Detection sensitivity of local tectonic earthquakes by borehole geophone arrays: A case study from central Alberta

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Summary

Defining the detection sensitivity of a seismic monitoring network is important but challenging, as it requires careful estimation of noise levels or other disturbances that may affect the detection quality of seismic recordings. Under ideal circumstances, the magnitude-distance detection threshold of a seismic network is a robust parameter that depends on factors including site conditions and the type of sensor. In this study, detection of local tectonic earthquakes has been tested using recordings extracted by continuous raw data from a 12-level downhole 15 Hz geophone array deployed at 2 km depth in a wellbore in central Alberta. Geophones are relatively insensitive to low frequencies (< 20 Hz) that are normally measured for local earthquake monitoring with seismograph networks. A new catalogue of seismic events, interpreted as local tectonic earthquakes, has been constructed by estimating the P, S time arrivals, epicentral distance, azimuth and Nuttli magnitude (mN) for each event. We compared our results with earthquakes listed by the Canadian National Seismic Network (CNSN). The national catalogue lists 16 earthquakes within 300 km of our array. These events occur within the magnitude range of $2.1 \leq mN \leq 3.5$ at distances of 151-292 km from the array. We found that 13 of these earthquakes (81%) were well recorded by our geophone array. We also identified 5 additional events at epicentral distances of 40-168 km that were not listed in the national catalogue. Our results indicate that downhole geophone arrays may be more suitable for earthquake monitoring than originally anticipated.

Introduction

The question of the extent to which an instrumental network is able to detect earthquakes raises various technical issues. Considerations include the distance from the epicentre to the sensors (epicentral distance), background noise levels and the magnitude distribution. In addition, the limit in the frequency band fixed by the bandwidth of the sensors is a technical limit to the detection sensitivity.

In this study, we investigate the use of a downhole geophone array deployed for microseismic monitoring of a hydraulic fracture treatment and the subsequent flowback and production periods. Continuous recordings were acquired for 10.5 months. The goal of this study is to assess the potential for detection of local earthquakes using this non-standard instrumentation. A secondary objective is to elucidate the waveform characteristics of local earthquakes, as recorded using geophones, to aid in their discrimination from other types of low frequency signals.

Seismicity in Alberta

Alberta is located near a transition from a relatively low-seismicity (Milne, 1970; Milne et al., 1978) in the stable interior of North America to more abundant seismicity in mountainous areas to the west. It is an area of active energy resource development, including coal, natural gas, conventional oil, and unconventional hydrocarbon resources. The distribution of the Alberta earthquakes is shown in Figure 1

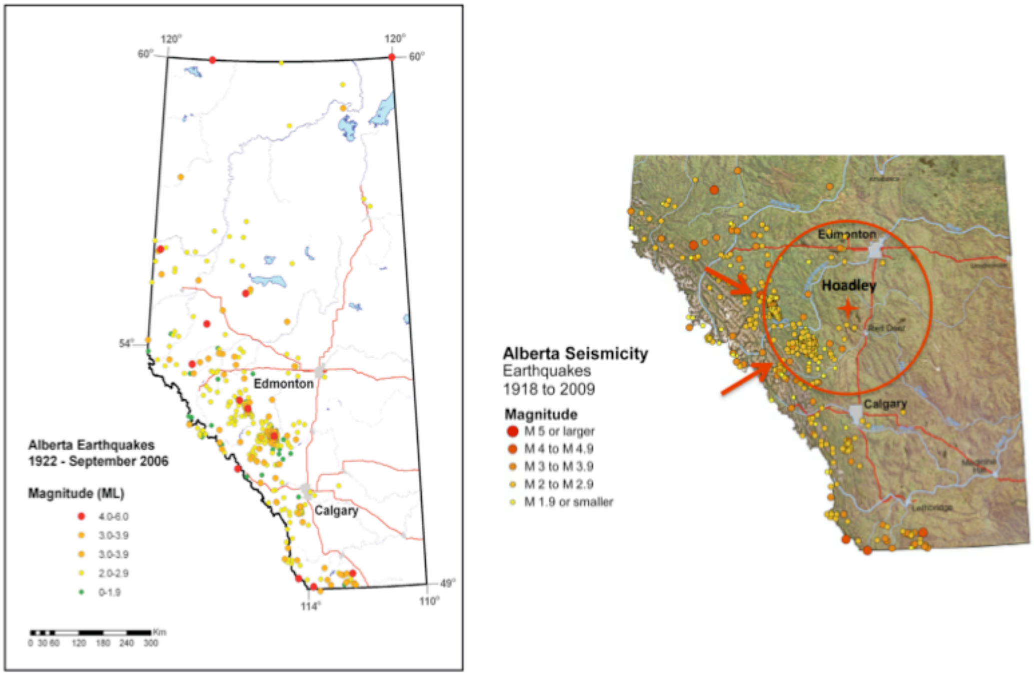


Figure 1: Alberta earthquakes recorded in Earthquake Canada's database from 1922 to September 2006 (Earthquakes Canada, 2011) (left). The location of the downhole geophone array near Hoadley, together with all the earthquakes from Stern et al. (2013). Arrows show locations of possible earthquakes detected by the geophone array.

(left). The locations of earthquakes are based on waveform data from five networks: the Canadian National Seismograph Network (CNSN), the Alberta Telemetered Seismograph Network (ATSN), the Canadian Rockies and Alberta Network (CRANE), the Montana Regional Seismic Network (MRSN), and the United States Reference Network (US-REF).

Earthquakes in Alberta are generally concentrated along the southeast-trending in the Canadian Rocky Mountains and adjacent foothills. Clusters of earthquakes have been observed in past studies (Stern et al., 2013). In Figure 1 (right) the location of the downhole geophone array near Hoadley is indicated, along with detected earthquakes from the catalog by Stern et al., (2013).

Results

Continuous raw data from the downhole geophone array for the time period September 18, 2012 to July 2, 2013 were inspected to identify potential local earthquakes. An example of a potential local earthquake is shown in Figure 2. From these recordings, the P, S time arrivals were picked and used to estimate epicentral distance using the following velocity model provided by the Alberta Geological Survey (Virginia Stern, pers. comm., 2013):

Depth	VP	VS
0-36 km	6.2 km/s	3.57 km/s
36 km	8.2 km/s	4.7 km/s

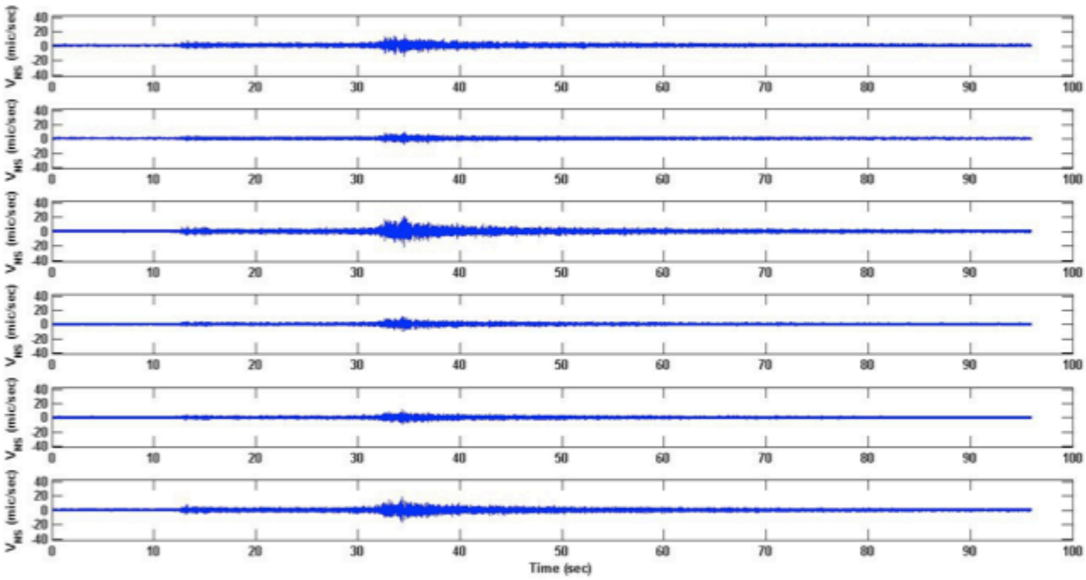
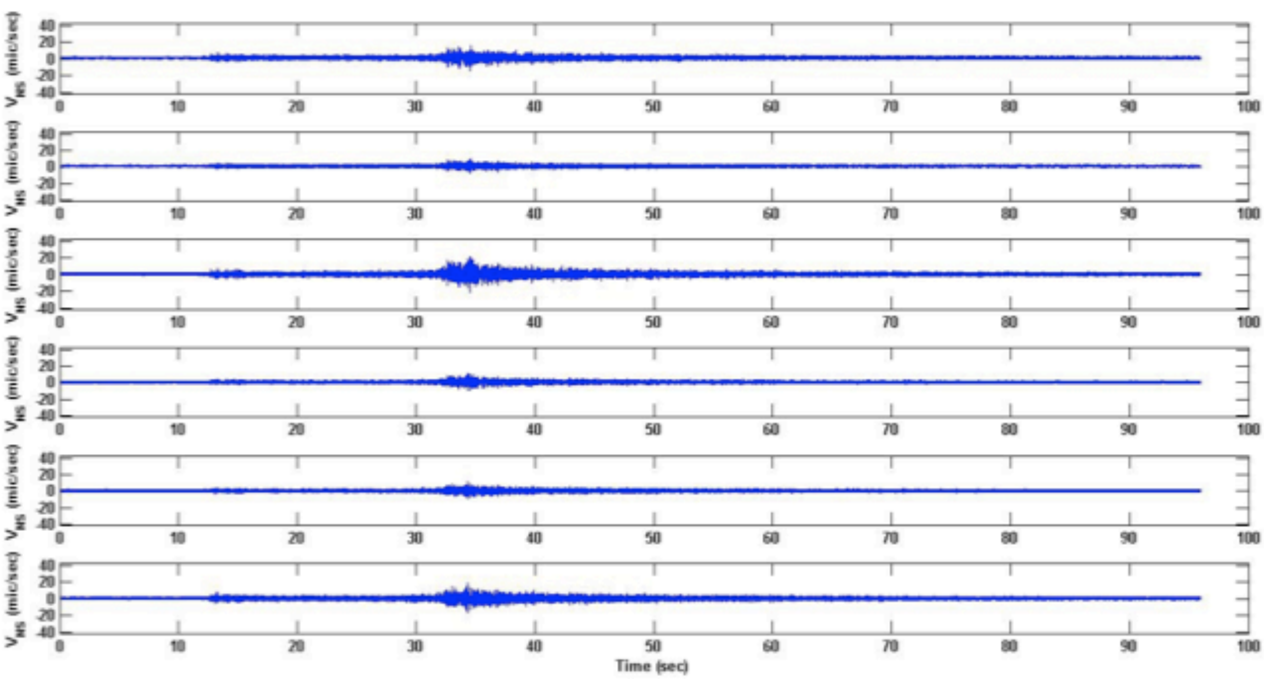


Figure 2: A small local earthquake detected by the geophone array on June 28, 01:02:37 UTC. This event is not listed in the CNSN Catalogue.

The raw data were converted into units of cm/s based on the geophone sensitivity of 86.6 V/m/s and pre-amplifier gain of 128 dB. The measured amplitudes were then used to estimate the Nuttli magnitude using the formula from Atkinson and Boore (1987). We chose the Nuttli magnitude for comparison with the national earthquake catalog. A preliminary catalog of events is given in Table 1.

Table 2 shows a catalogue of earthquakes obtained from the online CNSN. In terms of event times and distances, we find a good agreement between the two catalogues. However the Nuttli magnitude appears to be underestimated using the geophone array. This is most likely due to the low frequency



Date	Tp_av	Ts_av	Ts_av-Tp_av	Validity	Comments	d (km)	Az (°) N	MN	Listed in CNSN
17/09/2012	01:35:47.83	01:36:02.99	00:00:15.16	Ok	Local Earthquake	127.6071	50 230	1.4	No
19/09/2012	??	??		Ok?	Not yet processed				Yes
21/09/2012	19:06:51.34	19:06:56.14	00:00:04.80	Ok	Local Earthquake	40.3756	210 220	1.6	No
13/12/2012	01:47:25.50	01:47:39.74	00:00:14.24	Ok	Local Earthquake	119.8469	230	1.2	No
31/12/2012	23:10:32.26	23:10:47.48	00:00:15.22	Ok	Local Earthquake	128.0911	320 330	2.5	Yes
13/01/2013	13:03:51.87	13:04:29.80	00:00:37.93	Ok	Local Earthquake	319.2177	340	1.4	Yes
08/02/2013	23:06:54.92	23:07:13.73	00:00:18.81	Ok	Local Earthquake	207.1433	40	1.9	Yes
15/02/2013	18:03:41.52	18:03:56.57	00:00:15.05	Ok	Local Earthquake	126.6603	210	1.7	Yes
22/04/2013	16:32:53.50	MISSING!		Ok	Not yet processed				Yes
10/05/2013	12:06:18.75	12:06:36.30	00:00:17.55	Ok	Local Earthquake	193.2506	80	1.3	Yes
03/06/2013	03:15:09.52	03:15:26.58	00:00:17.06	Ok	Local Earthquake	143.5577	280 180 170 130 120	2.7	Yes
04/06/2013	13:54:47.48	13:55:22.37	00:00:34.89	Ok	Local Earthquake	293.6519	350 260 280 100 30 40	1.4	Yes
04/06/2013	17:19:55.85	17:20:20.00	00:00:24.15	Ok	Local Earthquake	203.2083	250	1.3	Yes
28/06/2013	01:02:49.73	01:03:09.68	00:00:19.95	Ok	Local Earthquake	167.8238	130	1.6	No
28/06/2013	03:56:04.45	03:56:14.94	00:00:10.49	Ok	Local Earthquake	88.2625	40	1.4	No
29/06/2013	06:20:25.31	06:20:51.70	00:00:26.39	Ok	Local Earthquake	222.1302	60	1.8	Yes
29/06/2013	06:23:18.73	MISSING!		Ok	Not yet processed				Yes
29/06/2013	07:41:59.43	07:42:25.25	00:00:25.82	Ok	Local Earthquake	217.2910	50	1.3	Yes

Table 1: Preliminary local earthquake catalogue derived from the geophone observations.

Date	Time (UTC)	Lat	Lon	Dist (km)	Depth	MN	Comment
2012/09/19	19:18:55	50.042	-114.903	292	1.0g	2.9	ML86 km ENE of Cranbrook
2012/10/07	19:11:22	50.062	-114.996	291	0.0g	2.9	ML83 km NE of Cranbrook
2013/01/01	06:10:10	52.815	-116.110	129	1.0g	3.0	ML95 km WNW of Rocky Mt. House
2013/01/13	20:03:10	50.112	-115.033	286	0.0g	2.7	ML86 km NE of Cranbrook
2013/02/09	06:06:30	52.083	-116.423	162	10.0	2.1	1ML109 km WSW of Rocky Mt. House
2013/02/16	01:03:20	52.807	-116.182	133	1.0g	2.9	ML98 km WNW of Rocky Mt. House
2013/04/22	22:32:21	52.932	-117.242	205	0.0g	2.7	ML56 km E of Jasper
2013/04/29	18:33:36	53.550	-116.813	200	0.0g	2.2	ML112 km ENE of Jasper
2013/05/10	18:06:05	54.545	-116.964	278	0.0g	2.8	Mw190 km S of Peace R.
2013/05/10	18:06:02	54.541	-116.379	254	0.0g	2.3	ML196 km SSE of Peace R.
2013/06/03	09:14:45	52.443	-116.431	151	1.0g	3.5	ML104 km W of Rocky Mt. House
2013/06/04	19:54:05	50.212	-114.909	274	0.0g	2.8	ML100 km NE of Cranbrook
2013/06/04	23:19:24	52.816	-117.247	204	0.0g	1.8	ML56 km E of Jasper
2013/06/29	12:19:51	50.691	-114.976	223	1.0g	3.1	ML67 km SE of Banff
2013/06/29	12:22:16	50.645	-115.000	228	1.0g	2.1	ML70 km SE of Banff
2013/06/29	13:41:24	50.691	-114.914	222	1.0g	2.8	ML70 km SE of Banff

Table 2: The CNSN catalogue for the Alberta area.

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