CONSORTIUM TO STUDY TRENDS IN SEISMICITY

Quarterly report:
January 1, 2019 through March 31, 2019

by

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May 15, 2019

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INTRODUCTION

The Kansas Geological Survey's Consortium to Study Trends in Seismicity (CSTS) is a public-private partnership aimed at studying trends in seismicity in sensitive areas of Kansas where public and private interests could benefit from high-sensitivity monitoring. In 2009, seismicity increased significantly (both in terms of earthquake numbers and magnitude) in the midcontinent and later in Kansas, leading to a need to better define and understand seismicity, particularly in proximity to subsurface fluid disposal. The CSTS operates a seismic network near private facilities that records and allows accurate location and magnitude estimates of seismicity for both felt earthquakes and especially microseismic events that are hundreds of times smaller than can be routinely identified with previous regional seismic networks. Understanding current micro-trends in seismicity and establishing a data-driven awareness of potential factors affecting seismicity should strongly guide governmental oversight and influence public opinion.

The CSTS is an alliance of the Kansas Geological Survey (KGS), a research and service division of the University of Kansas with a long history of studying the state's subsurface and seismic issues with members of the state's Class I disposal well community. Most Class 1 wells terminate in the Arbuckle Formation, are used for disposal of municipal and industrial waste, and are regulated by the Kansas Department of Health and Environment (KDHE). Membership in the CSTS is voluntary, with a common goal of locating and understanding seismicity, especially microseismicity, in proximity to member facilities. The CSTS works to establish the baseline or background seismicity near those facilities and provide a scientific basis for differentiating natural (or tectonic) from induced seismicity. Confidence distinguishing natural from induced earthquake trends is greatly enhanced through extended monitoring periods with near-event stations.

The following report describes CSTS activities for the first quarter of 2019 (which is also the third quarter of the second year of CSTS operation), including a discussion of membership status; network station installation and operation; earthquakes recorded and identified, and earthquake alerts provided to members; and other activities. Quarterly reports and an annual report have been provided to members since the Consortium's first meeting in July 2017, as per contractual agreement.

STATUS OF MEMBERS

The CSTS was established with a two-tier membership system. The CSTS provides Tier 1 members with equipment, installation, and monitoring of a seismograph station; maintains a catalog of seismic events, updated weekly, with a goal of providing e-mail alerts within 24 hours or less of any earthquakes greater than magnitude 2 within 30 miles of their facility; provides an annual report and quarterly reports of monitoring

findings; and hosts an annual meeting at which results are discussed and plans formulated for the coming year. Tier 2 members have access to general information about the seismicity being studied by the CSTS—but not the detailed studies or the quarterly reports, and can attend the annual meeting—but do not have the right to vote at that meeting. The CSTS currently has eleven Tier 1 members and one Tier 2 member.

STATUS OF NETWORK

The CSTS seismic network consists of twelve stations in Kearny, Ellsworth, Rice, McPherson, Reno, Kiowa, Sedgwick, Butler, and Johnson counties, Kansas (Figure 1). Waveforms for these stations are available for Tier 1 members on the seismic network page of the CSTS website (http://www.kgs.ku.edu/Geophysics/CSTS/index.html). For each of those locations, ambient noise tests were undertaken, identifying noise from nearby highways, trains, pump jacks, and other facilities that might create problems with earthquake analysis. In places where noise and vibrations interfered with a station's response, the station was relocated, mindful to retain sensitivity while improving signal to noise. Many of the existing sites are in cemeteries, on government property, or in other locations where noise levels are likely to be low. In all cases, written agreements with landowners are in place.

Each station consists of a seismic sensor that includes a shallowly buried seismometer (sensing motion polarized in x, y, and z directions) on a concrete platform embedded in a gravel layer, and a digitizer housed in an instrument enclosure powered by a sustainable battery system. Ground motion detected by the seismometer is transmitted back to KGS offices in Lawrence real-time via a cellular modem. That communication system is also powered by the sustainable battery system that includes a solar panel charging two deep-cycle marine batteries controlled by a power regulating circuit. The footprint for each station is approximately 10 feet by 10 feet. The stations have operated with a better than 98% continuous data stream and within designated operational sensitivity and signal-to-noise ratio.

In the first quarter of 2019, KGS staff contacted landowners and visited each station for general inspection of the site and performance of routine maintenance.

EARTHQUAKE ALERTS, CATALOG

Earthquakes with magnitudes of 2 or larger (some below felt levels) represent a threshold above which the CSTS network, in conjunction with the KGS regional and subregional networks, can provide highly confident automatic analysis. It is therefore reasonable to provide accurate epicenter locations using automated picking routines for each event at these energy levels, with results available within minutes of the fault rupture. Beginning in September 2018, the CSTS used an automated notification process to inform members of events of M 2 or larger earthquake within 30 miles of Tier 1 member wells. Those notifications provide epicenter latitude and longitude, origin time, and distance from the member well(s). These automatic notifications must be approved by a senior analyst before they can be sent to members to insure the authenticity of computer-interpreted earthquakes.

In the first quarter of the calendar year,16 earthquakes met these criteria (Table 1), about half the number of alerts in the previous quarter. This is primarily a result of seismic activity along the eastern margin of the Midcontinent Geophysical Anomaly shifting slightly to the north in Saline County, just beyond 30 mi from member wells in McPherson County. Microearthquake activity recorded by the KGS and CSTS networks was about the same as the previous quarter. A total of 65 earthquakes ranging from M 0.5 to 3.1 were recorded within 20 miles of member wells (Figure 2, Table 2). The number of microearthquakes decreased in Sedgwick and Sumner counties and increased slightly near Hutchinson in Reno County. Most epicenters are within previously identified clusters or along known trends. Subnetwork activity (Table 3) was similar to the previous quarter.

OTHER ACTIVITIES

As part of a KGS seminar series, Shelby Peterie gave a presentation to KGS staff and guests on "Earthquakes in Kansas Induced by Extremely Far-field Pressure Diffusion." Rex Buchanan represented the KGS at the annual meeting of the Regional Induced Seismicity Collaborative (RISC) at the University of Texas-Austin in January. RISC is a collaborative effort by the state surveys of Texas, New Mexico, Oklahoma, Arkansas, and Kansas, funded by the U.S. Department of Energy. In February, Rex Buchanan attended a meeting of the Groundwater Protection Council in Fort Worth, where RISC members gave updates on seismicity, monitoring, and research activities in their respective states.

Work began on the CSTS 2019 annual meeting, scheduled for Tuesday, July 23, in Hutchinson. The program will include presentations updating members on CSTS activities and a talk by Joe Ratigan, president of Ratigan Engineering and Consulting, who has a long history of involvement with natural gas storage, subsidence, rock mechanics, and other geologic and regulatory issues in the midcontinent. Shelby Peterie will discuss recent publications on seismicity and pressure change in the Arbuckle that might impact CSTS members. Dave Newell will provide an overview of the work KGS and partners are doing to increase fluid monitoring and testing in the Arbuckle. Newell and co-authors have submitted papers on the Arbuckle for publication in the Kansas Geological Society's *Bulletin* and KGS's *Current Research in Earth Sciences*. These papers use data from annual measurements taken in Class I wells to provide the only glimpse of Arbuckle response to the introduction or extraction of fluid.

PLANS

With almost two years of recording on some stations, and 18 months on all stations, very preliminary searches for associations can begin on a site-by-site basis looking at injection practices and seismicity at the 0.0 to 2.0 M levels. It is likely a bit premature to begin looking at correlations or response characteristics at individual facilities, but some systematic or baseline relationships might be identified for more directed study as trends continue to develop.

As the Statewide network is expanded to its full strength over the next few months, infill stations around Salina will provide improved location accuracy. An

additional station will allow the unique location of earthquake events currently too small to be recorded on three or more stations.

Preliminary investigations into the potential of incorporating products of the Arbuckle working group with seismic monitoring products (locations, waveforms, depths, distributions—spatial and temporal, etc.) should begin to expand the scope of the CSTS and increase the significance and first order use of CSTS products into a wide range of member needs.

CONCLUSION

This quarter's trends in seismicity, as they relate to CSTS facilities, are generally consistent with observations reported over the last six to twelve months. Clearly the relationship between the price of oil and Class II injection volumes is becoming well established and the temporally staggered correlations between the volumes of produced water disposed of in the Arbuckle and seismicity have been observed to track in a reasonably consistent fashion since 2013. That being said, monitoring seismic activity during this time of reduced disposal volumes and earthquake numbers and sizes is critical and will play a vital role in establishing natural recursion numbers for microseismicity and the associated development of expectations for distinguishing natural from induced seismicity. Natural recursion relationships and earthquake characteristics are most accurately quantified and statistically consistent when studied and averaged over long periods of time. Relying on small sample sizes (less than several years to a decade) for statistical analysis of temporally variable events will likely alias the results and minimize confidence in any future attempts to categorize triggering mechanisms.

Seismicity in proximity to CSTS member's facilities is sporadic, with some events sharing commonality with mapped structures and historic earthquakes. Many groups of earthquakes continue to establish and align with structural trends previously unmapped and with no prior evidence they existed, except CSTS identified earthquake epicenters.

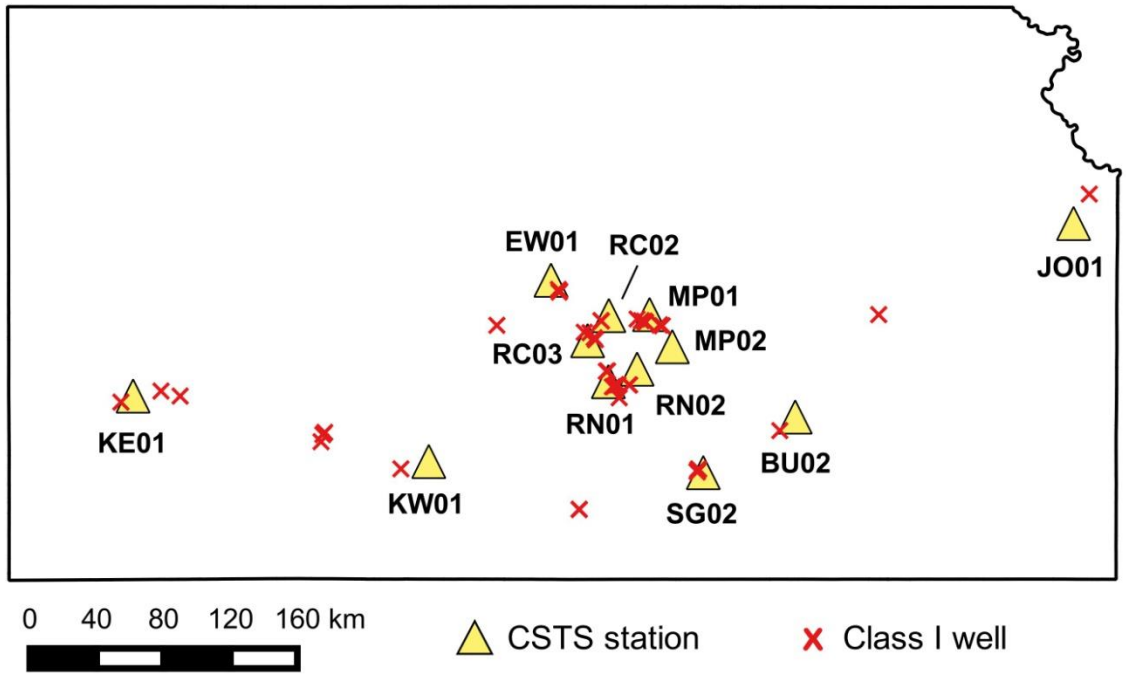

Figure 1. The 12 stations in the current CSTS seismic network.

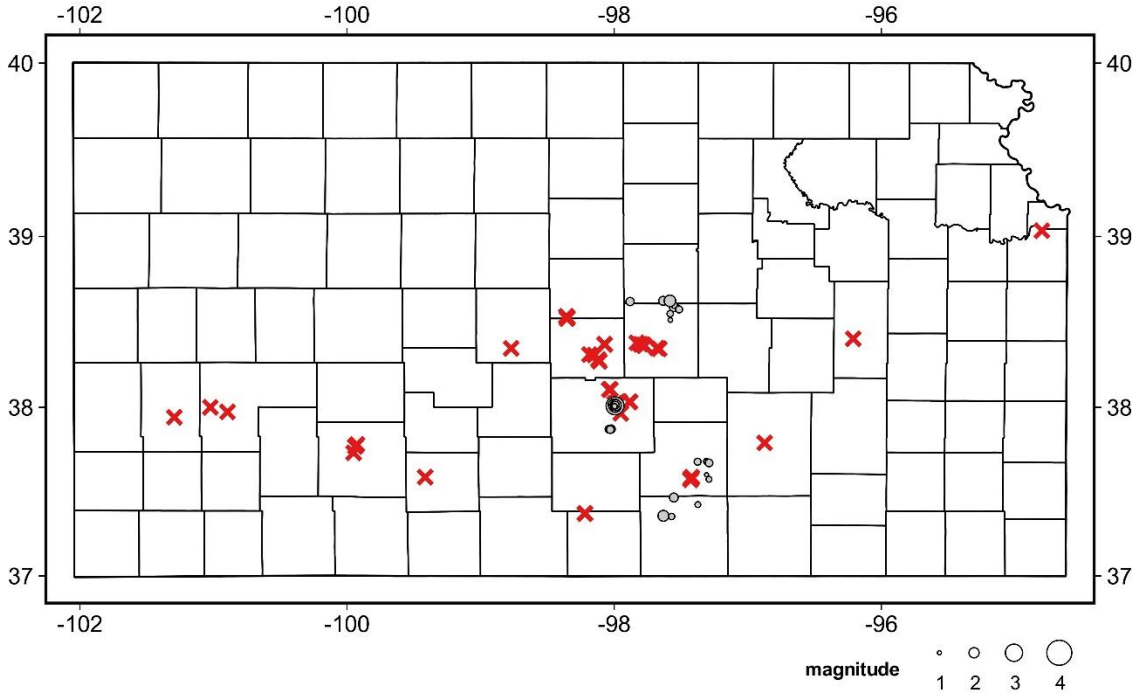

Figure 2. Earthquakes (gray circles) and Class I wells (red Xs) recorded by the KGS and CSTS seismic networks from January 1, 2019 through March 31, 2019, located within 20 miles of CSTS member wells.

Table 1. M 2 or larger earthquakes recorded from January 1, 2019 through March 31, 2019, with epicenters located within 30 mi of Tier 1 member wells.

Origin Time (UTC)	Latitude	Longitude	Magnitude	County
2019-01-02 07:10:55	37.422	-98.952	2.0	Barber
2019-01-03 10:32:08	37.358	-97.661	2.4	Sumner
2019-01-06 02:18:32	38.010	-97.991	2.5	Reno
2019-01-10 14:34:52	37.354	-97.853	2.2	Harper
2019-01-13 09:48:10	37.987	-97.997	2.1	Reno
2019-01-20 06:49:31	37.351	-97.622	2.1	Sumner
2019-01-22 17:10:12	37.358	-97.631	2.1	Sumner
2019-01-26 02:15:59	38.139	-96.970	2.4	Marion
2019-02-10 06:45:21	38.625	-97.582	2.2	Saline
2019-02-23 12:21:22	38.011	-97.991	2.3	Reno
2019-03-03 14:56:38	38.665	-97.486	2.7	Saline
2019-03-11 05:35:12	38.009	-97.993	3.1	Reno
2019-03-11 12:18:05	38.016	-97.994	2.2	Reno
2019-03-11 20:34:10	38.763	-97.524	2.0	Saline
2019-03-21 06:14:37	38.004	-97.996	2.2	Reno
2019-03-22 22:53:34	38.014	-97.989	2.1	Reno

Table 2. Earthquakes located within 20 miles of member wells.

Origin Time (UTC)	Latitude	Longi-tude	Magni-tude
2019-01-03 06:16:32	37.425	-97.373	1.3
2019-01-05 14:10:54	37.998	-98.007	1.5
2019-01-05 15:01:09	37.997	-97.992	1.4
2019-01-06 02:18:33	38.012	-98.001	2.7
2019-01-06 04:53:19	38.009	-97.990	1.5
2019-01-07 07:13:58	38.002	-97.991	1.3
2019-01-07 09:46:23	37.991	-97.998	1.4
2019-01-07 12:40:14	38.018	-97.994	1.9
2019-01-08 13:09:57	38.002	-97.995	1.6
2019-01-08 20:34:26	38.590	-97.551	1.9
2019-01-09 17:37:01	38.036	-97.998	1.0
2019-01-10 05:53:24	38.601	-97.551	1.4
2019-01-11 04:15:22	38.007	-97.997	1.6
2019-01-13 09:48:14	38.015	-97.995	2.2
2019-01-13 12:50:49	38.018	-97.989	1.1
2019-01-15 07:25:42	38.004	-97.998	1.0
2019-01-15 10:49:51	38.027	-97.999	0.9
2019-01-16 08:39:19	38.575	-97.514	1.5
2019-01-17 06:15:58	38.018	-97.997	1.4
2019-01-20 13:19:02	37.354	-97.570	1.4
2019-01-22 17:10:12	37.358	-97.631	2.1
2019-02-05 18:13:49	37.999	-97.991	1.0
2019-02-09 22:47:05	38.625	-97.633	1.8
2019-02-10 06:45:21	38.625	-97.582	2.2
2019-02-11 01:58:12	38.010	-98.000	1.4
2019-02-11 02:25:33	38.007	-97.985	1.7
2019-02-11 02:25:35	38.013	-97.982	1.9
2019-02-11 05:01:20	38.002	-97.996	1.3
2019-02-11 11:22:19	37.575	-97.290	1.3
2019-02-11 11:34:43	37.602	-97.308	1.0
2019-02-12 04:14:55	38.004	-97.988	0.9
2019-02-12 16:37:11	38.005	-97.995	1.5
2019-02-16 01:45:02	37.467	-97.553	1.8
2019-02-20 06:50:15	37.990	-97.981	1.2
2019-02-21 07:02:12	38.007	-98.004	1.9
2019-02-22 19:07:12	38.015	-97.990	1.7
2019-02-23 12:21:22	38.011	-97.991	2.3
2019-02-28 09:56:55	37.684	-97.310	1.2
2019-02-28 09:57:39	37.678	-97.310	1.2
2019-02-28 12:55:56	38.550	-97.580	1.4
2019-02-28 13:32:57	38.513	-97.579	1.1
2019-02-28 20:16:55	38.013	-97.989	1.9
2019-03-04 10:14:59	37.672	-97.289	1.6
2019-03-04 22:43:28	38.009	-97.992	1.5
2019-03-06 06:05:05	37.997	-97.986	1.2
2019-03-09 04:20:32	37.871	-98.021	1.6
2019-03-10 11:37:17	37.871	-98.038	1.5
2019-03-10 11:37:21	37.871	-98.039	1.6
2019-03-10 15:57:58	37.874	-98.021	1.6
2019-03-11 05:35:12	38.009	-97.993	3.1
2019-03-11 09:47:09	38.021	-97.987	1.8
2019-03-11 12:18:07	38.007	-97.993	2.3
2019-03-11 14:40:37	38.011	-97.990	1.9
2019-03-11 15:13:07	38.015	-97.991	2.1
2019-03-11 16:06:34	38.015	-97.988	2.0
2019-03-12 05:48:29	37.871	-98.018	1.5
2019-03-15 20:26:37	37.869	-98.029	1.6
2019-03-20 06:12:12	37.679	-97.375	1.5
2019-03-21 06:14:39	38.016	-98.000	2.2
2019-03-21 06:22:01	38.028	-97.996	0.5
2019-03-21 09:50:30	38.621	-97.881	1.7
2019-03-22 22:53:34	38.014	-97.989	2.1
2019-03-22 22:53:36	38.013	-97.988	2.1
2019-03-25 03:33:20	38.013	-97.991	1.6
2019-03-31 05:00:46	38.007	-97.996	1.2

Table 3. Possible subnetwork earthquakes from January 1 to March 31, 2019, recorded within 12 miles of member wells (the largest published distance between an induced earthquake swarm and causal well). Epicentral distance is the estimated distance from the earthquake epicenter to the seismic station where it was recorded.

Station	Origin Time (UTC)	Distance (Miles)	Magni-tude
BU02	2019-03-06 14:18:13	1.5	-0.4
MP01	2019-02-12 11:23:42	4.4	-0.6
MP02	2019-01-18 08:48:05	3.8	-0.6
MP02	2019-01-20 18:14:30	3.2	-0.6
MP02	2019-01-21 19:31:19	3.0	-0.6
MP02	2019-02-02 21:38:42	3.6	-0.6
MP02	2019-02-03 02:53:06	3.3	-0.9
MP02	2019-02-03 04:15:10	2.0	-0.9
MP02	2019-02-03 05:34:33	1.9	-0.9
MP02	2019-02-03 05:57:15	1.9	-0.9
MP02	2019-02-03 06:30:36	2.4	-0.9
MP02	2019-02-03 16:06:43	3.2	-0.9
MP02	2019-02-03 22:57:20	4.4	-0.6
MP02	2019-02-11 12:20:21	3.1	-0.9
MP02	2019-02-18 00:35:38	6.5	-0.6
RC02	2019-02-01 13:38:50	1.5	-1.5
RC03	2019-01-02 19:21:02	7.0	-0.4
RC03	2019-01-02 19:21:55	7.2	-0.4
RC03	2019-01-02 19:22:41	7.0	-0.2
RC03	2019-01-03 03:22:02	6.7	0.0
RC03	2019-01-03 19:19:09	7.2	-0.4
RC03	2019-01-05 19:14:55	7.1	0.2
RC03	2019-01-06 02:56:36	6.9	0.0
RC03	2019-01-06 02:57:14	6.4	0.1
RC03	2019-01-07 23:20:36	7.5	-0.2
RC03	2019-01-07 23:21:36	7.3	-0.2
RC03	2019-01-08 03:17:10	7.2	-0.4
RC03	2019-01-08 03:19:19	7.2	0.1
RC03	2019-01-08 23:20:21	7.3	0.2
RC03	2019-01-08 23:20:21	7.4	0.0
RC03	2019-01-08 23:21:54	7.5	0.0
RC03	2019-01-08 23:21:54	7.5	-0.2
RC03	2019-01-08 23:22:18	7.5	0.0
RC03	2019-01-10 03:03:17	6.9	0.0
RC03	2019-01-10 11:13:58	6.7	-0.2
RC03	2019-01-11 03:22:32	7.0	-0.4
RC03	2019-01-11 03:23:49	6.8	-0.4
RC03	2019-01-11 03:24:29	7.0	-0.4
RC03	2019-01-12 02:52:27	7.3	-0.2
RC03	2019-01-12 02:53:34	6.9	0.2
RC03	2019-01-14 12:21:35	7.6	0.3
RC03	2019-01-14 19:17:41	7.2	-0.2
RC03	2019-01-15 03:20:56	7.4	0.1
RC03	2019-01-15 11:14:46	7.0	-0.2
RC03	2019-01-15 11:15:07	6.8	-0.4
RC03	2019-01-15 11:15:28	7.3	0.0
RC03	2019-01-16 03:10:27	7.5	-0.2
RC03	2019-01-16 03:10:50	7.4	0.1
RC03	2019-01-17 03:16:10	7.8	0.2
RC03	2019-01-17 11:17:17	6.9	-0.2
RC03	2019-01-17 11:17:50	7.0	0.0
RC03	2019-01-17 11:18:32	6.7	0.1
RC03	2019-01-17 19:20:56	7.1	-0.4
RC03	2019-01-18 07:04:47	7.2	0.1
RC03	2019-01-18 19:25:10	7.2	0.0
RC03	2019-01-18 19:26:00	6.8	0.1
RC03	2019-01-18 19:26:40	7.0	0.1
RC03	2019-01-23 09:43:44	7.0	-0.2
RC03	2019-01-23 09:44:18	6.4	0.0
RC03	2019-01-23 19:30:35	6.8	-0.4
RC03	2019-01-23 19:31:09	6.9	-0.4
RC03	2019-01-24 03:23:20	7.6	-0.4
RC03	2019-01-24 03:24:07	6.9	0.1
RC03	2019-01-24 03:24:48	7.1	0.4
RC03	2019-01-25 11:20:47	6.9	0.0
RC03	2019-01-25 11:21:18	6.8	-0.2
RC03	2019-01-25 11:22:37	7.2	-0.4
RC03	2019-01-26 11:19:53	6.5	-0.2
RC03	2019-01-26 11:20:40	7.2	-0.4
RC03	2019-01-26 11:21:00	7.3	-0.2
RC03	2019-01-27 03:18:24	7.4	-0.2
RC03	2019-01-29 03:15:37	7.1	0.0
RC03	2019-01-29 11:13:02	7.0	0.0
RC03	2019-01-30 03:14:46	6.9	-0.2
RC03	2019-01-30 03:15:36	7.2	-0.4
RC03	2019-01-31 19:10:42	7.4	-0.4
RC03	2019-02-01 03:16:29	7.5	-0.2
RC03	2019-02-01 03:18:33	7.1	0.4
RC03	2019-02-01 19:20:41	7.2	-0.2
RC03	2019-02-01 19:21:28	6.9	-0.2
RC03	2019-02-03 03:08:25	7.2	0.0
RC03	2019-02-05 19:09:10	7.9	-0.4
RC03	2019-02-06 03:19:37	6.9	-0.4
RC03	2019-02-06 03:20:12	7.4	-0.2
RC03	2019-02-06 19:17:34	7.1	-0.2
RC03	2019-02-06 19:18:46	6.9	-0.2
RC03	2019-02-07 19:16:12	6.6	-0.4
RC03	2019-02-07 19:16:43	7.1	-0.4
RC03	2019-02-08 03:14:00	6.7	-0.2
RC03	2019-02-09 03:20:30	7.0	0.0
RC03	2019-02-11 11:14:11	6.9	-0.4
RC03	2019-02-11 19:15:58	6.8	-0.4
RC03	2019-02-11 19:16:58	7.0	-0.2
RC03	2019-02-11 19:17:43	7.2	0.0
RC03	2019-02-12 03:17:08	6.6	-0.2
RC03	2019-02-13 07:34:42	6.9	-0.4
RC03	2019-02-13 19:11:04	7.2	-0.2
RC03	2019-02-13 19:12:31	7.0	-0.2
RC03	2019-02-13 19:12:51	7.3	-0.2
RC03	2019-02-13 19:13:29	7.1	-0.2
RC03	2019-02-14 19:15:40	6.9	-0.4
RC03	2019-02-15 03:12:00	7.2	-0.2
RC03	2019-02-16 11:20:32	6.9	-0.2
RC03	2019-02-16 11:20:55	7.4	-0.2
RC03	2019-02-16 19:25:25	7.2	0.0
RC03	2019-02-16 19:28:19	7.3	0.0
RC03	2019-02-18 09:08:21	7.8	-0.4
RC03	2019-02-18 23:23:40	7.2	-0.2
RC03	2019-02-18 23:24:28	7.2	-0.2
RC03	2019-02-19 11:11:20	6.7	-0.2
RC03	2019-02-19 19:14:13	6.4	0.0

Table 3. Continued

Station	Origin Time (UTC)	Distance (Miles)	Magni-tude
RC03	2019-02-20 03:17:18	7.5	-0.2
RC03	2019-02-20 03:18:23	7.0	0.0
RC03	2019-02-20 03:19:14	7.0	0.0
RC03	2019-02-20 11:14:37	7.4	-0.2
RC03	2019-02-20 11:16:07	7.0	-0.2
RC03	2019-02-20 23:29:03	7.6	-0.4
RC03	2019-02-20 23:29:48	7.2	-0.2
RC03	2019-02-21 23:15:25	7.0	-0.2
RC03	2019-02-21 23:16:06	6.9	0.0
RC03	2019-02-21 23:16:47	7.3	-0.4
RC03	2019-02-22 03:15:45	6.7	-0.4
RC03	2019-02-23 03:20:23	7.0	-0.2
RC03	2019-02-23 03:21:11	7.2	-0.2
RC03	2019-02-23 03:21:47	7.1	-0.2
RC03	2019-02-26 19:19:01	6.5	-0.2
RC03	2019-02-27 19:16:24	7.0	-0.2
RC03	2019-02-28 03:16:05	6.9	0.0
RC03	2019-02-28 03:17:05	7.3	-0.2
RC03	2019-03-01 11:19:10	7.0	-0.4
RC03	2019-03-05 00:51:08	7.2	-0.2
RC03	2019-03-05 19:19:26	6.8	-0.2
RC03	2019-03-05 19:20:16	7.1	0.0
RC03	2019-03-06 03:17:25	7.0	0.0
RC03	2019-03-07 03:17:19	6.9	-0.4
RC03	2019-03-09 03:19:55	7.1	0.4
RC03	2019-03-11 18:19:28	6.5	-0.4
RC03	2019-03-12 02:19:13	7.0	-0.2
RC03	2019-03-12 02:19:47	6.2	-0.2
RC03	2019-03-12 02:20:27	8.7	0.1
RC03	2019-03-13 02:21:35	7.1	-0.4
RC03	2019-03-16 02:20:48	7.4	-0.4
RC03	2019-03-16 02:21:38	6.9	-0.2
RC03	2019-03-16 02:22:18	6.7	-0.4
RC03	2019-03-16 02:22:35	6.6	-0.2
RC03	2019-03-18 10:17:43	7.4	-0.2
RC03	2019-03-20 02:07:54	7.2	0.1
RC03	2019-03-20 02:08:36	7.0	0.0
RC03	2019-03-20 02:09:22	7.0	0.0
RC03	2019-03-20 10:19:19	6.8	-0.2
RC03	2019-03-20 10:19:54	7.3	-0.2
RC03	2019-03-20 10:20:13	7.0	-0.2
RC03	2019-03-21 10:16:38	7.3	-0.4
RC03	2019-03-21 10:16:58	7.5	-0.4
RC03	2019-03-22 02:19:46	7.2	-0.2
RC03	2019-03-22 02:20:48	7.1	-0.2
RC03	2019-03-23 02:05:05	7.3	-0.2
RC03	2019-03-23 02:05:48	7.3	0.0
RC03	2019-03-25 10:19:18	7.1	-0.4
RC03	2019-03-25 10:19:28	7.2	-0.2
RC03	2019-03-26 02:18:04	6.4	0.0
RC03	2019-03-26 02:18:36	7.1	-0.4
RC03	2019-03-26 02:18:59	6.9	-0.2
RC03	2019-03-27 02:17:20	7.8	0.0
RC03	2019-03-27 02:18:09	7.1	0.1
RC03	2019-03-29 18:17:37	6.9	-0.4
RC03	2019-03-29 18:17:58	7.2	-0.2
RC03	2019-03-29 18:19:06	6.7	-0.4
RC03	2019-03-31 02:21:10	6.9	0.1
RC03	2019-03-31 02:21:44	7.0	0.0
RN01	2019-01-01 02:21:00	5.0	-0.2
RN01	2019-01-01 23:51:02	5.3	0.4
RN01	2019-01-03 10:59:59	4.7	-0.4
RN01	2019-01-05 15:59:51	4.9	-0.2
RN01	2019-01-06 02:19:40	4.8	-0.4
RN01	2019-01-06 02:42:31	4.8	-0.2
RN01	2019-01-06 02:44:15	4.8	-0.6
RN01	2019-01-07 06:11:53	5.1	0.3
RN01	2019-01-12 09:49:22	5.2	-0.4
RN01	2019-01-13 08:17:40	4.8	-0.4
RN01	2019-01-13 08:26:52	4.9	-0.2
RN01	2019-01-13 09:51:29	4.9	-0.4
RN01	2019-01-13 10:50:07	5.1	-0.4
RN01	2019-01-13 10:50:14	4.7	-0.2
RN01	2019-01-13 11:39:27	5.0	0.0
RN01	2019-01-13 12:51:14	4.9	-0.4
RN01	2019-01-13 13:50:33	4.9	-0.4
RN01	2019-01-13 14:01:52	4.8	-0.6
RN01	2019-01-14 02:00:47	4.8	-0.6
RN01	2019-01-14 05:07:21	4.7	-0.6
RN01	2019-01-15 09:10:50	5.0	-0.2
RN01	2019-01-16 23:46:20	4.4	-0.2
RN01	2019-01-17 01:32:51	7.9	0.1
RN01	2019-01-17 02:33:57	4.9	-0.6
RN01	2019-01-17 11:19:09	5.0	-0.2
RN01	2019-01-23 00:31:11	4.7	-0.4
RN01	2019-01-23 07:38:16	5.1	-0.4
RN01	2019-01-24 11:55:25	4.7	-0.6
RN01	2019-01-29 09:00:33	5.3	-0.6
RN01	2019-01-29 09:00:42	5.0	-0.9
RN01	2019-01-30 23:25:11	4.8	-0.6
RN01	2019-01-30 23:27:46	4.7	0.1
RN01	2019-02-01 06:09:00	4.8	-0.6
RN01	2019-02-02 08:50:43	4.8	-0.4
RN01	2019-02-02 12:47:42	4.5	-0.9
RN01	2019-02-02 12:47:48	4.9	-0.6
RN01	2019-02-03 15:46:40	5.2	-0.6
RN01	2019-02-07 12:49:21	4.9	-0.4
RN01	2019-02-08 18:53:27	5.0	-0.4
RN01	2019-02-10 09:48:39	4.9	-0.6
RN01	2019-02-10 19:00:05	5.0	-0.6
RN01	2019-02-10 23:35:45	5.0	-0.6
RN01	2019-02-10 23:54:33	4.8	-0.6
RN01	2019-02-11 02:28:29	5.2	-0.6
RN01	2019-02-11 02:28:32	5.0	-0.6
RN01	2019-02-11 02:56:26	5.2	-0.2
RN01	2019-02-11 16:18:07	4.7	-0.4
RN01	2019-02-13 12:17:18	4.8	-0.4
RN01	2019-02-13 19:23:01	4.7	-0.4
RN01	2019-02-14 00:25:56	4.9	-0.6
RN01	2019-02-16 09:06:30	5.4	-0.6
RN01	2019-02-16 18:18:23	4.5	-0.6
RN01	2019-02-19 01:21:53	4.8	-0.6
RN01	2019-02-19 01:22:24	5.0	-0.6
RN01	2019-02-20 06:36:58	5.3	-0.6
RN01	2019-02-21 16:07:26	5.1	-0.4
RN01	2019-02-22 14:18:54	5.7	-0.4
RN01	2019-02-27 01:15:17	5.0	-0.4
RN01	2019-03-01 12:19:03	4.8	-0.4
RN01	2019-03-04 22:43:15	5.0	-0.6
RN01	2019-03-07 03:26:26	5.2	-0.6

Table 3. Continued

Station	Origin Time (UTC)	Distance (Miles)	Magni-tude
RN01	2019-03-08 06:22:11	5.0	-0.4
RN01	2019-03-11 09:50:29	5.0	-0.6
RN01	2019-03-11 10:23:59	5.5	-0.6
RN01	2019-03-11 10:24:29	4.8	-0.6
RN01	2019-03-11 14:52:33	5.0	-0.4
RN01	2019-03-11 22:46:08	4.6	-0.6
RN01	2019-03-13 00:54:42	5.2	-0.4
RN01	2019-03-16 06:53:17	2.1	-1.5
RN01	2019-03-18 10:12:43	4.7	-0.4
RN01	2019-03-18 20:46:44	4.3	-0.6
RN01	2019-03-21 07:53:32	6.6	0.0
RN01	2019-03-21 08:40:05	4.8	-0.6
RN01	2019-03-31 10:42:09	5.0	-0.6
RN02	2019-01-03 07:14:07	8.1	0.0
RN02	2019-01-03 07:15:52	7.8	-0.2
RN02	2019-01-03 07:16:54	7.5	-0.4
RN02	2019-01-05 07:04:14	9.1	0.0
RN02	2019-01-05 07:05:13	7.1	0.0
RN02	2019-01-26 07:04:44	10.1	-0.2
RN02	2019-01-26 07:06:38	8.4	0.0
RN02	2019-01-26 07:07:58	9.3	0.0
RN02	2019-01-26 07:09:19	9.2	0.1
RN02	2019-01-26 07:10:34	8.8	0.0
RN02	2019-01-27 19:29:49	2.5	-0.6
RN02	2019-01-27 22:31:27	2.9	-0.2
RN02	2019-02-02 20:03:32	2.3	-0.6
SG02	2019-01-11 04:51:57	3.8	0.2
SG02	2019-03-08 01:32:58	8.8	0.0
SG02	2019-03-14 07:50:05	8.8	0.5
SG02	2019-03-20 10:05:33	8.2	0.2