Discriminating characteristics of tectonic and human induced seismicity

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Examined Regions:

Induced seismicity

- Geysers
- TauTona

Tectonic seismicity

- San Jacinto
- Coso nongeothermal

Mixed seismicity

- Coso geothermal
- Salton Sea

Examined regions

Region	Duration	Magnituge range	No. of events	Type of seismicity
The Geysers, California	1984/01 - 2011/12	1.0 - 4.5	75,991	Induced
TauTona gold mine, South Africa	2004/09 - 2010/09	1.5 - 4.2	8,519	Induced
Coso geothermal field, California	1981/01 - 2013/12	1.0 - 4.41	4,412	Mixed
Salton Sea geothermal field, California	1981/01 - 2013/12	1.5 - 5.11	6,018	Mixed
Coso non- geothermal area, California	1981/01 - 2013/12	1.0 - 5.75	56,801	Tectonic
San Jacinto fault zone, California	1981/01 - 2013/12	1.0 - 5.43	39,768	Tectonic

Earthquake cluster analysis

Baiesi and Paczuski, *PRE*, **69**, 066106 (2004) Zaliapin *et al.*, *PRL*, **101**, 018501 (2008) Zaliapin and Ben-Zion, *GJI*, **185**, 1288–1304 (2011) Zaliapin and Ben-Zion, JGR, **118**, 2847-2864 (2013)

Distance from an earthquake *j* to an earlier earthquake *i* :



Property:

$$\eta = TR$$
, $\log \eta = \log T + \log R$

Rescaled time $T = \tau 10^{-bm_i/2}$, Rescaled distance $R = r^d 10^{-bm_i/2}$

[M. Baiesi and M. Paczuski, PRE, **69**, 066106 (2004)] [Zaliapin *et al.*, *PRL*, **101**, 018501 (2008)]

Separation of clustered and background parts in southern California



Zaliapin and Ben-Zion, JGR (2013)

Seismicity as a flow of clusters

Identification of clusters: data driven



Artifacts of catalog uncertainties

Zaliapin and Ben-Zion, GJI, to appear (2015)

Spatial variability of absolute horizontal error in southern California



Artifact 1: Inflated distance-to-parent



Tectonic vs Induced seismicity

2-D distribution of time and space components of the EQ distance

Mixed

Tectonic

Induced





2-D distribution of time and space components of the EQ distance

Induced seismicity shows:

- Higher intensity of repeaters
- Higher background rate
- Higher spatial offspring separation
- Higher temporal offspring separation

Temporal decay of close offspring

is faster for induced seismicity





Induced seismicity shows:

- Less intense clustering
- Higher background



Tectonic:

- Low background
- High clustering
- No repeaters

Mixed:

- High background
- Low clustering
- Active repeaters

Increase of background rate in induced seismicity (5-year moving average with value placed at the window's end)



Reduced clustering of induced seismicity



Increased intensity of repeaters in induced seismicity

rescaled time-to-parent for offspring within one rupture length from parent



Tectonic seismicity:

- Almost no repeaters
- Unimodal time distribution

Mixed seismicity:

- High intensity of repeaters
- Bimodal time distribution

Summary



Seismically active regions of three types are examined:

- Tectonic seismicity (San Jacinto and Coso non-geothermal)
- Induced seismicity (Geysers and TauTona)
- Mixed seismicity (Coso geothermal and Salton Sea)



Induced seismicity shows:

- Higher rate of background events
- Faster temporal offspring decay
- Higher intensity of repeaters
- Larger proportion of small clusters
- Larger spatial offspring separation



Reported differences successfully discriminate between tectonic and induced seismicity in Coso and Salton sea observed before and after active geothermal production

Ref: Zaliapin & Ben-Zion (2015), Discriminating characteristics of tectonic and human-induced seismicity. In review



Geysers geothermal field | 1984/01 – 2011/12 | M1.0-4.5 | 75,991 events relocated catalog of *Waldhauser and Schaff* [2008]



TauTona golden mine, South Africa | 2004/09 – 2010/09 | M1.5-4.2 | 8,519 events catalog of *Boettcher* [2009]



Coso geothermal | 1981/01 – 2013/12 | M1.0-4.41 | 4,412 events Relocated catalog of *Hauksson et al.* [2013]







Coos non-geothermal | 1981/01 – 2013/12 | M1.0-5.75 | 56,801 events Relocated catalog of *Hauksson et al.* [2013]



San Jacinto | 1981/01 – 2013/12 | M1.0-5.43 | 39,768 events Relocated catalog of *Hauksson et al.* [2013]

