Defining the Normal to Single out the Odd:

Baseline Studies of Regional Seismicity for Major Shale Gas Basins in Canada

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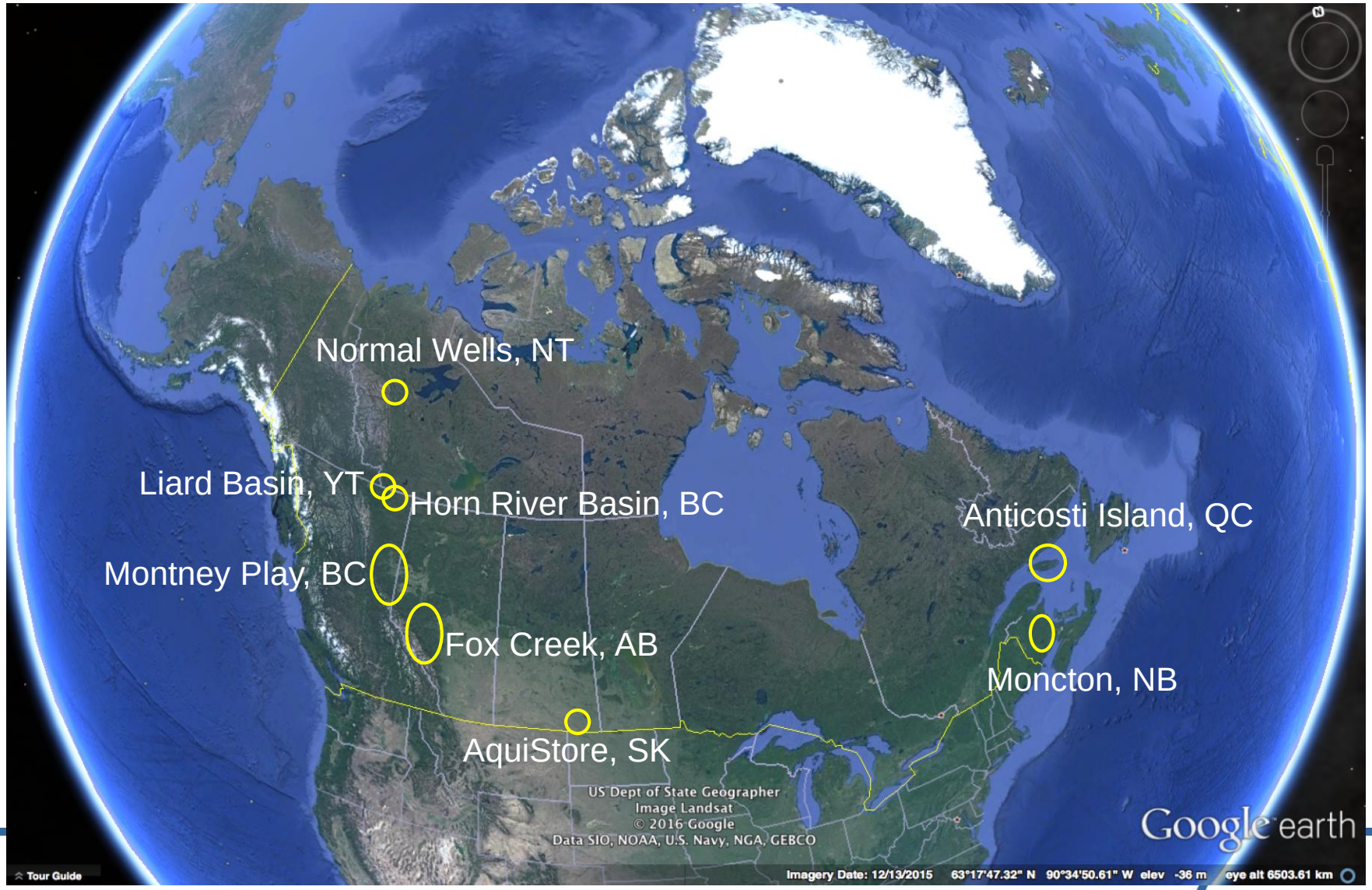
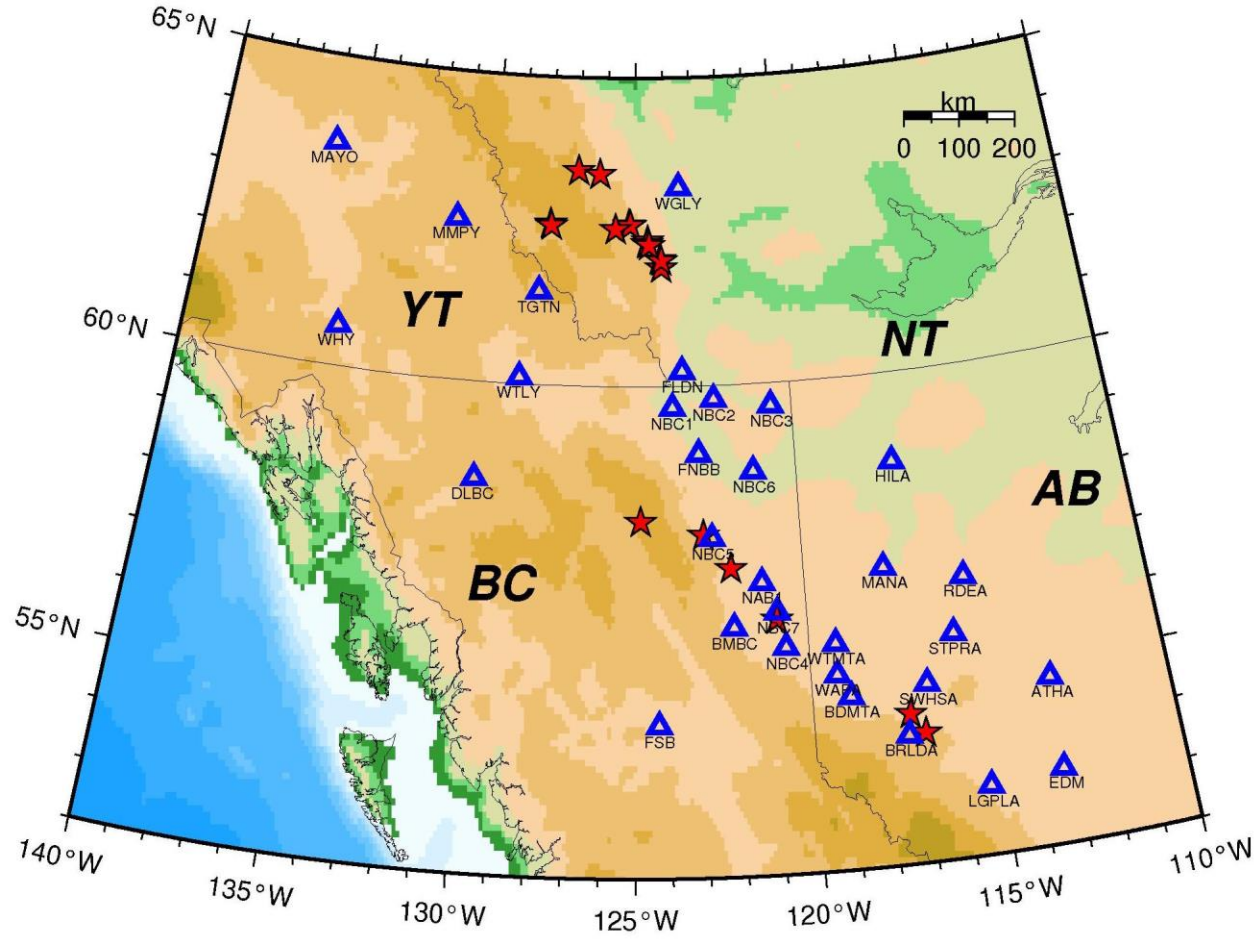
NRCan's Induced Seismicity Research Objectives

- Improve earthquake monitoring for areas with shale gas development potential.
- Conduct detailed studies of background seismicity to establish pre-development reference lines.
- Investigate variation of seismic patterns before and after shale gas development.
- Conduct targeted case studies of significant induced seismic events to delineate seismogenic characteristics.
- Provide observation-based conclusions to help improve regulatory performance.

NRCan ISR Project's Current Study Areas



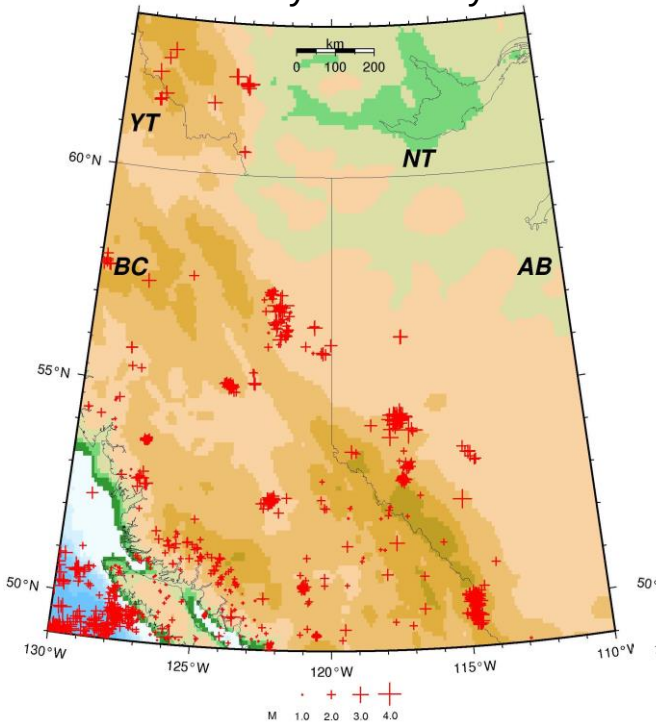
Earthquake Relocation for NE BC and SW AB



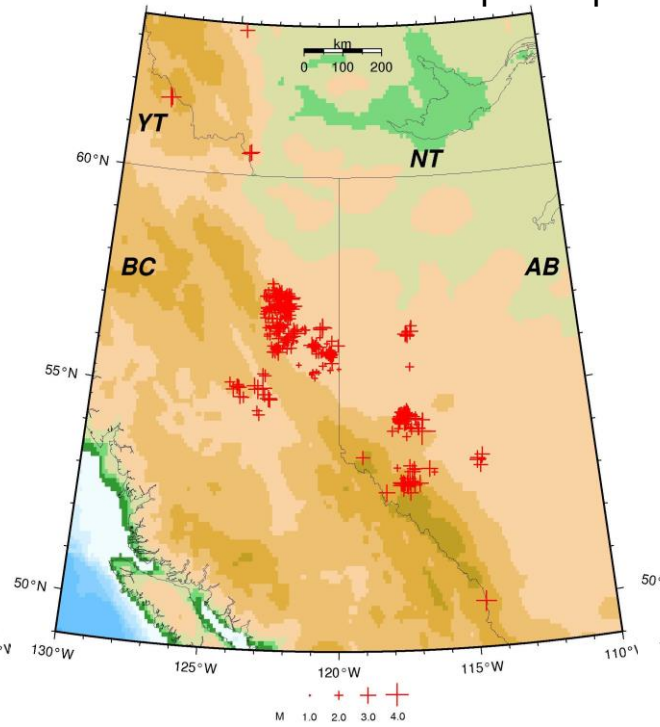
M 4+ events reported by NRCan

2015 Seismicity in NE BC

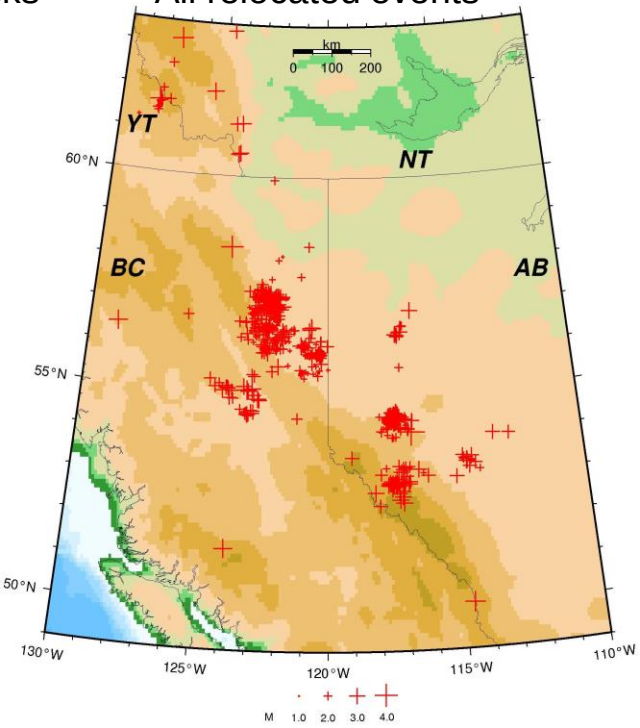
Events routinely located by NRCan

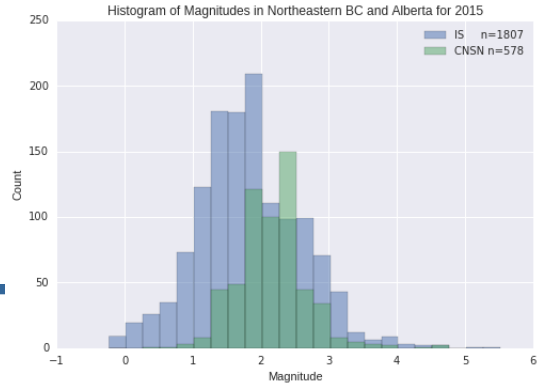


Relocated events with >5 phase picks



All relocated events

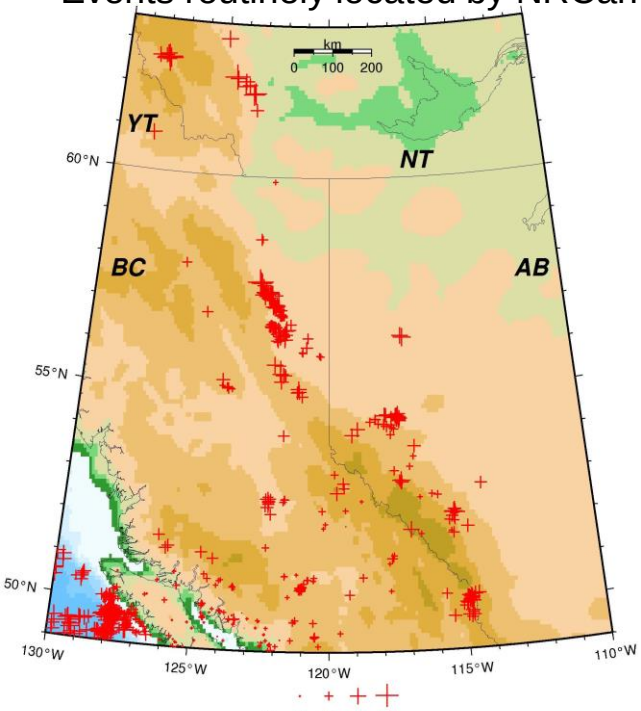




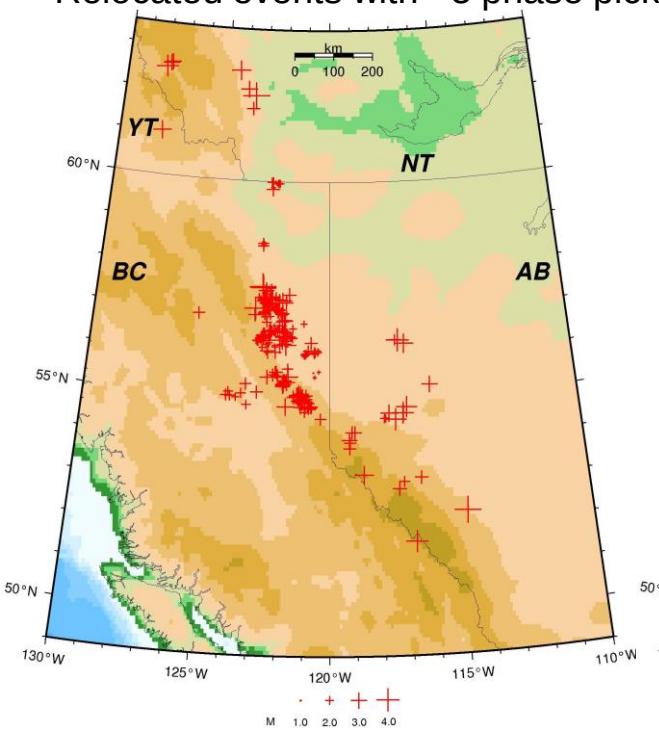
- Unfortunately, many events are missing from the NRCan's routine catalogue.
- Most missing events have ML < 2.
- The network's magnitude of completeness (Mc) is ~1.5.

2014 Seismicity in NE BC

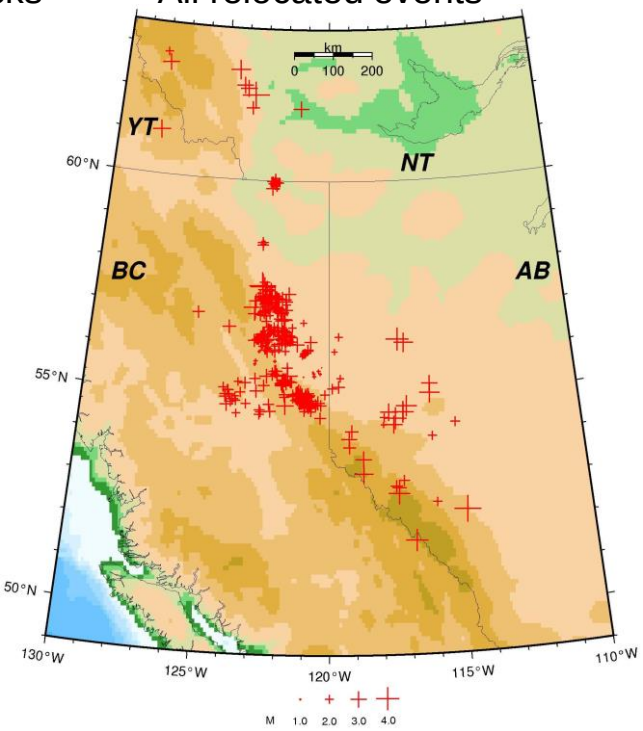
Events routinely located by NRCan

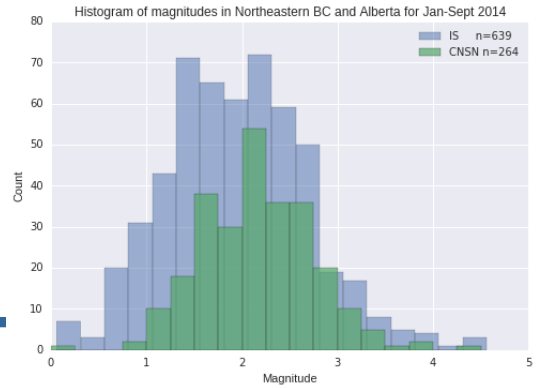


Relocated events with >5 phase picks



All relocated events

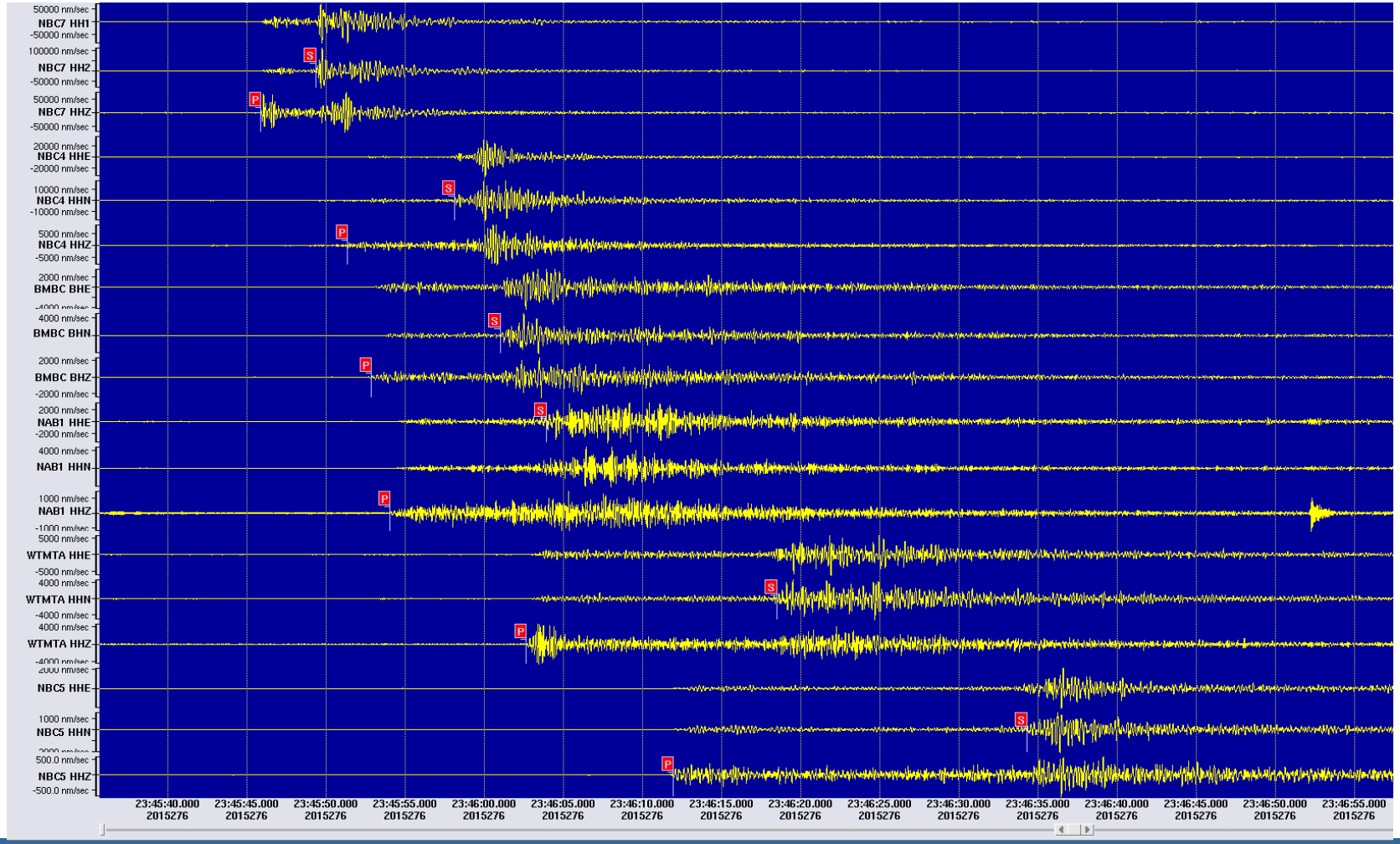




- The pattern of missing events is similar to that of 2015.
- Number of earthquakes becomes more than double after careful re-analysis of seismic waveforms.

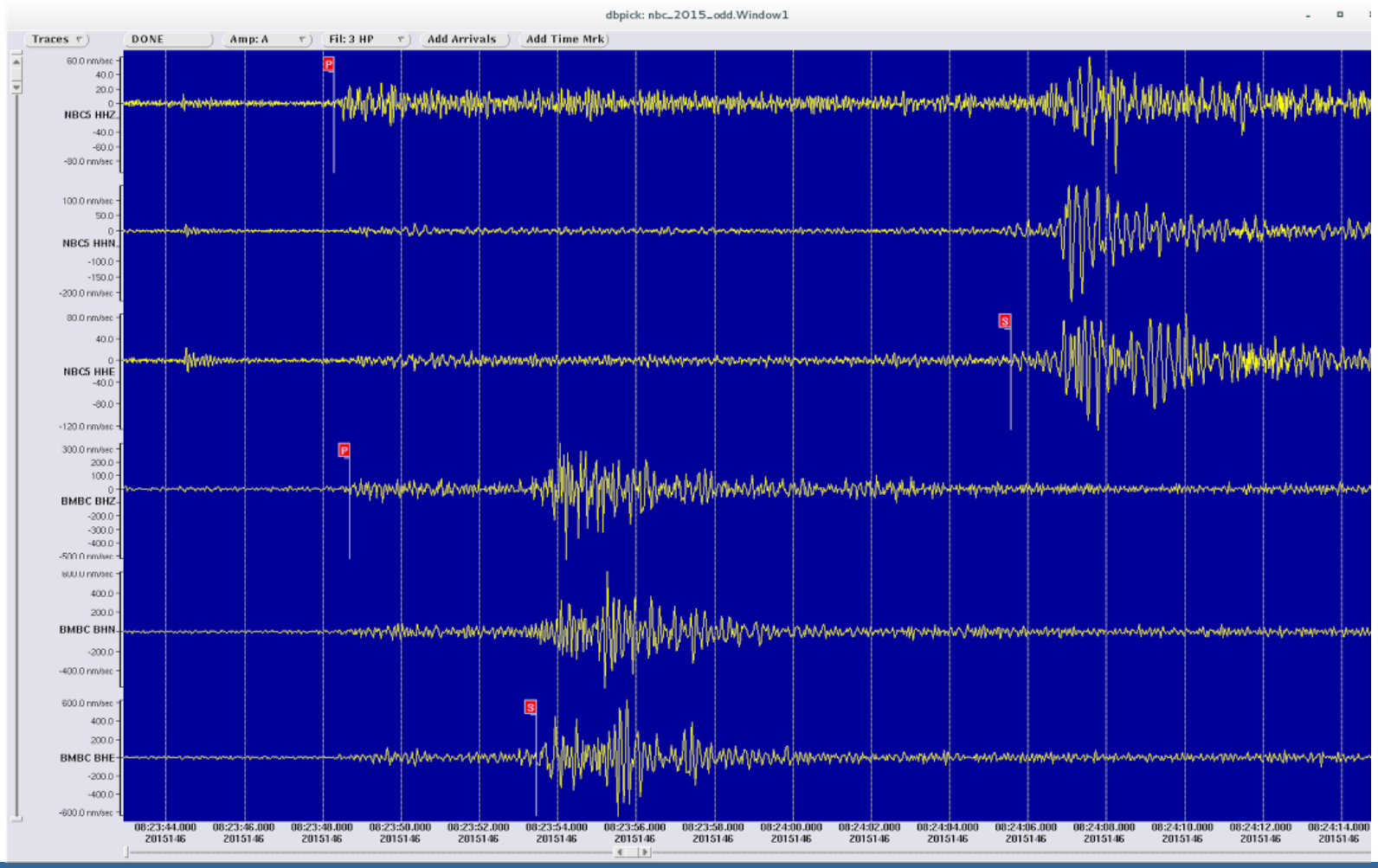
Examples of Missing Events

2015/10/03 23:45:42.5, 56.11N 121.13W, Z = 5 km, ML = 3.2

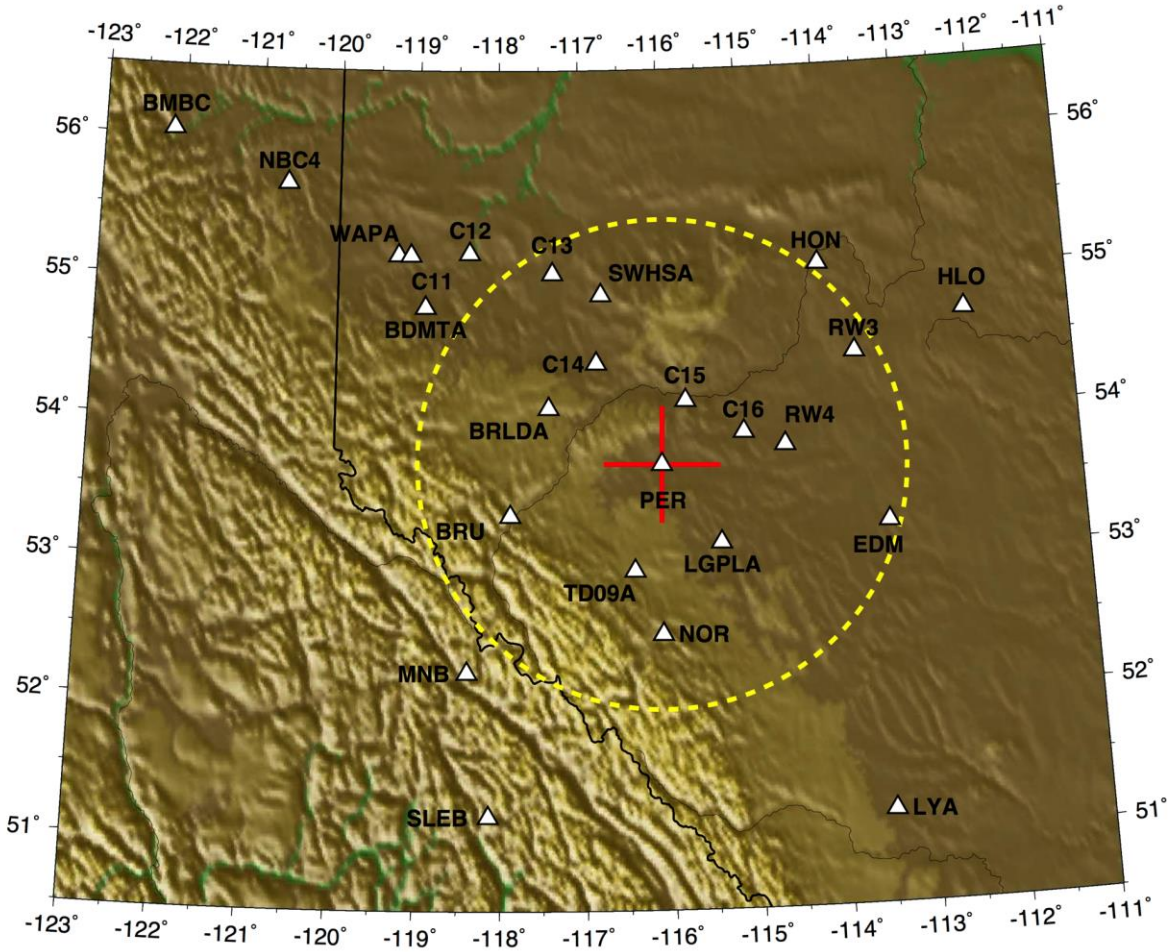


Examples of Missing Events

2015/5/26 8:23:48.6, 56.01N 122.13W, Z = 3 km, ML = 0.9

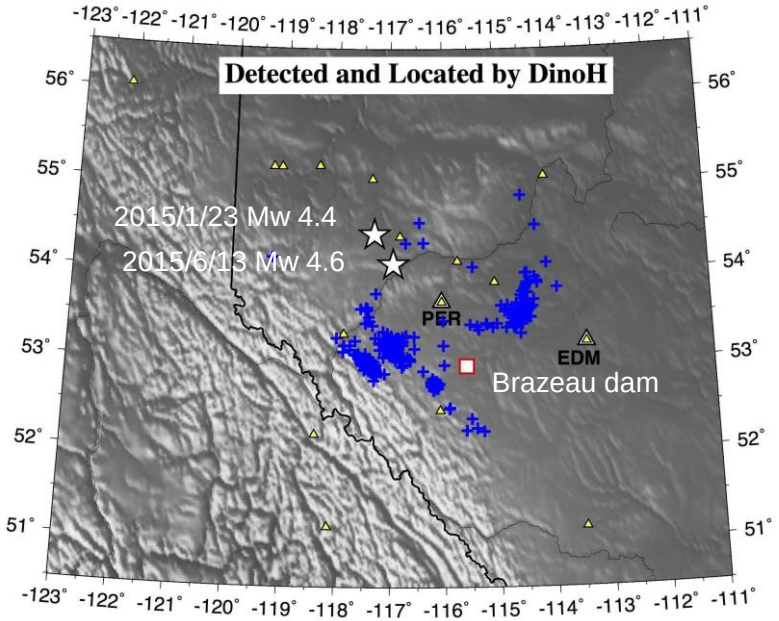


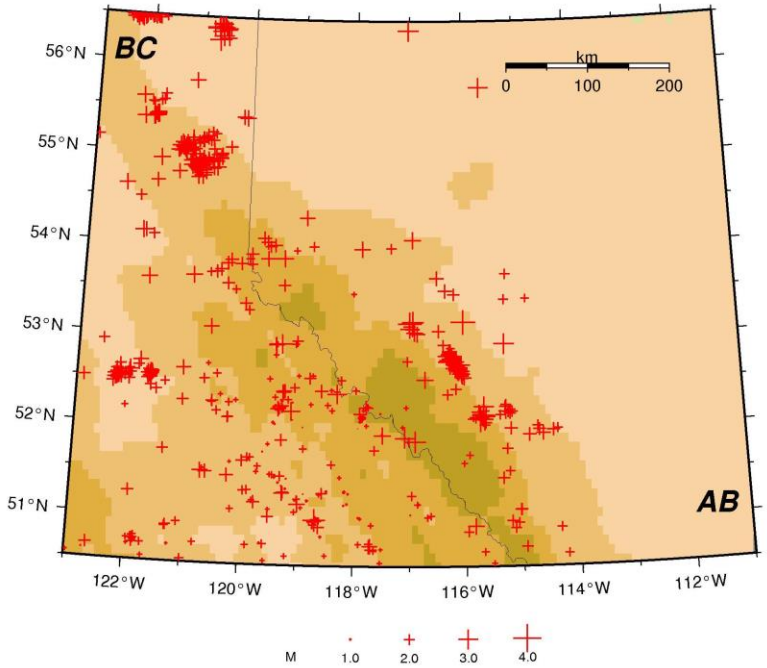
Detailed Seismicity Study for SW AB



- Use station PER as the primary reference;
- Search all events with *S-P* time difference < 20 s (i.e., within ~200 km from PER);
- Include all available stations in the region (CNSN, POLARIS, RV, CRANE, TransAlta);
- Pre-HF time window: 2004/3/07 - 2010/6/24
- Post-HF time window: 2010/6/25 – 2015/5/29

Pre-HF Seismicity in SW AB

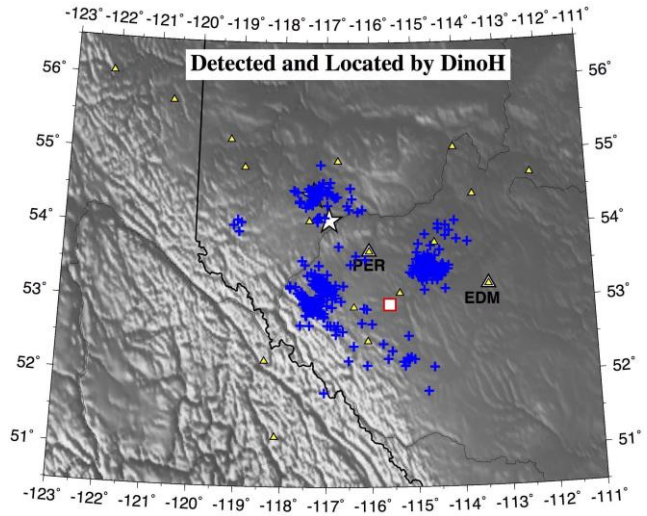


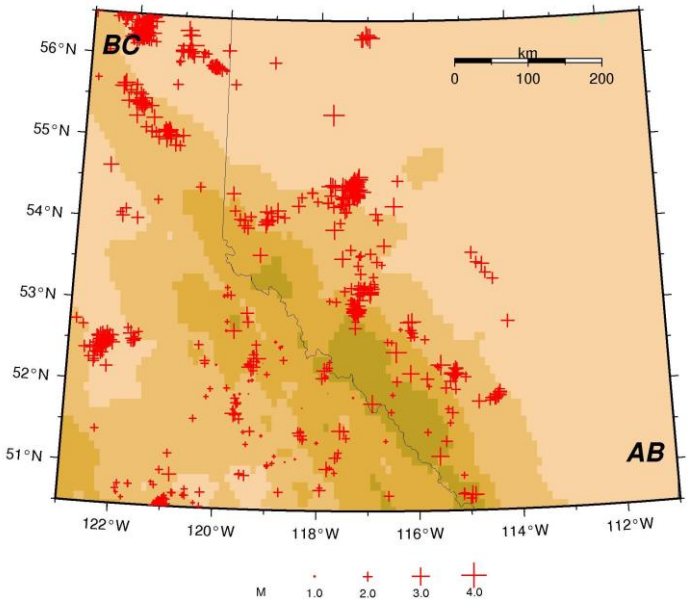


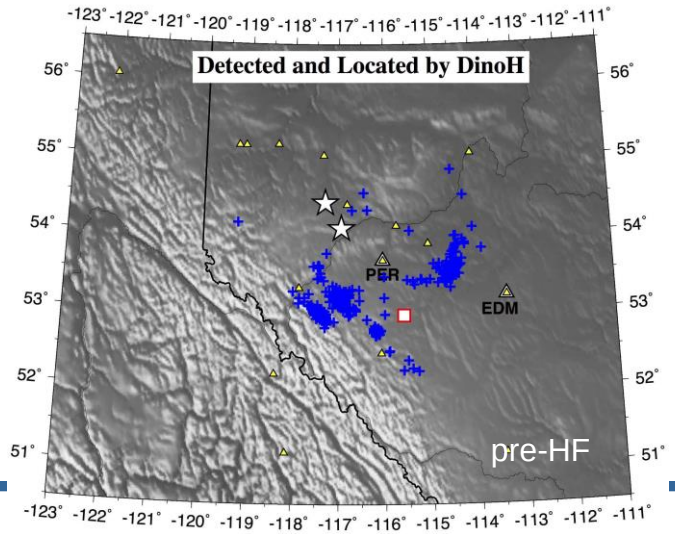
- 2004/3/07 - 2010/6/24;
- Use the velocity models provided by AGS;
- Can identify at least 6 earthquake clusters on 3 major seismogenic structures;

- Many events are missing from the NRCan routine catalogue;
- The Fox Creek area was seismically inactive during the pre-HF period.

Seismicity in SW AB After HF Began in 2010







- 2010/6/25 - 2015/5/29;
- The largest increase is observed at the Fox Creek area;
- Previously identified structures remain active;
- Discrepancies need to be investigated in detail.

Conclusions

- Many small-magnitude events are missing from the NRCan routine catalogue.
- NRCan routine operation is not adequate for near-real-time monitoring of small-magnitude induced seismicity in NE BC and SW AB. Specific arrangement must be made if rapid response to small induced events is desired.
- NRCan’s ISR project has completed detailed baseline studies of regional seismicity for major shale gas basins across Canada.