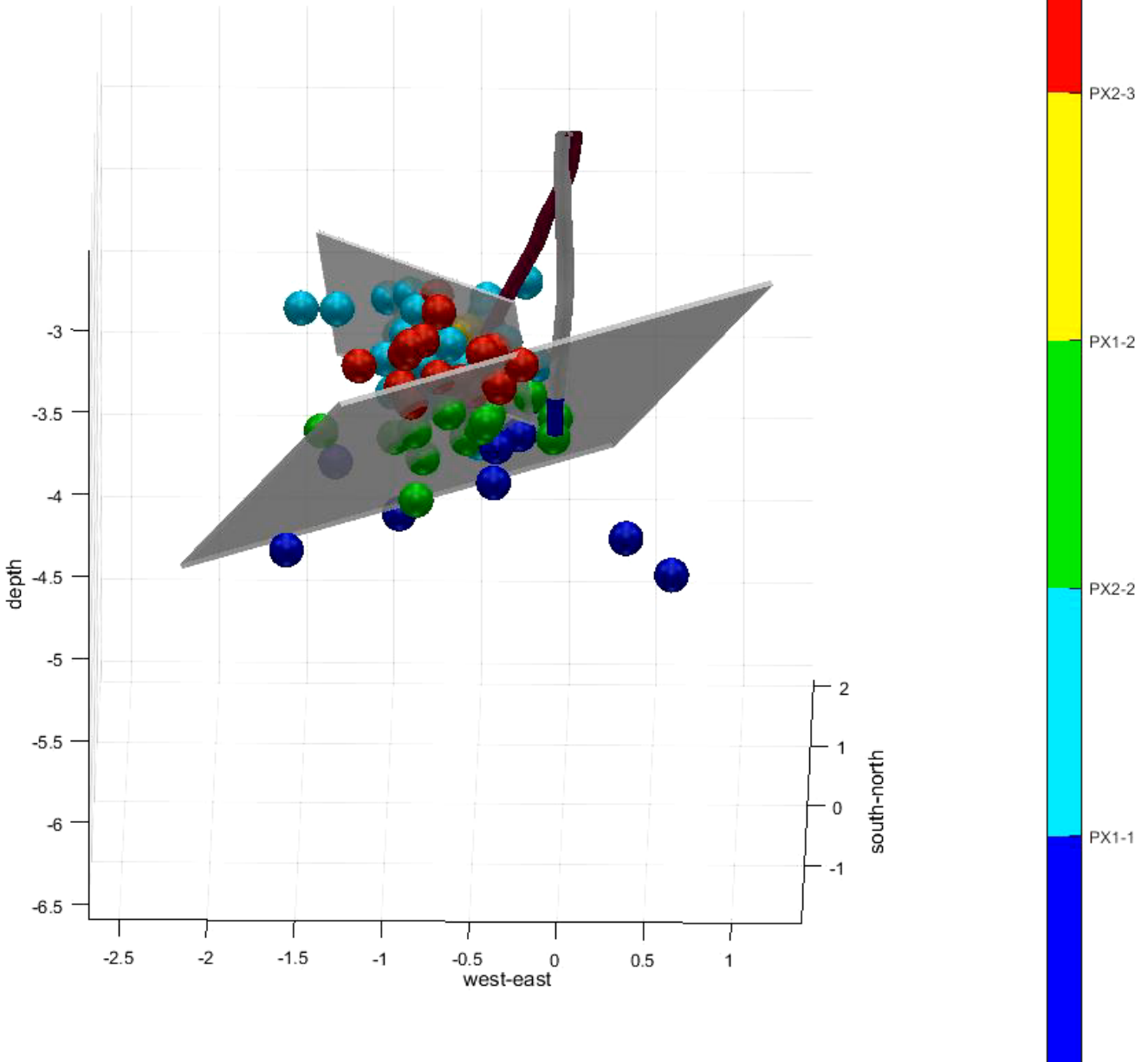


Conceptual model of a mature fault zone in South-eastern Korea from Choi et al. (2015).

6.3.2019

Hydraulic data PX1-1: 2D flow at beginning and non-linear no-flow boundary




Phase:
PX2-3
PX1-2
PX2-2
PX1-1
depth
-3
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
west-east
2
1
0
-1
south-north

First Pohang stimulation in PX2-1: max magnitude 1.4 traditional traffic light system => does not detect any problems

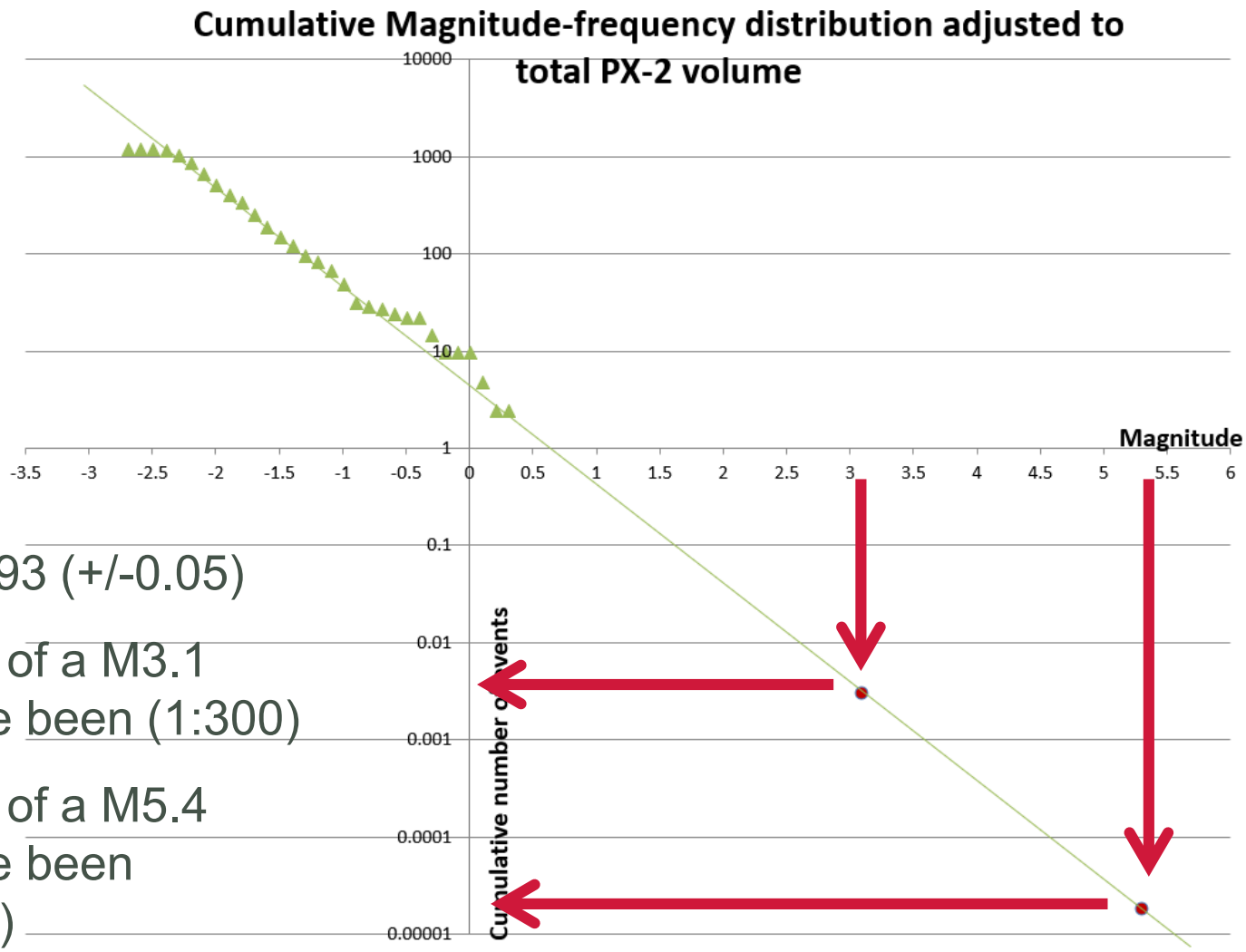
M_L		Pumping	Injection pressure	Report	PGV (cm/s)
	Stage 5	Stop	Bleed off excess pressure	Alarm to H.S. team Report to research institutions Report to local and project related institutions (KMA, Pohang city, MOTIE, KETEP)	
2.0					2.0
	Stage 4	Stop	Bleed off excess pressure	Alarm to H.S. team Report to research institutions (SNU, KICT, KIGAM, POSCO, INNOGEO)	
1.7					1.0
	Stage 3	Reduction or stop	Reduction or constant pressure	Alarm to H.S. team (H.S. team, M.S. monitoring team, Boards of NEXGEO)	
1.4					0.5
	Stage 2	Constant flow rate	Constant pressure	Report to hydraulic stimulation team (H.S. team, M.S. monitoring team)	
1.0					0.08
	Stage 1	Regular operation	Regular operation	Regular report (Microseismicity monitoring team)	

* Flow rate and injection pressure would be regulated accordingly during hydraulic stimulation.
* Axis of M_L and PGV do not correspond to one-to-one each other.

Fig. 9. Traffic light system for the first hydraulic stimulation of the Pohang EGS project.

Kim Kwang-Il, Ki-Bok Min, Kwang-Yeom Kim, Jai Won Choi, Kern-Shin Yoon, Woon Sang Yoon, Byungjoon Yoon, Tae Jong Lee, Yoonho Song, Protocol for induced microseismicity in the first enhanced geothermal systems project in Pohang, Korea, (2018a) Renewable and Sustainable Energy Reviews, Volume 91, 2018, Pages 1182-1191, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2018.04.062

Preliminary results b-values for PX2-1



- b- value 0.93 (+/-0.05)
- Probability of a M3.1 would have been (1:300)
- Probability of a M5.4 would have been (~1:70‘000)

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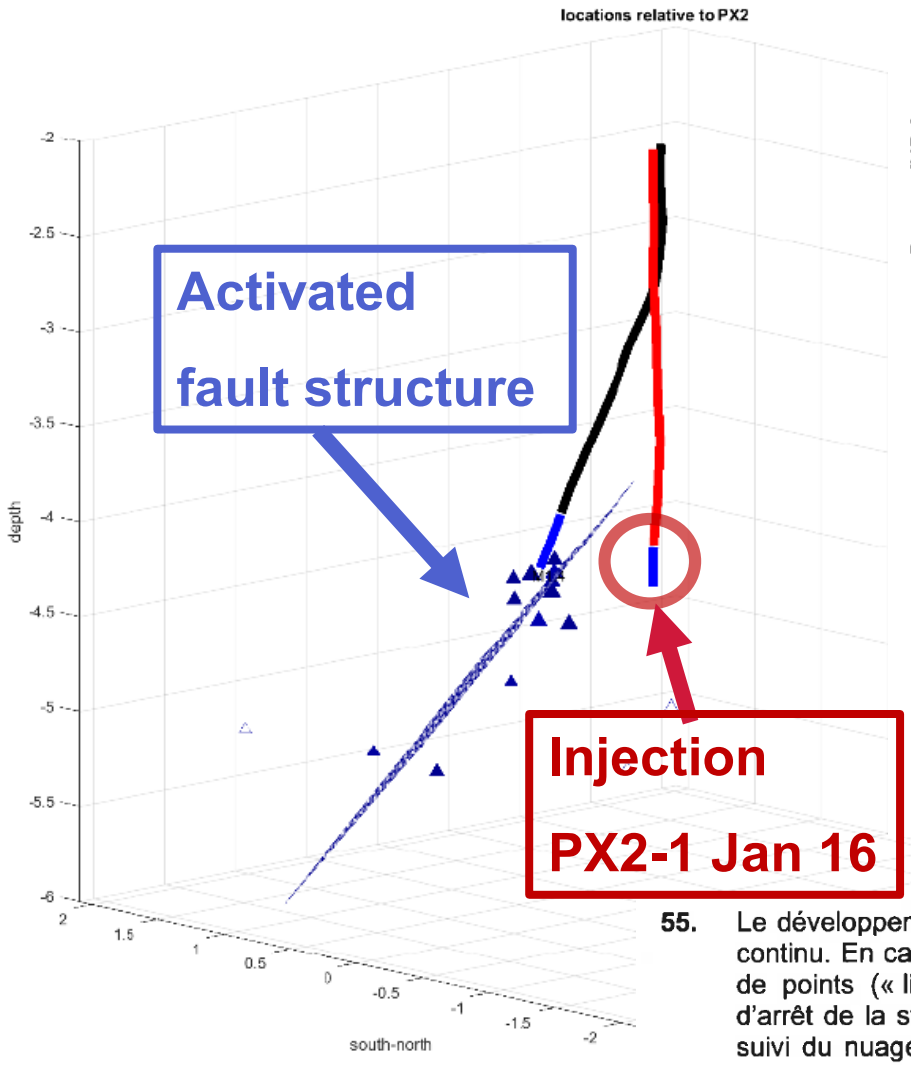
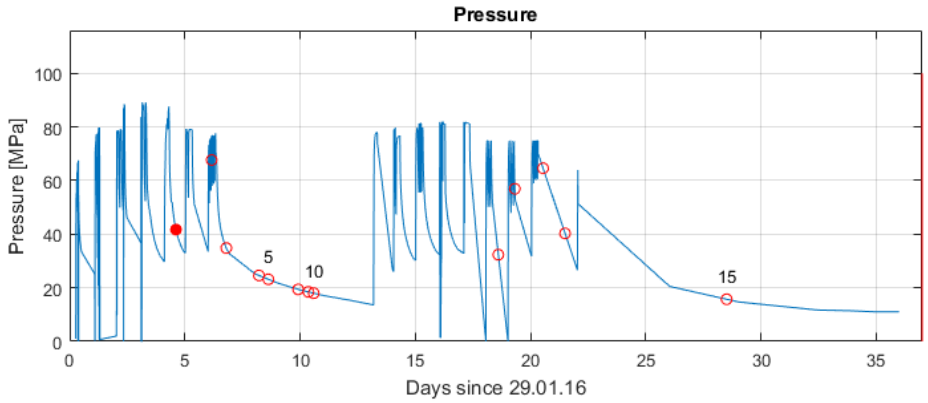
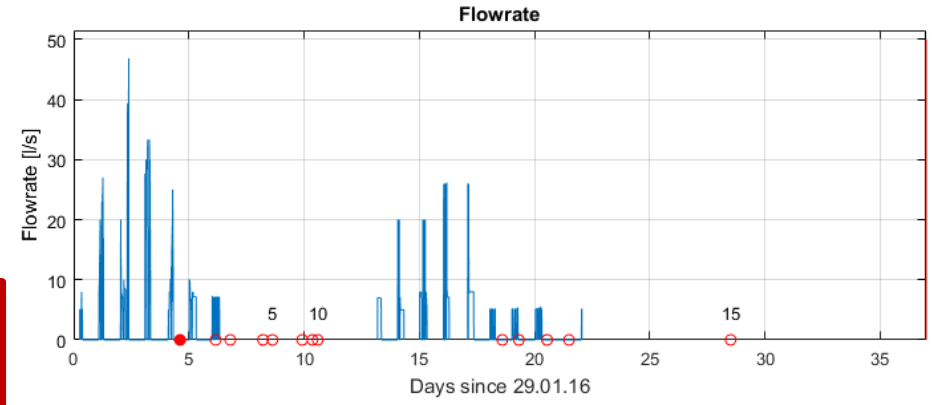
Eye opener: Triggering of a fault can only be detected with timely and accurate localisation of events (and integration of borehole geological and hydraulic data) !







55. Le développement du nuage de points représentant les séismes induits sera surveillé en continu. En cas d'observations particulières, telles que le développement d'un alignement de points (« lineament ») ou l'accélération du développement du nuage, le protocole d'arrêt de la stimulation sera immédiatement appliqué et le risque sismique réévalué. Le suivi du nuage de points et les critères d'arrêt de la stimulation seront définis en détail avec le groupe d'experts.

According to article 55 of the permit for Haute-Sorne the first stimulation in Pohang (PX2-1) would have been stopped after detecting events at a distance of several hundreds of meters from the injection point

Conclusions

- Triggering of an earthquake may not be avoided with
  - traditional traffic light system only
  - b-value based predictions only
  - predictions based on «injection volume – magnitude» relationships only
- Integration of geological and hydraulic data into risk assessment as a continuous process throughout all project phases is crucial
- Timely and accurate localization of events is paramount to detect triggering indications on close faults at early times.
  - If events at a distance of several hundreds of meters from the injection point are detected, the project must be halted and the risks must be re-evaluated leading probably to a stop of the project.
  - The permit for the Haute-Sorne EGS project contains such conditions.
- Advanced traffic light systems and risk studies are needed as a basis to take informed decisions. These studies need to be actualized throughout the duration of a deep geothermal project and need to be discussed by experts independant from the project development.

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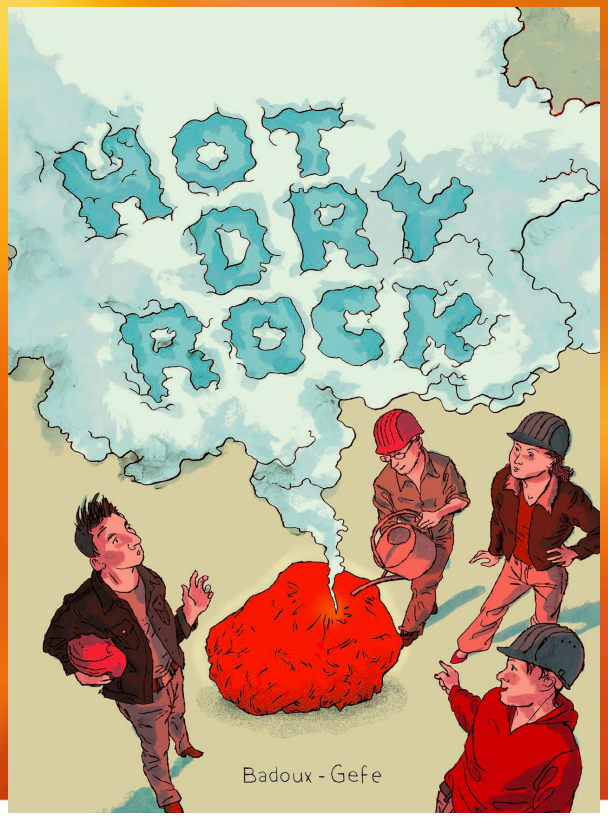
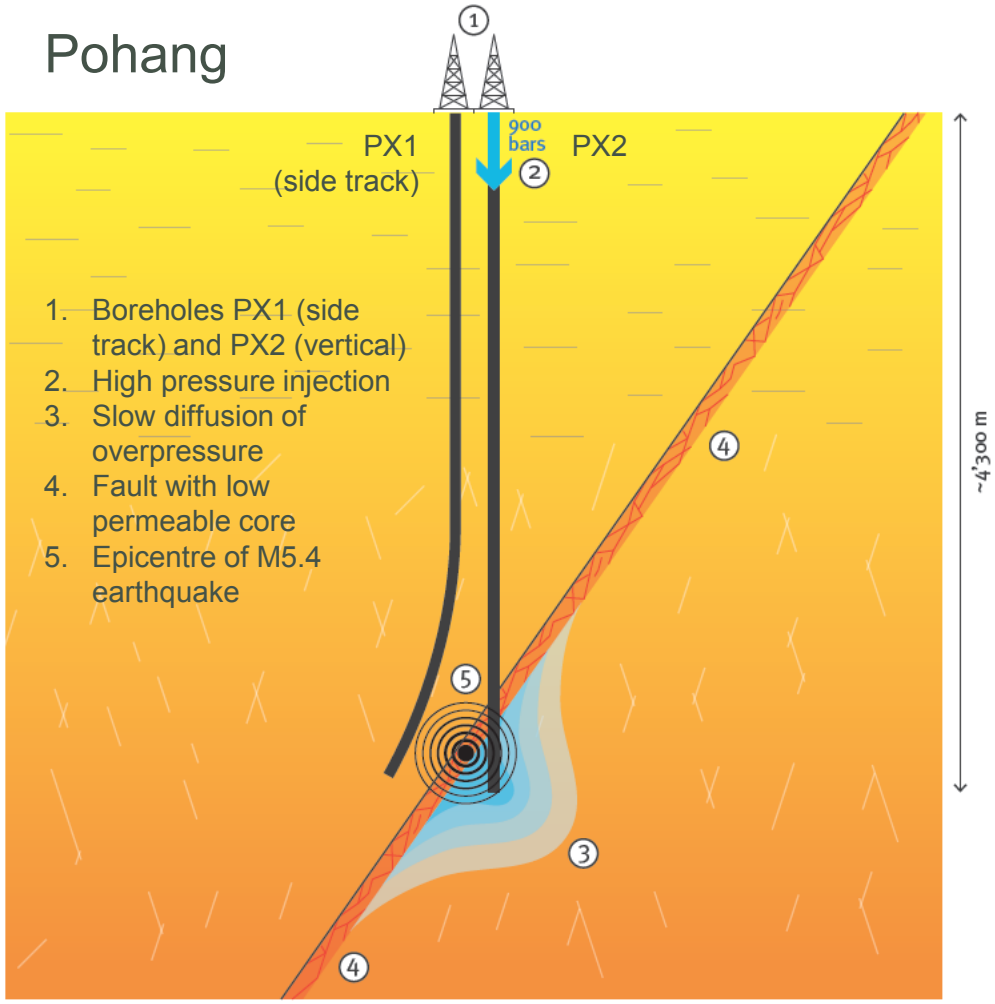


Thank you for your attention!

Summary of GES work:
Most probable szenario leading to the Pohang M5.4 EQ



- PX2 intersects at ~3800 m a **large fault with a low permeable core**
- Pohang is within a **seismic active region** of South-East Korea
- Epicenter of M5.4 EQ November 2017 is within **the same rock volume that was stimulated in April & September 2017 with high pressures of up to 900 bar at the well head of PX2**
- P 900 bar @4200 m ~ 132 MPa >> vertical & min horizontal rock stresses σv (109 MPa) & σhmin
- **The high pressures were motivated to (desperately) estabilsh a circulation between both wells, but not feasible because of the low permeable fault core**
- Slow overpressure diffusion destabilizing continuously larger parts of the fault (maybe in combination of creeping fault core material) could explain the time delay of M5.4 EQ

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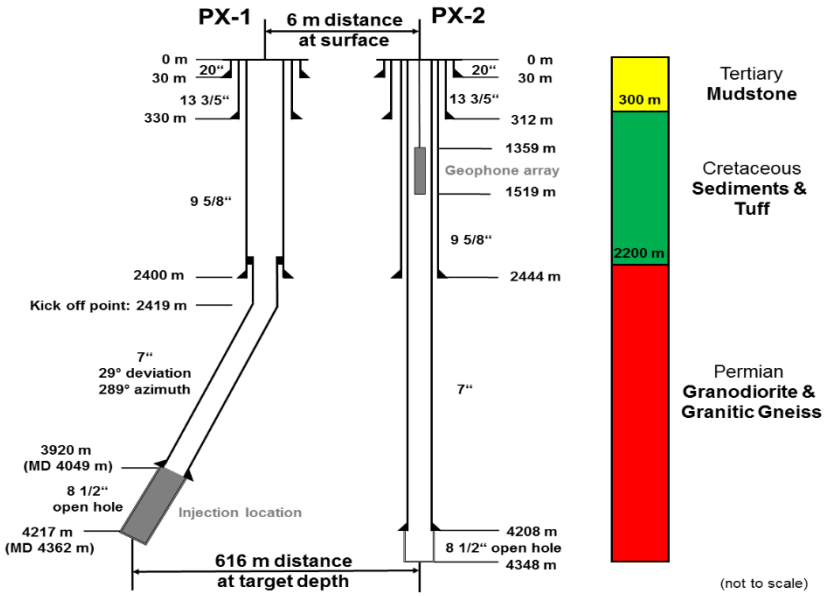
Overview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6 m distance at surface
PX-2
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Kick off point: 2419 m
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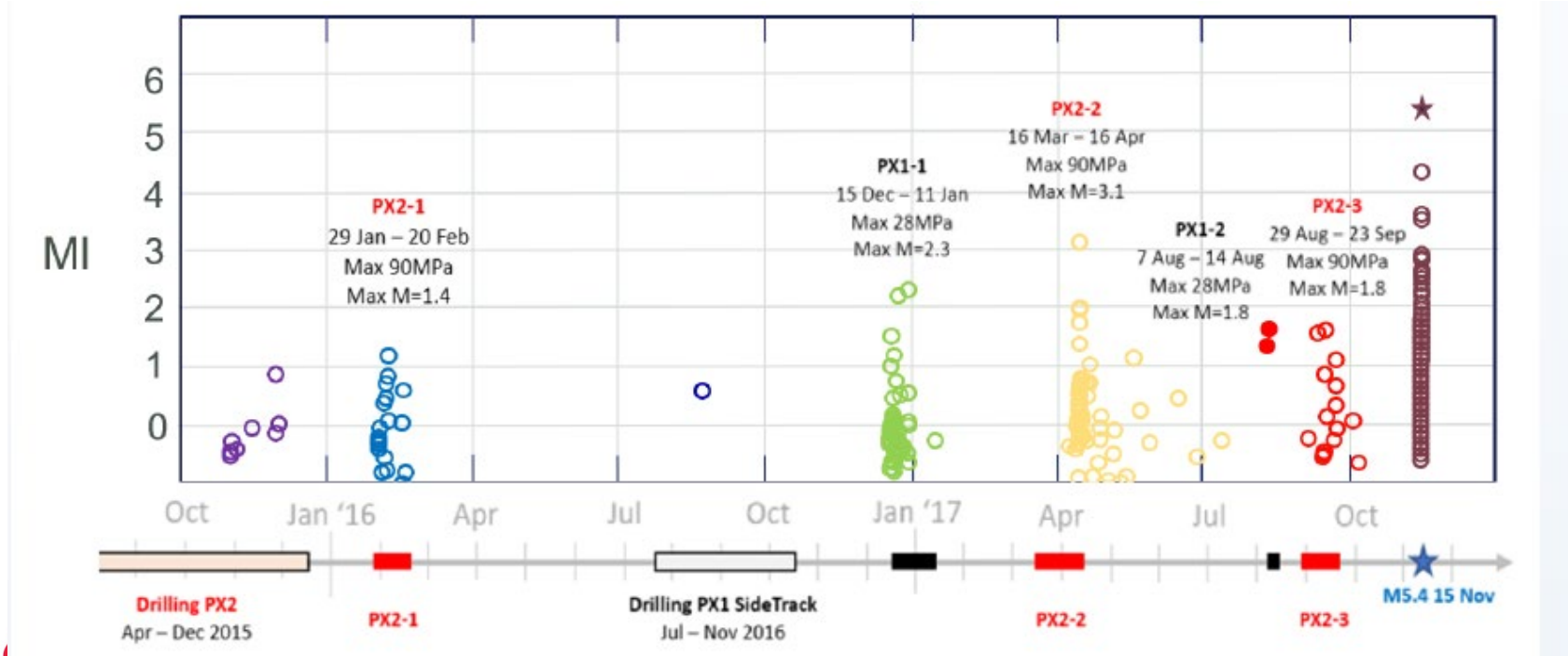
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Oct
Jan '16
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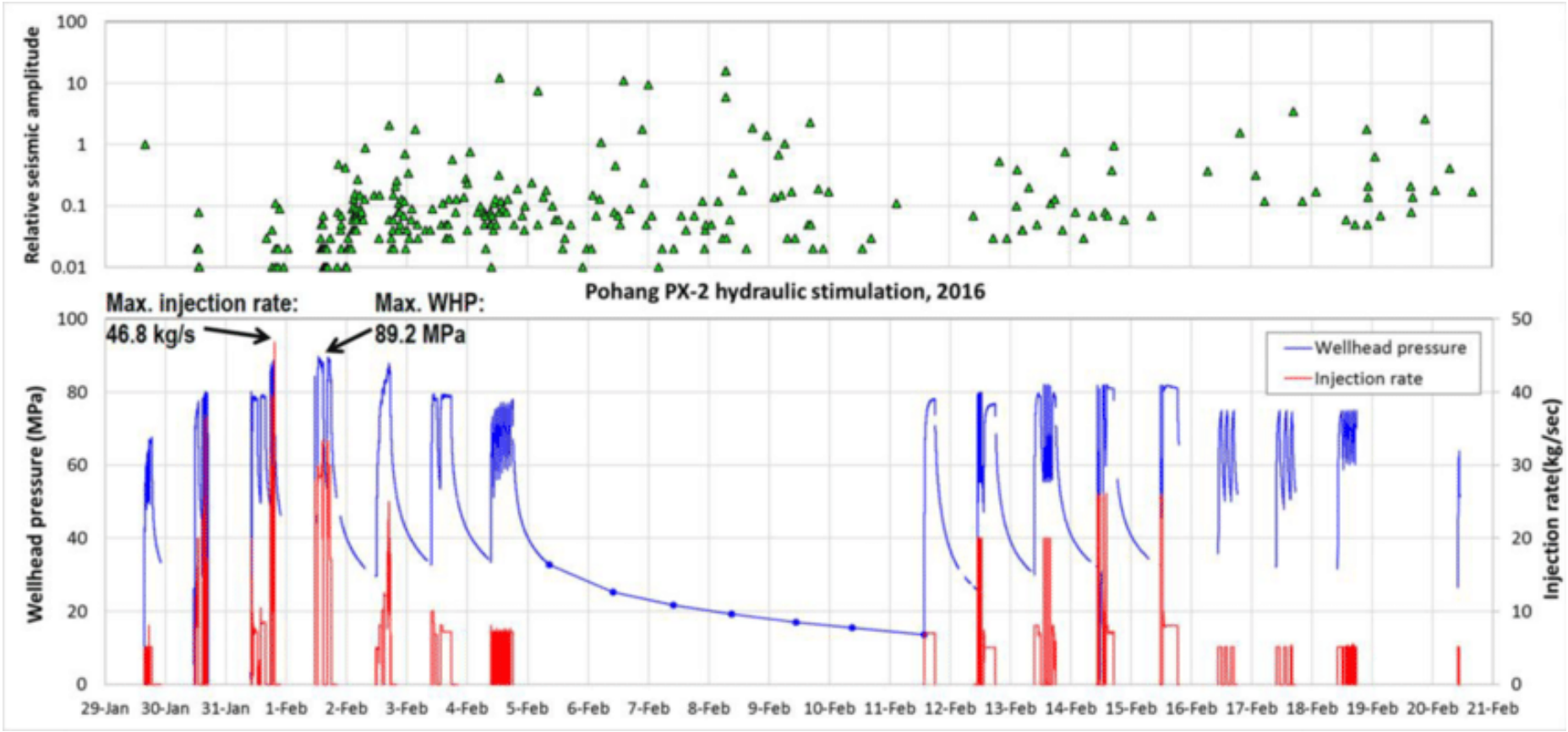
Jul
Oct
Jan '17
Apr
Jul
Oct
Drilling PX2
Apr – Dec 2015
PX2-1
Drilling PX1 SideTrack
Jul – Nov 2016
PX2-2
PX2-3
M5.4 15 Nov

Very first stimulation PX2-1: Max magnitude 1.4



Park Sehyeok, Linmao Xie, Kwang-Il Kim, Saeha Kwon, Ki-Bok Min, Jaiwon Choi, Woon-Sang Yoon, Yoonho Song, (2017) First Hydraulic Stimulation in Fractured Geothermal Reservoir in Pohang PX-2 Well, Procedia Engineering, Volume 191, 2017, Pages 829-837, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2017.05.250

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