



Oklahoma's induced seismicity strongly linked to wastewater injection depth

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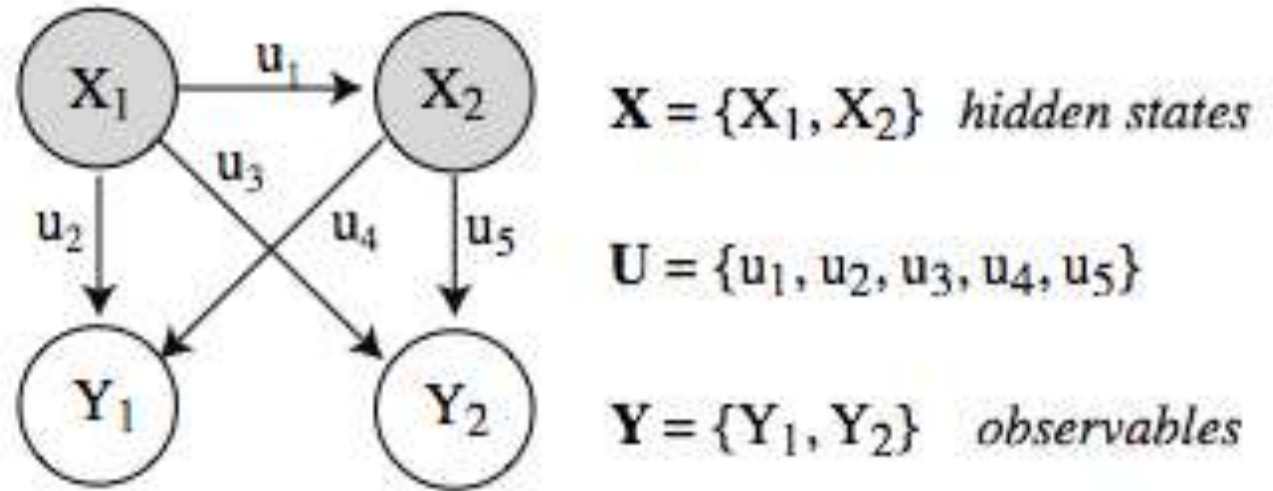
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One sentence summary:

A Bayesian Network approach implicates well depth as the most important geologic factor for induced earthquakes.

Brief background: Bayes (Belief) Net(works)

Causal probabilistic network
directed acyclic graph



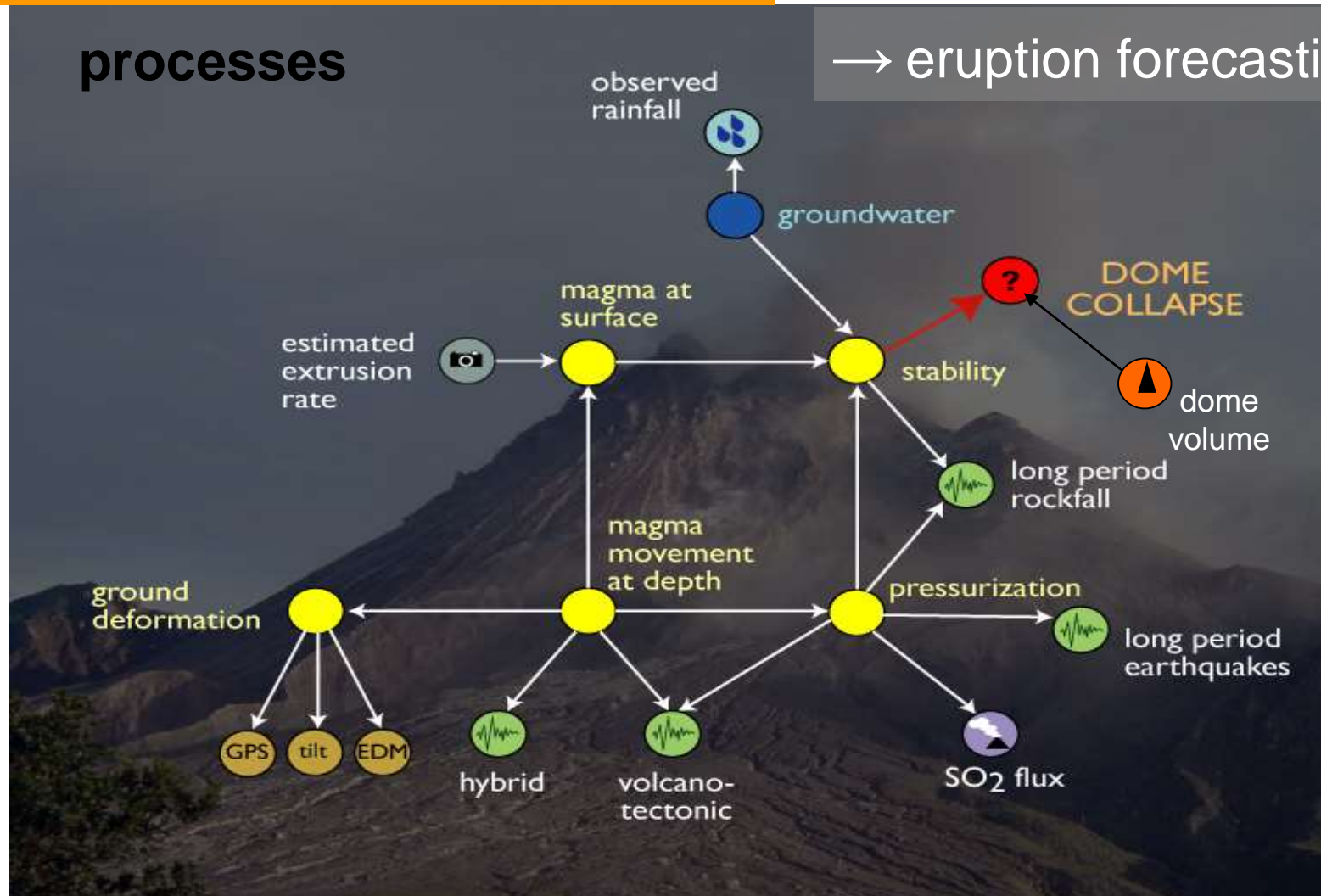
Set of **variables** (nodes) *discrete or continuous*
representing hidden or observable states of the system

Set of **directed links** (arcs) representing conditional
dependencies between nodes

Bayes Net for volcano unrest

processes

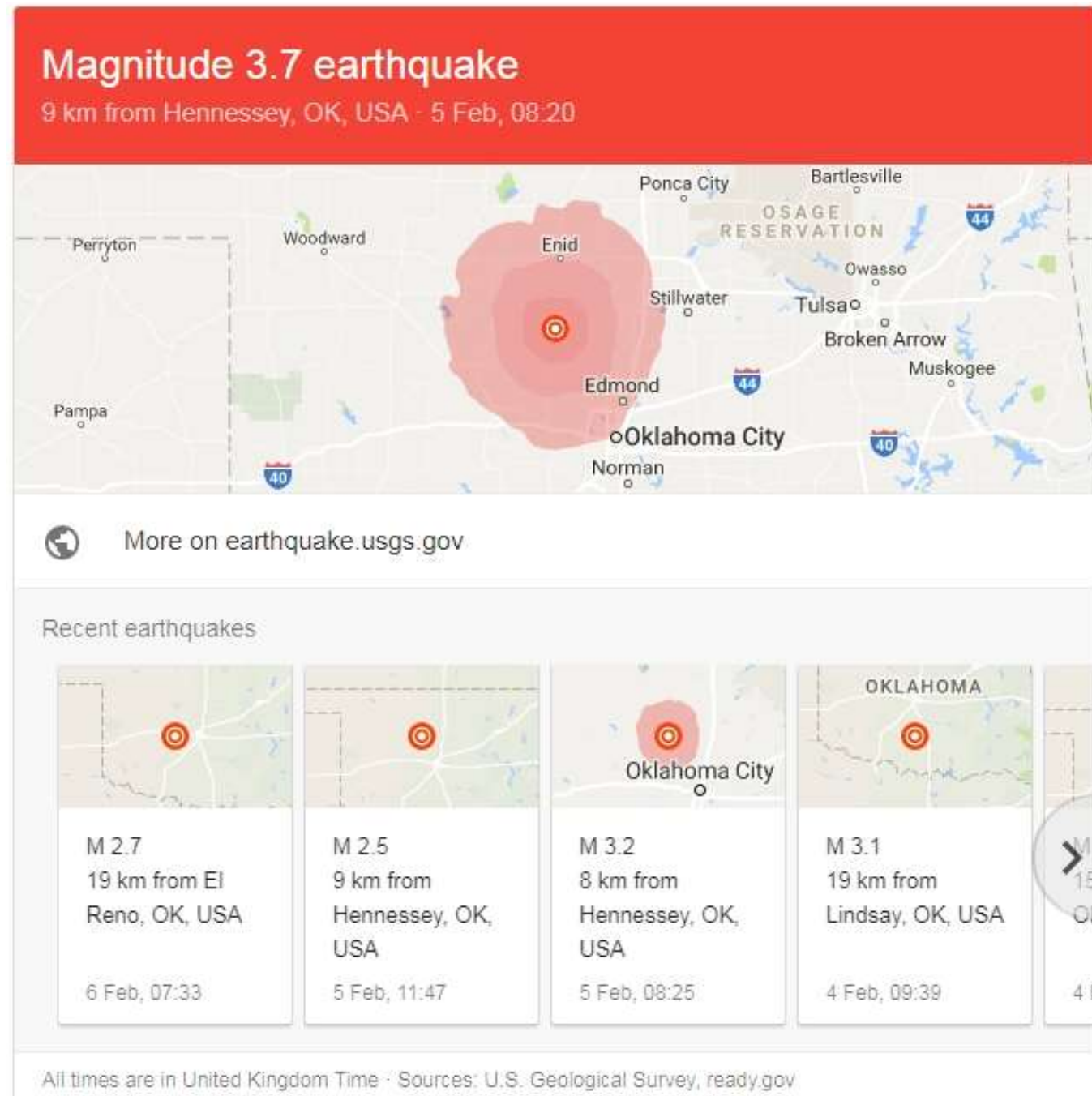
→ eruption forecasting



Aspinall W.P. and Woo G. (2014) Santorini unrest 2011–2012: an immediate Bayesian belief network analysis of eruption scenario probabilities for urgent decision support under uncertainty. Journal of Applied Volcanology 3[1]:12, doi:10.1186/s13617-014-0012-8

Induced OK seismicity is on-going

.....

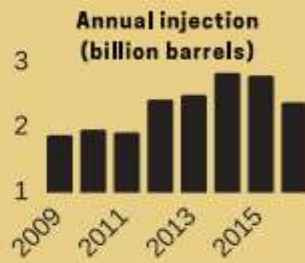
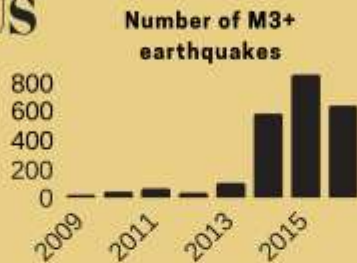


INDUCED SEISMICITY

is the term given to earthquakes caused by human activity. It is often related to the injection of wastewater into underground layers of rock



Oklahoma, US



Seismicity increase is due to **fluid injection** into deep rock formations.

5.8



The largest magnitude earthquake in Oklahoma caused injury and damage to buildings

September 2016, Pawnee



National Security Threat

Earthquakes could affect major oil storage facilities.



Most earthquakes occur in crystalline basement rocks

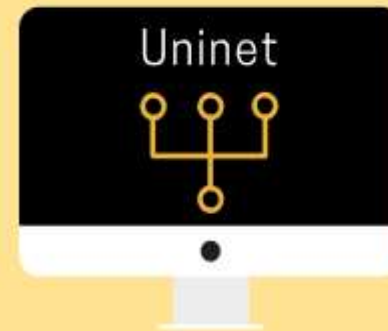


The number of active disposal and oil recovery wells in Oklahoma



2.3 billion

The average number of barrels of water injected underground in Oklahoma per year, since 2011
wastewater disposal and oil recovery



A new computer model investigates the **joint effect** of injection volume, depth and location on the energy released by earthquakes

www.lighttwist.net/wp/uninet

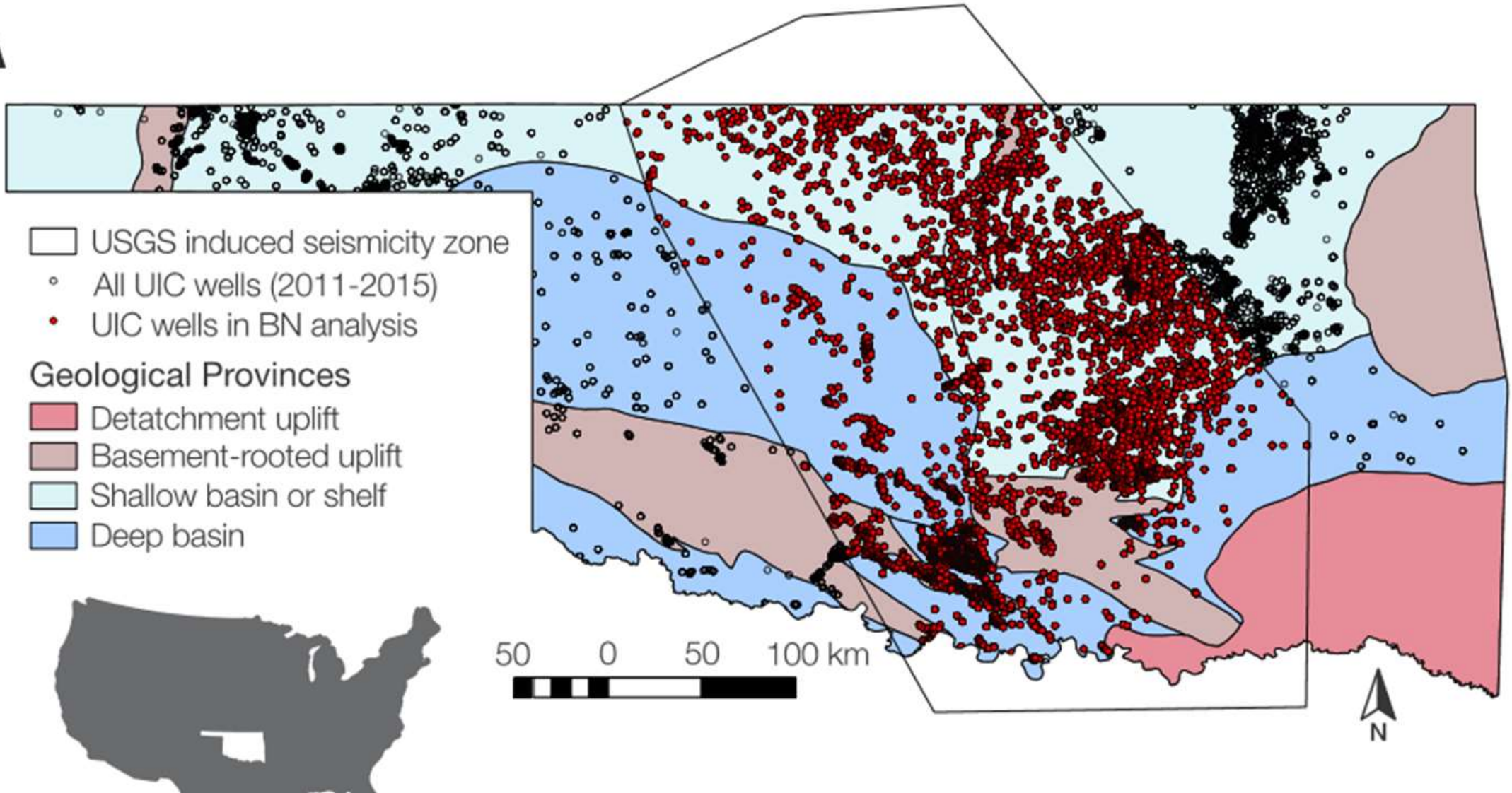


The models show that injecting **closer to the basement** leads to greater seismic moment release

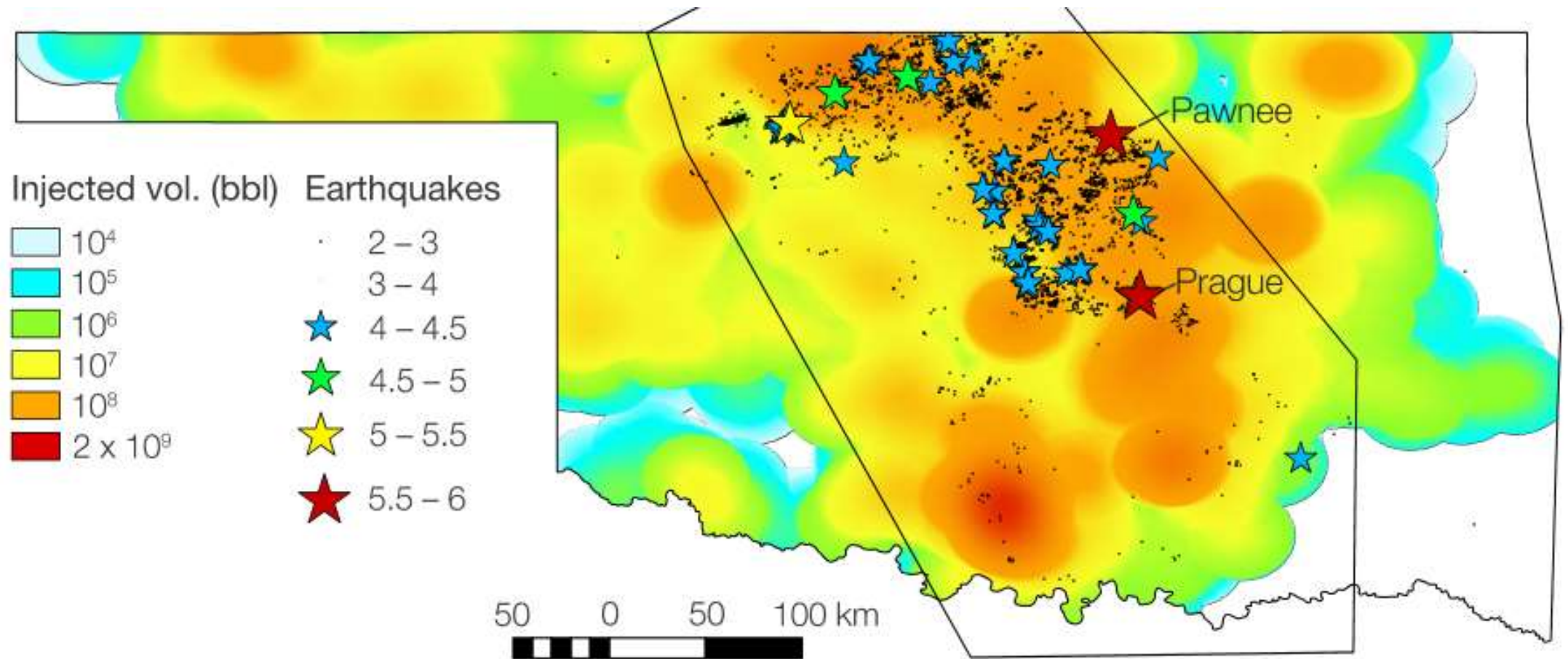


The novel modeling approach will aid operators and regulators in wastewater disposal regions

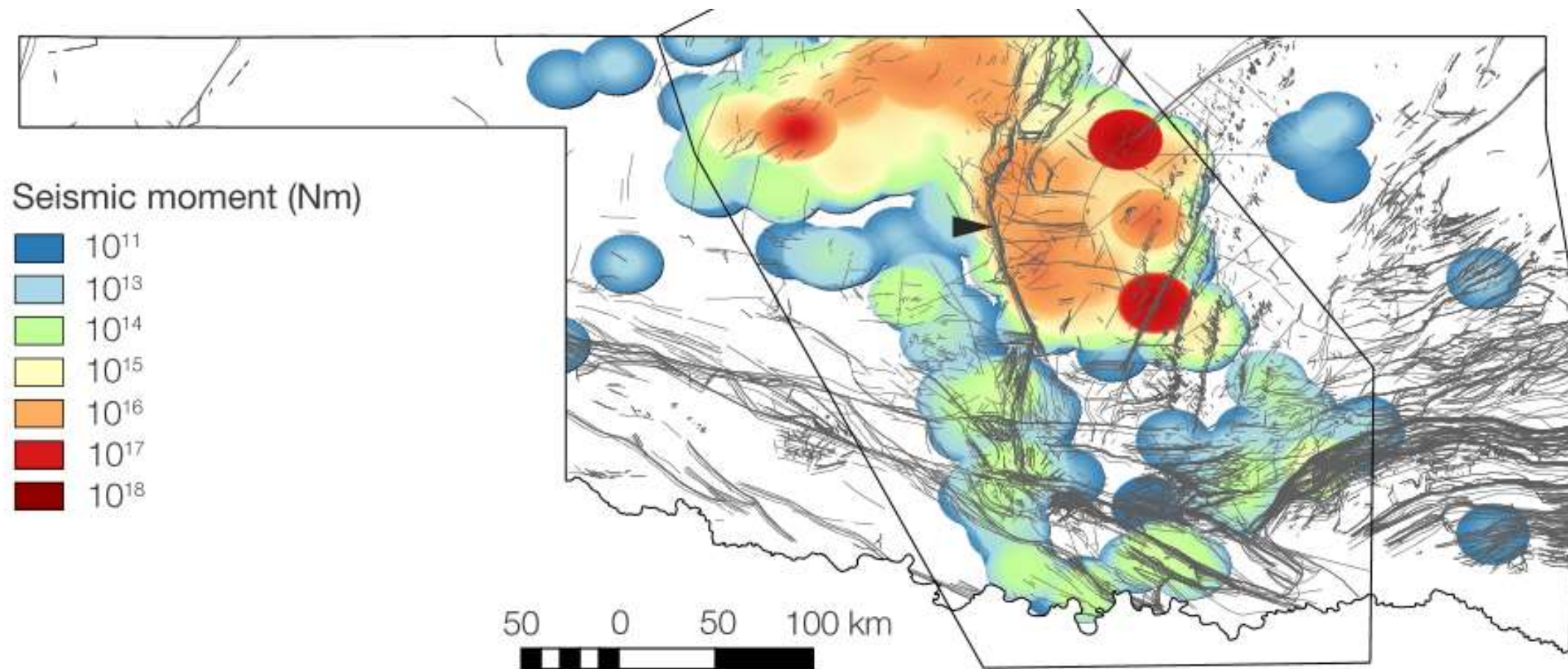
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Enhanced oil recovery and saltwater disposal wells in Oklahoma

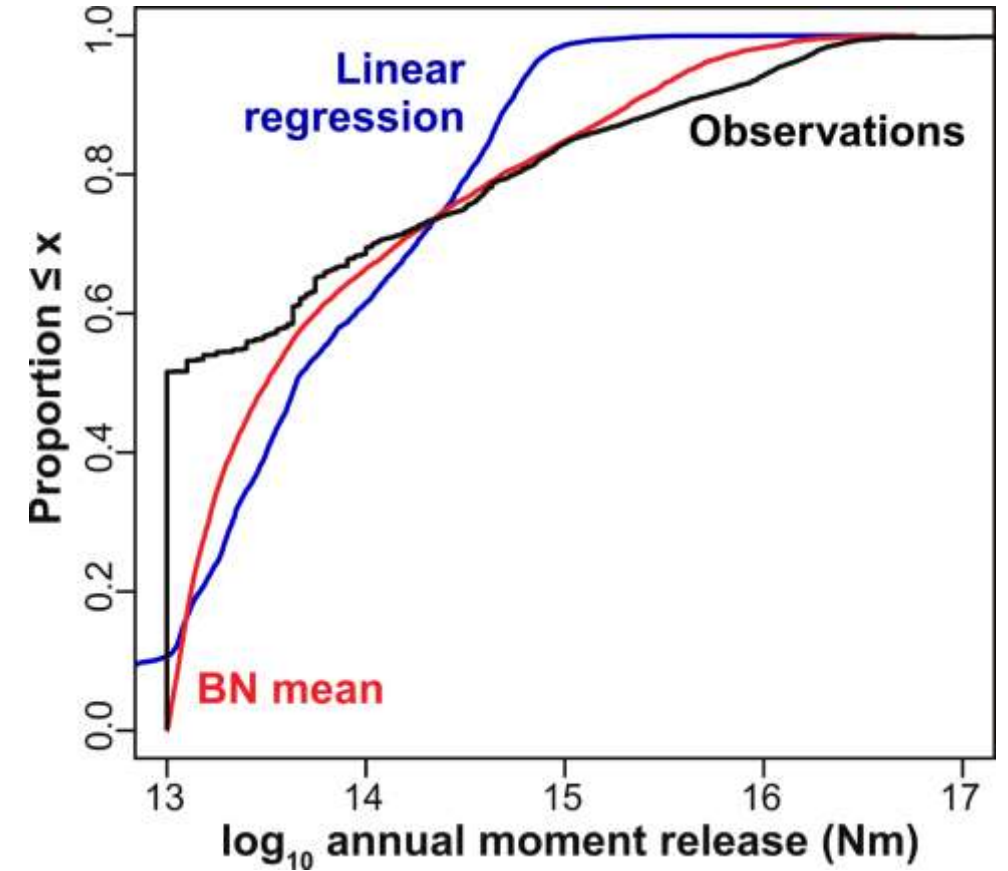
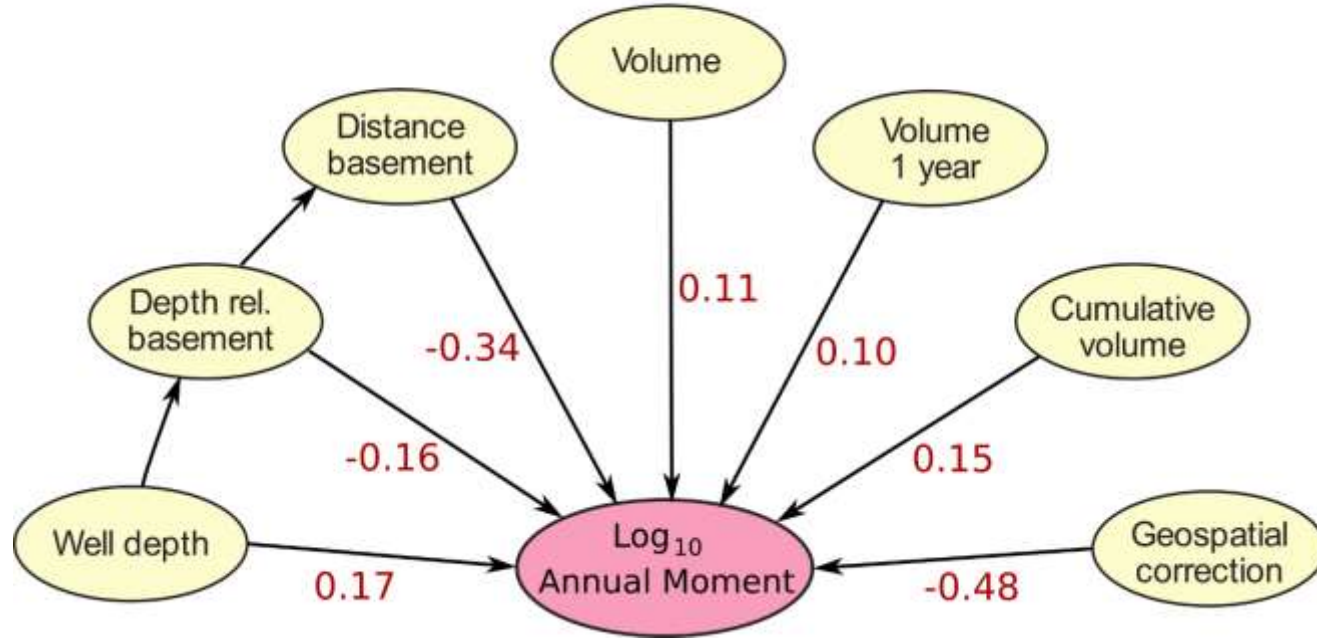


Injection volumes from disposal wells in Oklahoma and recorded earthquakes

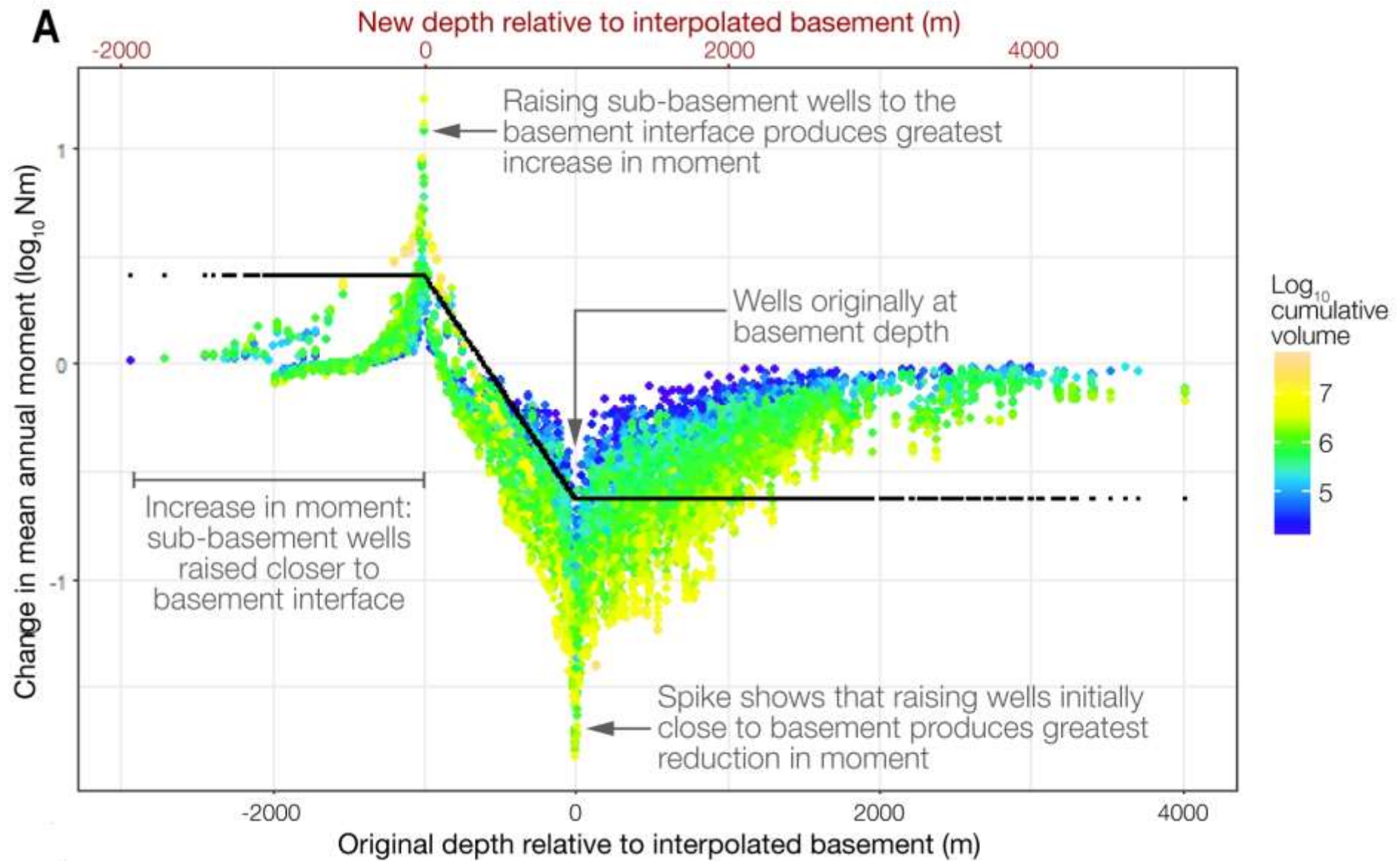


Total seismic moment release in Oklahoma

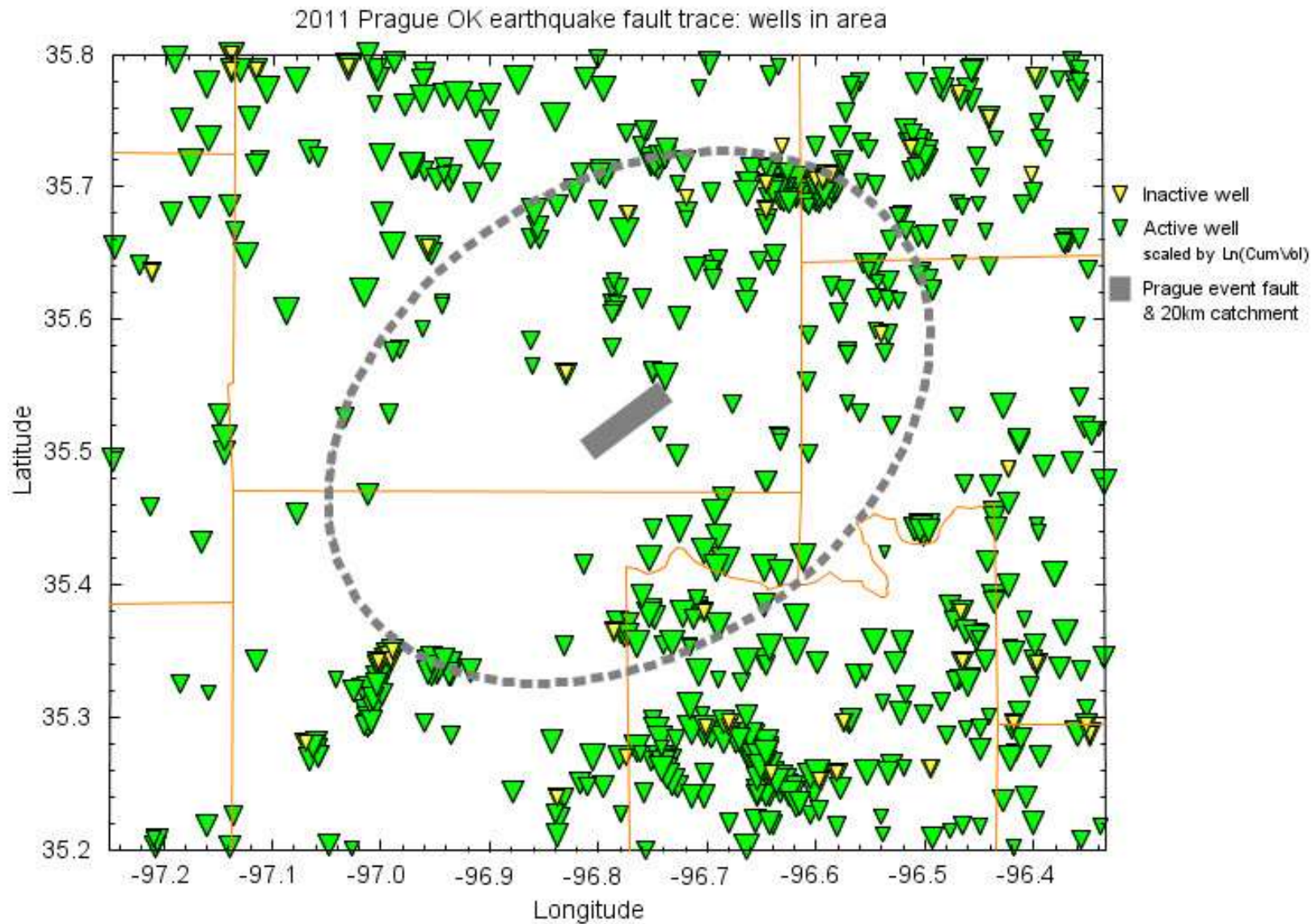
BN unconditional rank correlations



Induced seismicity Bayes Net: correlating seismic moment with well parameters (left), and superior performance relative to traditional regression analysis (right)

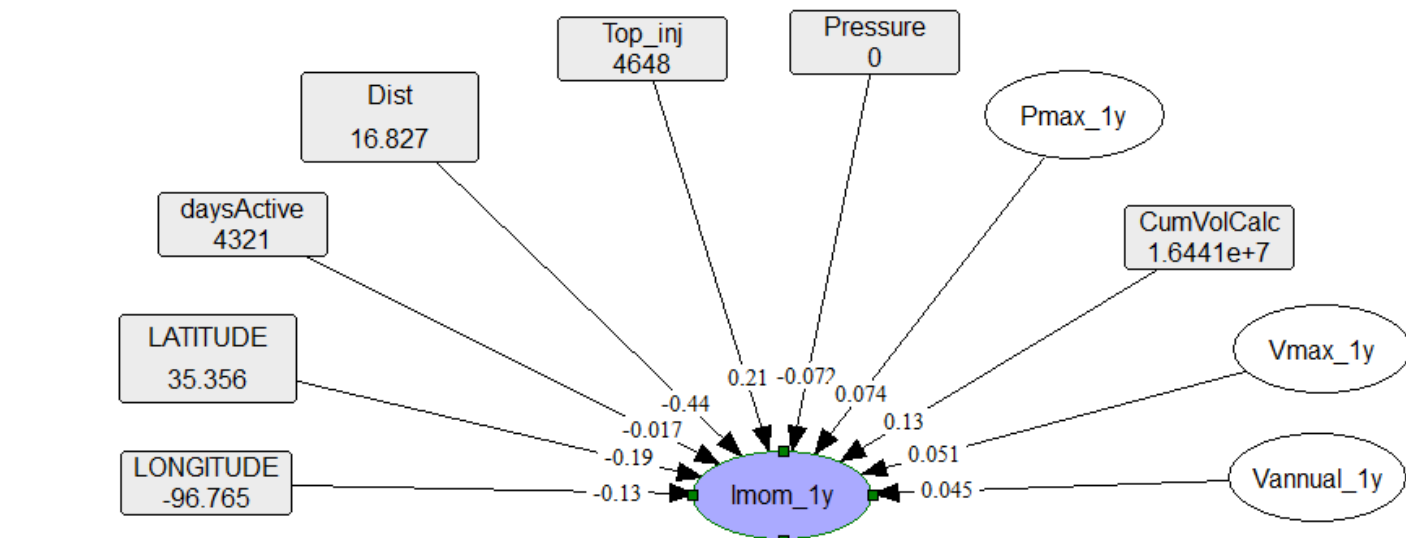


BN inferences about seismic moment release due to injection depth relative to basement, not captured by ordinary linear regression (black dots)



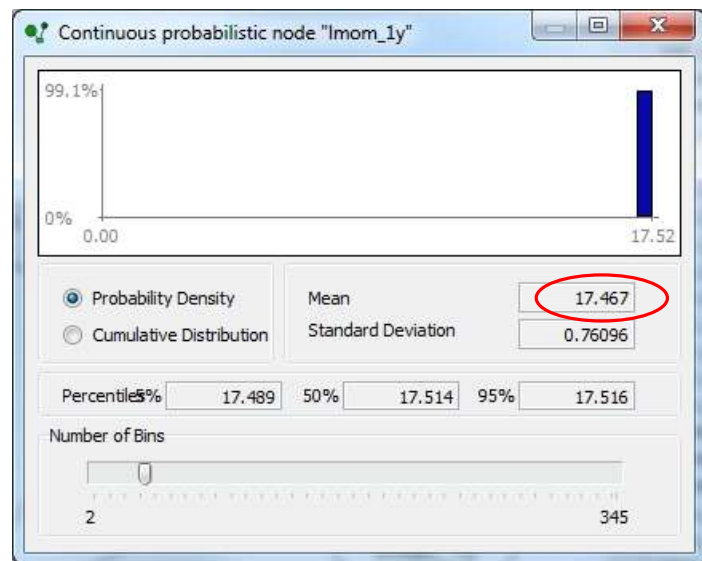
Note: other authors consider wells only within 5 → 10 km of fault

Attribution: active and inactive wells near 2011 Prague OK earthquake fault



BN conditionalized (instantiated) with data from one well to estimate contribution to total seismic moment

..... repeated over all disposal wells within 20km of fault and normalized to 100%:



BBN Conditionalizing variables								Moment attribution		
Well	Latitude	Longitude	Top_inj	Pressure	Dist	daysActive	CumVol Calc	mean Log[mom]	mean Moment	%_Moment by well
1	35.5305	-96.5584	4300	30	16.376	6512	1.97E+05	15.049	1.12E+15	0.01%
2	35.5796	-96.5754	1366	200	15.203	4382	1.08E+04	15.190	1.55E+15	0.02%
3	35.5367	-96.6765	3050	175	5.670	5416	8.06E+04	17.362	2.30E+17	2.70%
4	35.5578	-96.7384	4400	0	1.315	4686	2.65E+07	17.512	3.25E+17	3.82%
..										
..										
49	35.3561	-96.7649	4648	0	16.827	4321	1.64E+07	17.467	2.93E+17	3.44%

Attribution of percentage seismic moment to individual wells

The way ahead:

- Add to our analysis the most recent seismicity and well operations data
- Extend Bayes Net model to include temporal evolution of data and parameters
- Refine the geophysical basis for the important latent “geospatial factor”, which indicates local variability in seismic potential
- Introduce spatial fractal dimension characterization into OK Bayes Net
- Develop well attribution criteria for regulators, insurers
- Seek to amend model to other areas and conditions (e.g. gas extraction and geothermal field exploitation)
- Explore application to ordinary earthquake hazard assessment methodology



Thank you for your kind attention!

over to Daniel