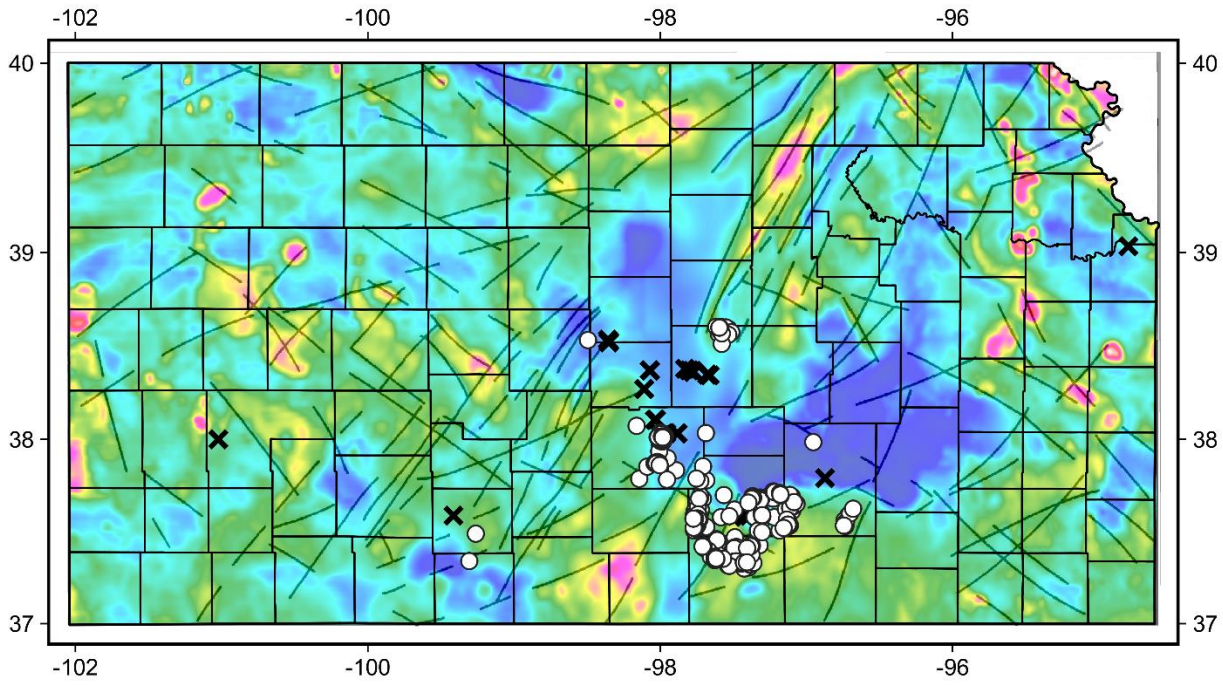
Consortium to Study Trends in Seismicity



July 1, 2018 – June 30, 2019

Annual Report by
Rex Buchanan, Shelby Peterie, Rick Miller

Kansas Geological Survey Open-file Report 2021-4

Cover Figure Caption: Earthquakes (white) located using CSTS stations that otherwise would have not been located by any other seismic network. Correlated with structural trends, the earthquakes provide insight into the stress conditions and relative stability of both unmapped faults and faults interpreted geologic and geophysical datasets.

Kansas Geological Survey
Consortium to Study Trends in Seismicity

2018-2019 Annual Report

NOTICE: This annual report was released in draft to Consortium members, as well as the Kansas Department of Health and Environment, at the Consortium's 2019 annual meeting held on July 23, 2019, and was subject to further review and comment by Consortium members until January 30, 2020. The KGS was then allowed an additional three months to revise the draft annual report and distribute the final annual report.

CONSORTIUM TO STUDY TRENDS IN SEISMICITY

Annual Meeting – July 23, 2019
Water Treatment Center
803 E. 23rd Avenue – Hutchinson, Kansas

AGENDA

9:30 a.m.	**Registration**, pick-up materials, coffee
10:00 a.m.	**Introductions, Welcome, and National Perspective on Induced Seismicity** – *Rex Buchanan*, Kansas Geological Survey (KGS)
10:15 a.m.	**Consortium Status** – *Rick Miller*, KGS
10:30 a.m.	**Network and Monitoring Results** – *Shelby Peterie*, KGS
11:00 a.m.	**Experiences with Solution-Mined Caverns and Associated Brine Disposal Wells in North America** – *Joe Ratigan*, Ratigan Engineering and Consulting
Noon	**Lunch**
12:45 p.m.	**Consortium Website/Earthquake Mapper** – *Mike Killion*, KGS
1:10 p.m.	**Recent Publications on Mid-continent Induced Seismicity** – *Shelby Peterie*, KGS
1:30 p.m.	**Update on Arbuckle Data-gather, Publication** – *Dave Newell*, KGS
2:15 p.m.	**Consortium Future Activities, Discussion** – *Rick Miller*, KGS
3:00 p.m.	**Tour of Hutchinson Reverse Osmosis operations** (optional)

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CONSORTIUM TO STUDY TRENDS IN SEISMICITY
KANSAS GEOLOGICAL SURVEY
Fourth Quarter / Annual Report
July 1, 2018 – June 30, 2019

INTRODUCTION

The Kansas Geological Survey's Consortium to Study Trends in Seismicity (CSTS) is a public-private project aimed at studying trends in seismicity in Kansas. The consortium focuses on areas where public and private entities could benefit from high-sensitivity seismic monitoring. Seismicity has increased significantly in Kansas and the midcontinent since 2013, leading to a need to better define and understand earthquake activity, particularly as it relates to subsurface fluid disposal. The CSTS oversees the operation of a seismic network that records and allows accurate location and magnitude estimates of seismicity for felt earthquakes and particularly for 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 help with industry response, guide governmental oversight, and inform public opinion.

The CSTS is operated by 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. Current members of the CSTS are from the state's Class I disposal well community—wells that are used for disposal of municipal and industrial waste and regulated by the Kansas Department of Health and Environment (KDHE). Membership in the CSTS is voluntary; the CSTS objective is understanding seismicity in proximity to member facilities. The CSTS works to establish baseline or background seismicity near those facilities and provide a scientific basis for differentiating natural from induced seismicity. Confidence in distinguishing natural from induced earthquake trends is greatly enhanced through extended monitoring periods with stations near earthquake events.

The following report describes the second year of CSTS activities, including a discussion of membership status; network station installation and operation; earthquakes recorded and identified, and earthquake alerts provided to members; web page development; other activities, especially involving publications, presentations, and meeting attendance; and plans for the coming year. Three quarterly reports were provided to members since the Consortium's annual meeting in July 2018. This current report includes summaries of seismicity and CSTS activities in both in the past quarter (April, May, and June of 2019) and for the past year.

STATUS OF MEMBERS

The CSTS was established with a two-tier membership system. For Tier 1 members the CSTS provides 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 a facility; provides 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 information

related to the general information about the seismicity being studied by the CSTS and can attend the annual meeting, but do not have the right to vote at that meeting or use the reports while still under confidential status.

The CSTS currently has eleven Tier 1 members and one Tier 2 member.

STATUS OF NETWORK

The CSTS seismic network currently 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. For each of those locations, ambient noise tests were completed to establish background noise levels. Those tests identified noise from nearby highways, trains, pump jacks, and other facilities that might interfere with earthquake analysis. Stations were relocated with a site-specific ambient noise test, when initially deployed in places where noise and vibrations interfered with station response characteristics above a pre-determined threshold. Many of the existing sites are in cemeteries, on government property, or in other locations where noise levels are measured to be low and are likely to remain low. In all cases, KGS has obtained written agreements with landowners of each station location.

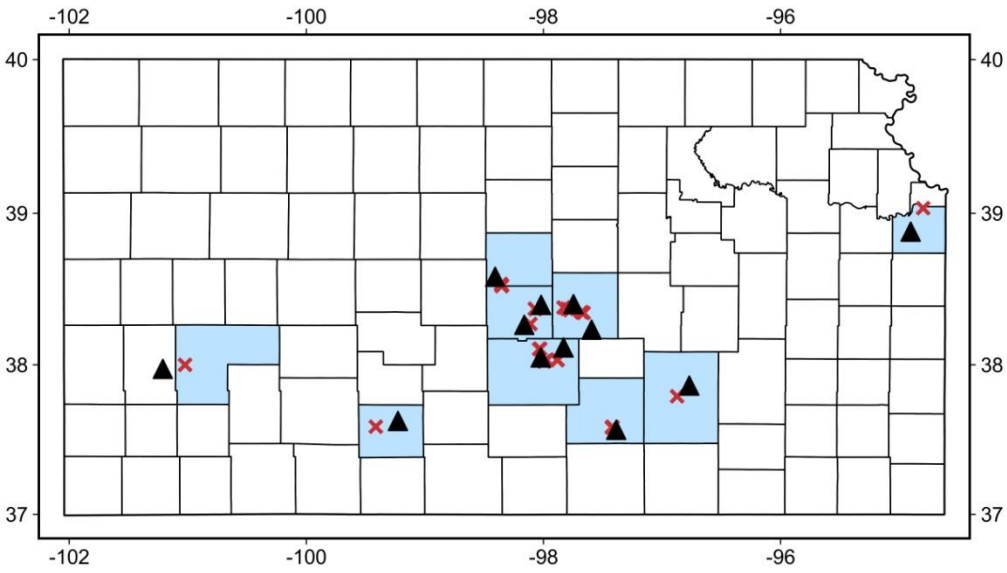

Figure 1. Earthquake stations (black triangles) with member facilities (red X) provide high sensitivity coverage with the potential to identify earthquakes with magnitudes below 0 within 20 miles of each facility.

Each station consists of a seismic sensor that includes a shallowly buried seismometer embedded in a concrete platform atop a gravel layer, and a digitizer. Ground motion detected by the seismometer is transmitted back to KGS offices in Lawrence real-time via a cellular modem. That communication system is powered by a solar panel that charges two deep-cycle marine batteries. The footprint for each station is approximately 10 feet by 10 feet. The stations have operated over the last year with a better than 98% continuous data stream and within designated operational sensitivity and signal-to-noise ratio.

EARTHQUAKE ALERTS, CATALOG

Earthquakes with magnitudes of 2 or larger are below felt levels but represent a threshold above which energy levels provide highly confident automatic analysis for feeds coming from a network as dense as the CSTS network and especially in conjunction with the KGS regional and subregional networks. It is therefore reasonable to provide accurate epicenter locations using automated picking routines for each event down to M 2, with results available within minutes of the fault rupture. KGS staff notify CSTS members of a M 2 or larger earthquake within 30 miles of Tier 1 member wells. There were 110 earthquake alerts from July 2018 through June 2019 (Table 1), about 17% fewer alerts than the previous year (133 from July 2017 through June 2018).

INTERESTING OBSERVATIONS AND SIGNIFICANT TRENDS

Regional Seismicity (M 2 or larger)

More than 400 earthquakes magnitude (M) 2 or larger were recorded in Kansas during the past year (Figure 2). The overall earthquake rate continued to decline, and the number of regional scale events (M 2 or larger) decreased by about 15% relative to the previous year (510 from July 2017 through June 2018). The vast majority of these events either occurred in parts of the state where historic earthquakes occurred along prominent basement structures or where earthquakes were recorded in recent years. However, some of areas experienced a notable change in the rate and/or magnitude of earthquakes, primarily along the Central Kansas Uplift.

South-Central Kansas

Similar to last year, more than half of the regional-scale earthquakes (M 2 or larger) recorded by the KGS network were located in south-central Kansas, primarily in Harper and Sumner counties (Figure 3). The rate of earthquakes of this size in these counties has dropped dramatically since the KGS network was installed in 2015. About 230 M 2 or larger earthquakes were recorded in Harper and Sumner counties during the past year, which is about 30% less than the previous reporting period and an overall decrease of about 80% relative to 2015. Earthquake clusters generally occurred in areas where earthquakes were observed in previous years. One notable exception was a M 4.4 earthquake on August 30, 2018, that occurred in the northwest corner of Harper County in an area with only occasional, sparse seismic activity in the past few years.

From 2015 to 2017, earthquakes migrated from the highly active zones of seismicity in Harper and Sumner counties progressively farther along structural trends into surrounding counties, including Sedgwick, western Butler, Kingman, and Reno counties. Earthquakes along these trends are most likely induced, triggered as a result of elevated pore pressure that effectively reduced frictional resistance along critically-stressed basement faults. Seismicity has continued near Hutchinson in Reno County and near Cheney in Sedgwick County with 12 and 6 M 2 or larger earthquakes, respectively. Outside of these clusters during the past year, very few regional-scale earthquakes occurred in counties surrounding Harper and Sumner.

Table 1. M 2 or larger earthquakes recorded from July 2018 through June 2019 with epicenters located within 30 mi of member wells.

Origin Time (UTC)	Latitude	Longitude	Magnitude	County
2018-07-25 18:16:17	38.014	-97.997	2.4	Reno
2018-08-22 17:07:41	37.386	-97.825	2.0	Harper
2018-08-23 16:41:56	38.014	-97.982	2.6	Reno
2018-08-25 01:13:37	37.346	-97.844	2.0	Harper
2018-08-25 03:19:14	37.342	-97.858	2.0	Harper
2018-08-26 06:18:36	37.345	-97.802	2.0	Sumner
2018-08-26 06:52:48	37.348	-97.854	2.7	Harper
2018-08-26 11:51:00	37.347	-97.855	2.3	Harper
2018-08-27 09:54:05	37.353	-97.858	2.7	Harper
2018-08-27 12:40:39	38.645	-97.510	2.3	Saline
2018-08-29 03:21:26	37.350	-97.851	2.0	Harper
2018-08-29 19:24:29	37.352	-97.853	2.2	Harper
2018-08-29 19:36:55	37.350	-97.851	2.9	Harper
2018-08-29 20:06:06	37.348	-97.854	3.0	Harper
2018-08-29 23:56:20	37.347	-97.857	3.3	Harper
2018-08-30 00:04:19	37.339	-97.859	2.1	Harper
2018-08-30 00:05:04	37.332	-97.859	2.1	Harper
2018-08-30 00:12:56	37.344	-97.849	3.3	Harper
2018-08-30 00:51:13	37.346	-97.850	2.0	Harper
2018-08-30 02:49:55	37.353	-97.829	2.0	Harper
2018-08-30 04:54:14	37.346	-97.858	3.5	Harper
2018-08-30 08:45:14	37.351	-97.864	2.2	Harper
2018-08-30 20:37:08	37.341	-97.850	4.4	Harper
2018-08-30 21:30:52	37.349	-97.869	2.1	Harper
2018-08-30 21:56:43	37.350	-97.854	2.0	Harper
2018-08-30 22:03:46	37.347	-97.861	2.0	Harper
2018-08-30 23:34:19	37.344	-97.875	2.8	Harper
2018-08-31 01:08:59	37.345	-97.875	2.5	Harper
2018-08-31 04:00:11	37.354	-97.865	2.0	Harper
2018-08-31 04:55:21	37.351	-97.860	2.4	Harper
2018-08-31 06:20:04	37.343	-97.876	2.8	Harper
2018-08-31 07:15:27	37.347	-97.858	2.5	Harper
2018-08-31 08:22:48	37.347	-97.856	2.8	Harper
2018-08-31 08:37:15	37.353	-97.858	2.2	Harper
2018-08-31 09:35:34	37.352	-97.861	2.6	Harper
2018-08-31 12:48:43	37.344	-97.861	3.0	Harper
2018-08-31 13:30:22	37.342	-97.874	2.1	Harper
2018-08-31 14:03:55	37.347	-97.869	2.1	Harper
2018-08-31 14:36:46	37.352	-97.856	2.2	Harper
2018-09-03 08:33:51	37.343	-97.860	2.4	Harper
2018-09-05 03:21:54	38.011	-97.983	2.3	Reno
2018-09-06 07:06:08	37.350	-97.855	2.2	Harper
2018-09-08 04:14:08	37.347	-97.845	2.5	Harper
2018-09-13 07:59:08	37.354	-97.872	2.0	Harper
2018-09-18 18:07:47	37.345	-97.876	2.3	Harper
2018-09-19 19:15:30	37.347	-97.859	2.1	Harper
2018-09-21 05:04:54	37.350	-97.865	2.5	Harper
2018-09-28 00:51:52	37.172	-97.449	2.4	Sumner
2018-09-29 10:39:48	37.180	-97.452	2.3	Sumner
2018-09-29 18:07:36	37.175	-97.457	3.0	Sumner
2018-09-29 19:25:35	37.182	-97.455	3.0	Sumner
2018-09-29 20:33:53	37.175	-97.438	2.1	Sumner
2018-09-30 08:39:07	37.177	-97.449	2.8	Sumner
2018-09-30 11:09:23	37.183	-97.451	2.3	Sumner
2018-10-01 00:32:27	37.185	-97.448	2.3	Sumner
2018-10-01 00:33:23	37.169	-97.443	3.3	Sumner
2018-10-01 00:57:19	37.174	-97.452	2.2	Sumner
2018-10-03 16:49:03	37.357	-97.984	2.0	Harper
2018-10-19 12:21:56	38.584	-97.443	2.0	McPherson

Table 1. Continued

2018-10-30 14:55:21	37.493	-99.762	3.4	Ford
2018-10-30 17:11:47	38.010	-98.005	2.1	Reno
2018-11-15 00:48:51	37.412	-97.394	2.4	Sumner
2018-11-16 08:58:27	38.739	-97.543	2.0	Saline
2018-11-17 03:47:08	38.726	-97.535	2.0	Saline
2018-11-17 04:20:54	38.722	-97.533	2.0	Saline
2018-11-17 08:09:20	38.716	-97.536	2.0	Saline
2018-11-17 13:24:39	38.727	-97.542	2.1	Saline
2018-11-17 21:34:26	38.747	-97.542	3.0	Saline
2018-11-17 22:02:32	38.695	-97.544	2.5	Saline
2018-11-18 09:59:24	38.741	-97.532	2.0	Saline
2018-11-19 07:44:12	38.744	-97.548	2.9	Saline
2018-11-19 09:01:03	38.732	-97.541	2.8	Saline
2018-11-19 09:31:24	38.755	-97.568	2.2	Saline
2018-11-19 12:37:06	38.741	-97.544	2.5	Saline
2018-11-19 13:12:47	38.730	-97.507	2.3	Saline
2018-11-21 11:30:51	37.319	-97.803	2.0	Sumner
2018-11-24 10:29:22	38.725	-97.535	2.0	Saline
2018-11-26 22:19:09	38.701	-97.559	2.0	Saline
2018-11-29 06:03:00	37.406	-97.498	2.2	Sumner
2018-12-16 20:13:38	37.562	-97.743	2.1	Sedgwick
2018-12-16 23:18:30	37.560	-97.748	2.2	Sedgwick
2018-12-16 23:52:45	37.562	-97.744	2.3	Sedgwick
2018-12-17 00:08:14	37.562	-97.737	2.0	Sedgwick
2018-12-17 04:31:11	37.561	-97.748	2.3	Sedgwick
2018-12-17 20:36:16	37.410	-97.387	2.7	Sumner
2018-12-20 20:56:54	37.555	-97.747	2.5	Sedgwick
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
2019-04-08 15:57:13	37.245	-97.642	2.1	Sumner
2019-04-13 18:57:40	37.177	-97.615	2.7	Sumner
2019-04-15 00:47:10	37.646	-97.077	2.1	Butler
2019-04-20 18:49:53	37.873	-98.011	2.0	Reno
2019-04-22 22:06:53	38.022	-97.990	2.4	Reno
2019-05-08 23:56:41	37.293	-97.710	2.0	Sumner
2019-05-09 19:34:53	37.649	-97.078	2.2	Butler
2019-06-05 23:16:36	37.598	-99.065	2.1	Kiowa

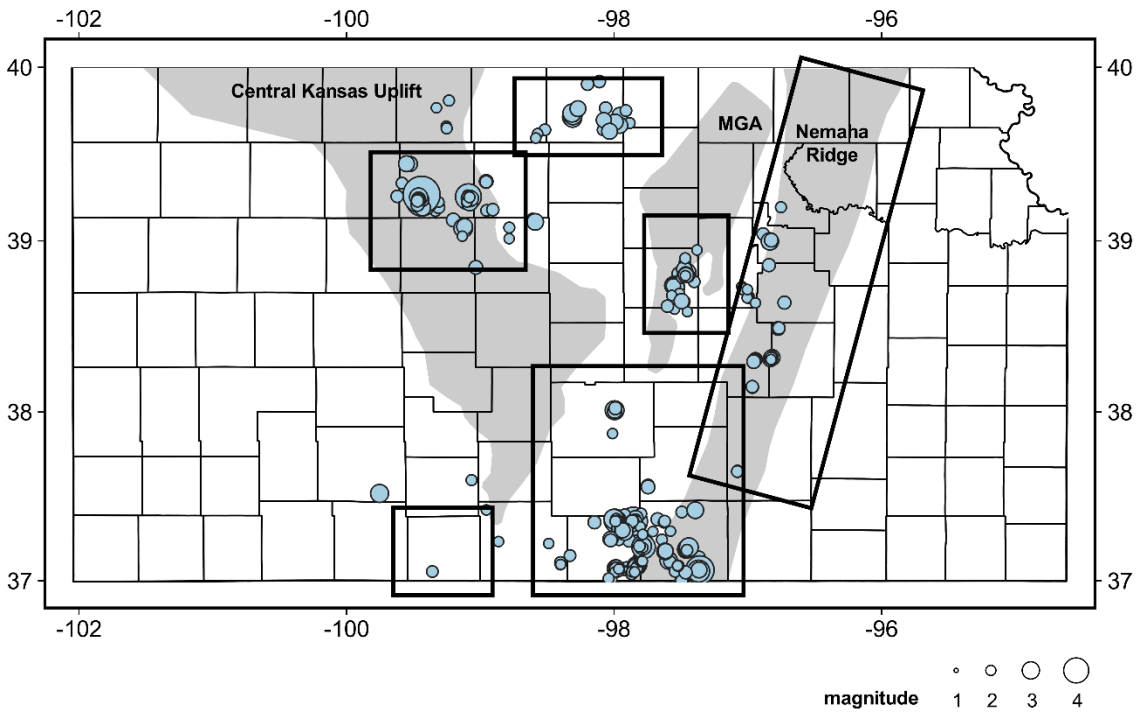

Figure 2. M 2 or larger earthquakes recorded in Kansas by the KGS seismic network from July 2018 through June 2019 superimposed on the prominent basement structures (gray). Black boxes indicate areas discussed in the text.

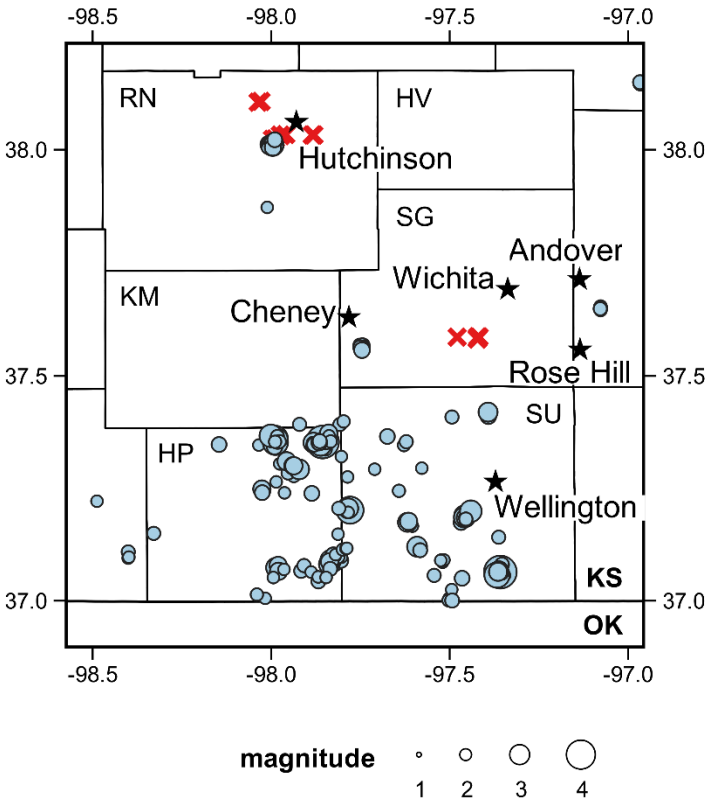

Figure 3. M 2 or larger earthquakes recorded in south-central Kansas from July 2018 through June 2019.

Comanche County

Only one regional-scale earthquake occurred in Comanche County during the past year (Figure 4). This is noteworthy because more than 60 M 2 or larger earthquakes were recorded in Comanche County from July 2017 through June 2018. Because those events occurred in an area of elevated pore pressure measured in the Arbuckle Group, these events were likely triggered along hydraulically-connected, critically-stressed basement faults. The large reduction in seismicity during the past year indicates that crustal stresses may be lower here, relative to neighboring Harper and Sumner counties. After the stress on this previously-unidentified fault or set of faults was initially released, the crustal stress applied to these faults was not sufficient during the past year to produce additional earthquakes. That is not to say additional earthquakes are not possible, but rather that the stress accumulated during the past year did not exceed the triggering threshold of these faults.

Central Kansas Uplift

About 75 M 2 or larger earthquakes were recorded in areas affected by the Central Kansas Uplift, primarily within three clusters (Figure 5). The most active cluster is located in southwestern Rooks County with more than two dozen events, the largest of which was a M 4.8 on June 22, 2019. The location of this cluster is within 10 km of an area of historic seismicity in the late 1980s that was believed to be induced as a result of deep fluid injection (Armbruster et al., 1989). These three clusters in Rooks and Ellis counties are within 20 km of saltwater disposal wells injecting large volumes of fluid into the Arbuckle Group. Although reliable pressure measurements are not available from wells that penetrate the full thickness of the Arbuckle Group (as in central and south-central Kansas), analysis of earthquake decay rate suggests the rate of decay in this area is low relative to natural seismicity and, thus, these earthquakes may be induced.

North-Central Kansas (Salina Basin)

About two dozen M 2 or larger earthquakes were recorded in Smith, Jewell, and Republic counties during the past year (Figure 6). These events largely persist in the same clusters as the previous year, but are occurring at a lower rate. At this time, the source of these earthquakes remains unclear, but they appear to occur along faults interpreted from aeromagnetic data.

Midcontinent Geophysical Anomaly

The Midcontinent Geophysical Anomaly (MGA, the largest positive gravity anomaly in North America) is interpreted to be the result of a thick sequence of mafic igneous rocks that formed during major late Precambrian rifting as part of the Midcontinent Rift System. Two ongoing clusters of earthquakes have been recorded along the southeastern margin of the MGA since the KGS network was installed in 2015. More than 50 M 2 or larger earthquakes were recorded in distinct clusters in eastern Saline County (Figure 7), about double the rate of seismic activity relative to the previous reporting period. These clusters are discussed in greater detail in the section on local seismicity near McPherson County member wells.

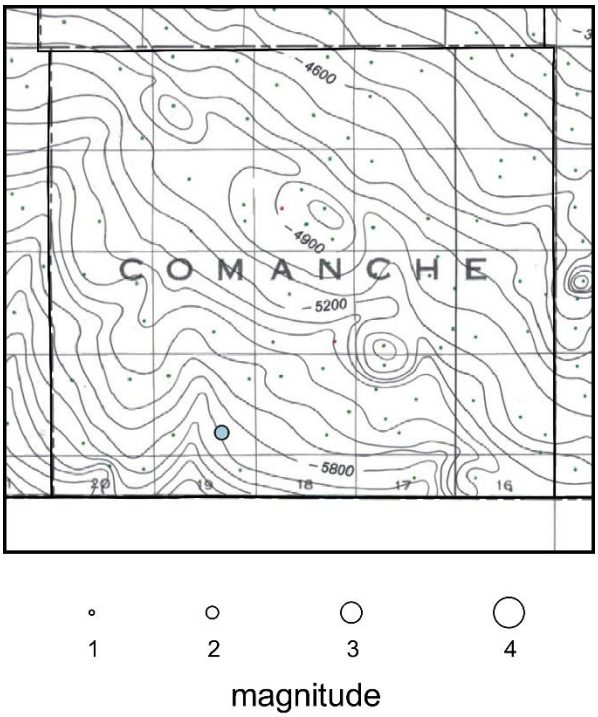

Figure 4. M 2 or larger earthquakes recorded in Comanche County from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976).

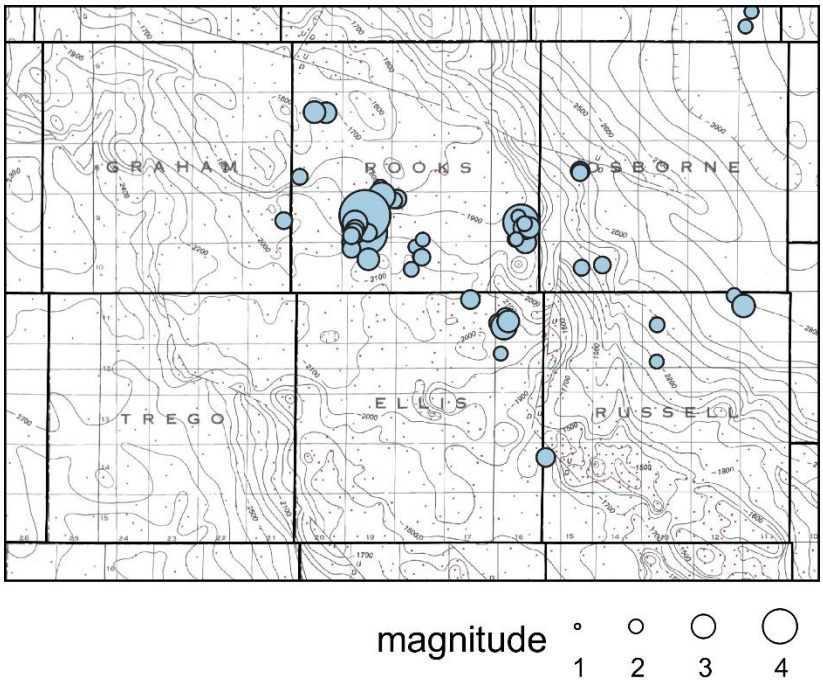

Figure 5. M 2 or larger earthquakes recorded near the Central Kansas Uplift from July 2018 through June 2019.

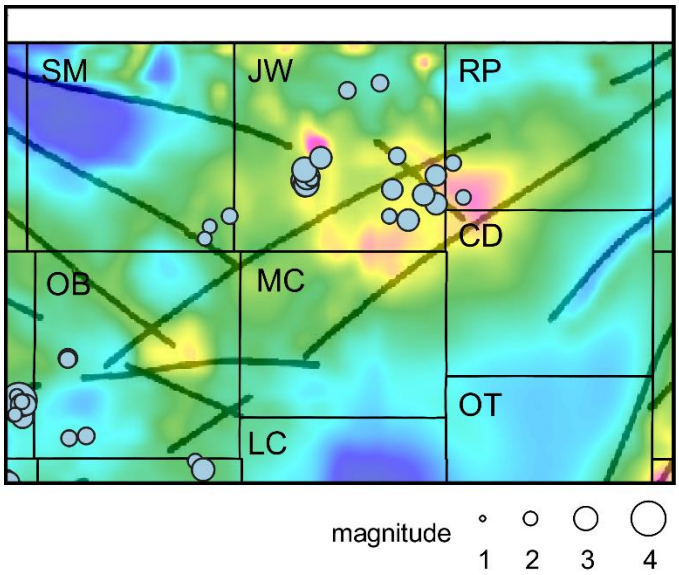

Figure 6. M 2 or larger earthquakes recorded in the Salina Basin from July 2018 through June 2019.

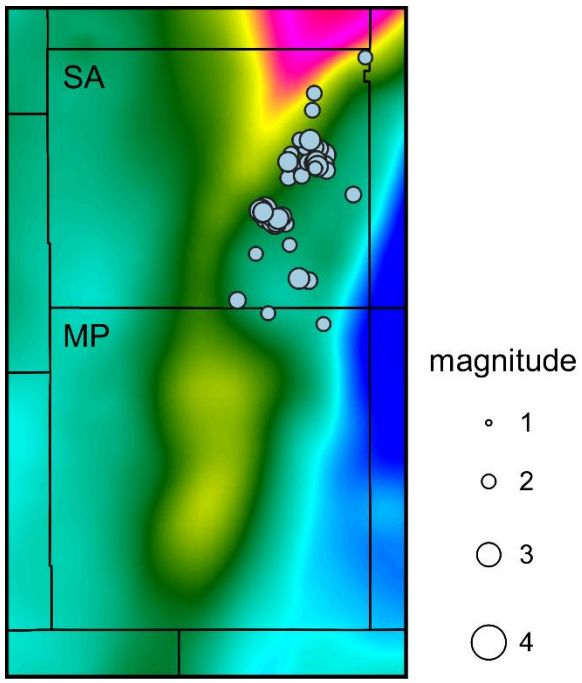

Figure 7. M 2 or larger earthquakes recorded near the Midcontinent Geophysical Anomaly from July 2018 through June 2019 superimposed on the gravity anomaly map of Kansas.

Nemaha Ridge

The Nemaha Ridge is one of the most prominent crustal features in Kansas, extending across the state with a northeast-southwest orientation. The Nemaha Ridge formed during post-Mississippian uplift of Precambrian age granite. A system of normal and reverse faults on the eastern margin of the Nemaha Ridge forms the Humboldt Fault Zone. Transform faults with a northwest-southeast trend intersecting the Nemaha Ridge represent a pre-Phanerozoic crustal extension associated with the Midcontinent Rift System. Dozens of historic earthquakes have been felt or recorded along the Nemaha Ridge, including an estimated M 5.2 near Wamego in 1867.

More than two dozen M 2 or larger earthquakes were recorded during the reporting period along the Nemaha Ridge ranging from Riley County to Marion County (Figure 8), about the same as the previous year. Earthquakes in northern and southern Butler County occurred on the crest of and eastern margin of the Nemaha Ridge, respectively. These do not occur along the trends of induced earthquakes to the southwest, and likely represent natural movement on faults associated with the Nemaha Ridge.

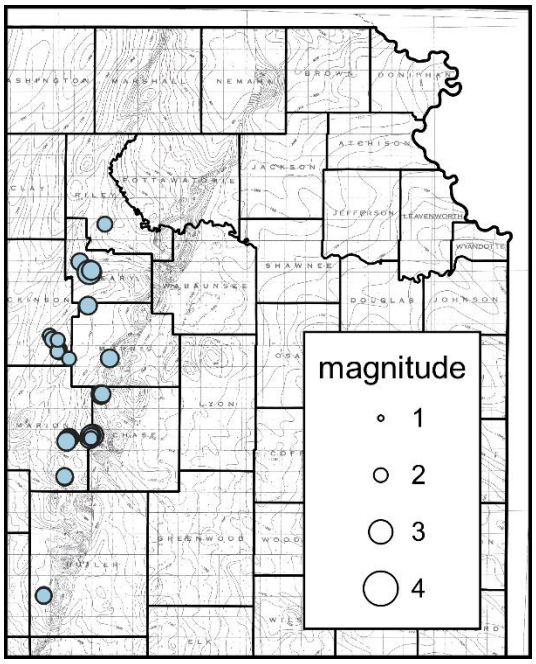

Figure 8. M 2 or larger earthquakes recorded along the Nemaha Ridge from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976).

Local Seismicity within 20 mi of Member Wells

During the past year, more than 1,700 microearthquakes (M less than 2) were recorded by the KGS seismic network (with enhanced sensitivity and improved location accuracy with the addition of CSTS stations) (Figure 9). Similar to regional scale earthquakes, the overall number of microearthquakes is down slightly (about 20%) relative to the previous year. Analysis of events well below M 2 greatly improves our ability to interpret earthquakes relative to structures and evaluate possible causal factors.

Finney County

No earthquakes were located within 20 mi of member wells in Finney County.

Kiowa County

Only sparse seismicity was recorded in Kiowa County. The largest of three events recorded in Kiowa County was a M 2.1 on June 5, 2019. This event was about 20 mi east of the member well in Kiowa County (Figure 10) at about the same location as a cluster of earthquakes recorded during the previous reporting period. These earthquakes are located northwest of the Sun City earthquake swarm along structural trend consistent with the southwest margin of the Central Kansas Uplift and Pratt Anticline. Rising bottomhole fluid pressure measured in Kiowa County suggests pressure diffusion from the Kansas–Oklahoma border to the northwest, probably along the Pratt Anticline. Similar to Comanche County, pore pressure changes and crustal stresses are probably lower here, requiring more time to accumulate stress on active faults and, thus, a lower earthquake rate compared to south-central Kansas. Just beyond 20 mi from the

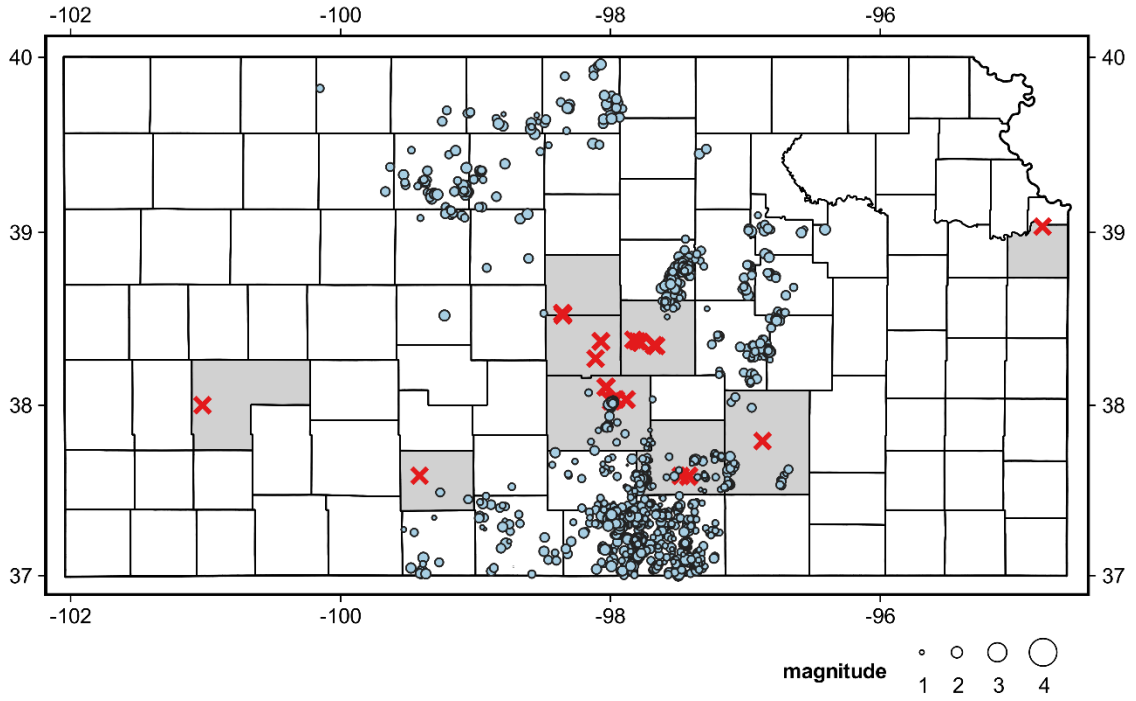

Figure 9. Microearthquakes (M less than 2) recorded in Kansas by the KGS seismic network from July 2018 through June 2019. Gray shading indicates counties with CSTS member wells (red Xs).

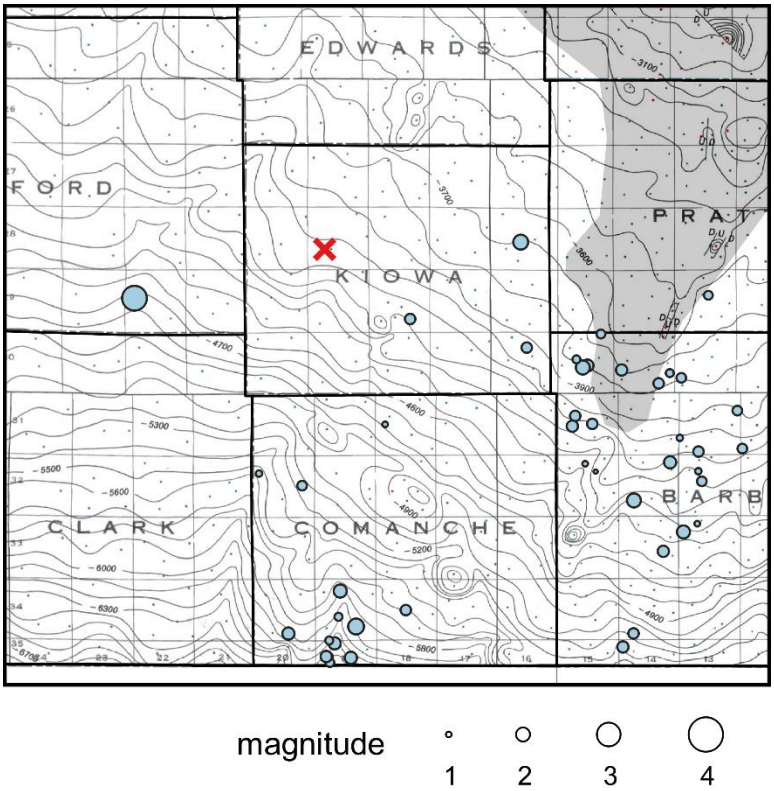

Figure 10. Earthquakes recorded in Kiowa County from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976) and inferred Pratt Anticline at the southern end of the Central Kansas Uplift (gray). CSTS member well(s) are indicated by a red X.

Kiowa County member well, a M 3.2 earthquake was recorded on October 30, 2018, in south-eastern Ford County. Given the absence of numerous foreshocks and/or aftershocks observed in most induced earthquake sequences, this may have been an isolated natural event.

Reno County

Two distinct clusters were recorded in Reno County, one southwest of Hutchinson and one east of Arlington (Figure 11). The locations of these clusters are consistent with earthquakes recorded during the previous reporting period. The Hutchinson cluster was the most active with more than 100 earthquakes during the past year, which is consistent with earthquakes observed during the previous reporting period. The largest event was a M 3.2 on March 11, 2019. Seismic activity occurred here more or less regularly throughout the year. Similar to previous years, this cluster is a dense, circular swarm about 2 mi in diameter. The maximum size of an earthquake is related to the length of the fault that ruptures. Based on the fault trace delineated by the Hutchinson earthquakes themselves, it is unlikely an earthquake with the potential to cause major damage is possible within this cluster. Notably, a single M 1.4 earthquake occurred 13 mi west of Hutchinson on April 14, 2019. Regional pore pressure increases extend into this area and, therefore, this event may have been induced.

The Arlington cluster is much less active, with only about a dozen earthquakes during the past year. The largest event was a M 2.0 on April 20, 2019. The two earthquake clusters in Reno County all occur within a structural low, bounded by the Central Kansas Uplift to the

west and the Voshell Anticline to the east (Figure 11). In late 2016 and 2017, earthquakes progressed from the south along this structural low toward the axis of the Conway Syncline, a south-plunging synclinal fold at the northern margin of the Sedgwick Basin that extends northeast into McPherson County. The northward progression of earthquakes is likely the result of elevated fluid pressure from high-volume saltwater disposal near the Kansas–Oklahoma border (Peterie et al., 2018).

Elsewhere in Reno County, seismicity is sparse and low-energy. Notably, several microearthquakes occurred in southeastern Reno County throughout the year. These events appear to be an extension of the activity in the Cheney clusters observed over the past several years.

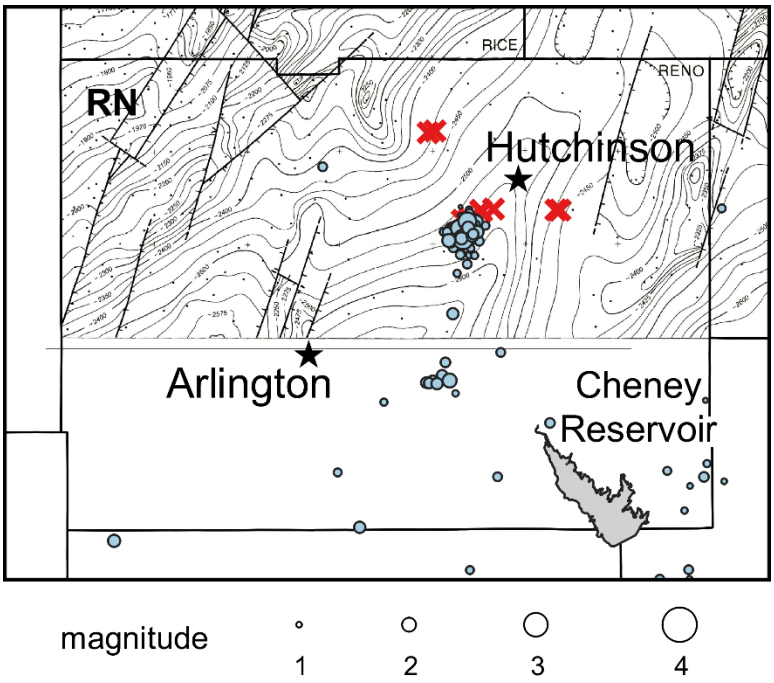

Figure 11. Earthquakes recorded in Reno County from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976). CSTS member well(s) are indicated by a red X.

Rice and Ellsworth Counties

A single M 1.4 earthquake occurred in neighboring Barton County on September 18, 2018 (Figure 12). This event is about 8 mi west of member wells located near the Rice–Ellsworth county line. This earthquake spatially coincides with subnetwork events recorded by station EW01 during the previous reporting period, within a small margin of error. Thus, the earlier subnetwork events likely indicated very low-energy movement on this active fault within the Central Kansas Uplift.

McPherson County

Although no earthquakes were recorded in proximity to member wells in McPherson County, about 20 were recorded near the McPherson–Saline county line within 20 km of member wells (Figure 13). These events occur near the eastern margin of the Midcontinent

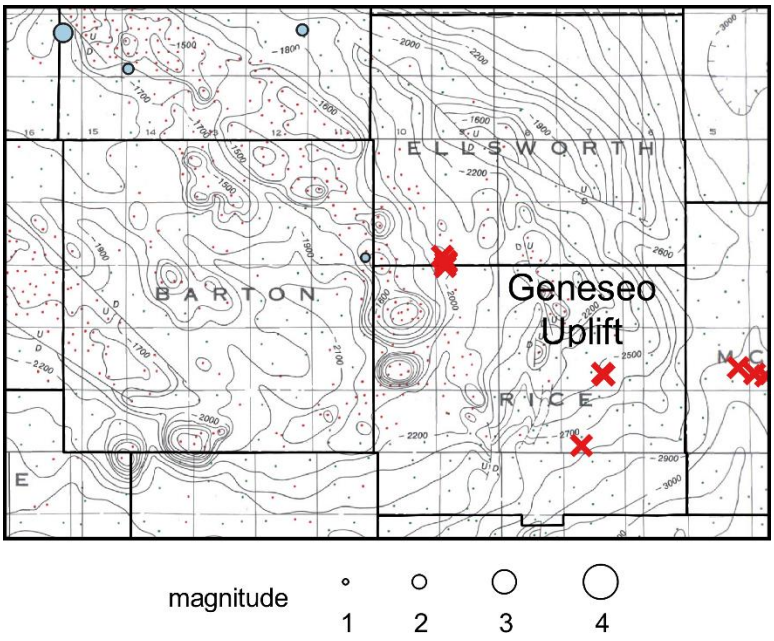

Figure 12. Earthquake in Barton County (adjacent to Rice and Ellsworth counties) from July 2018 through June 2019 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

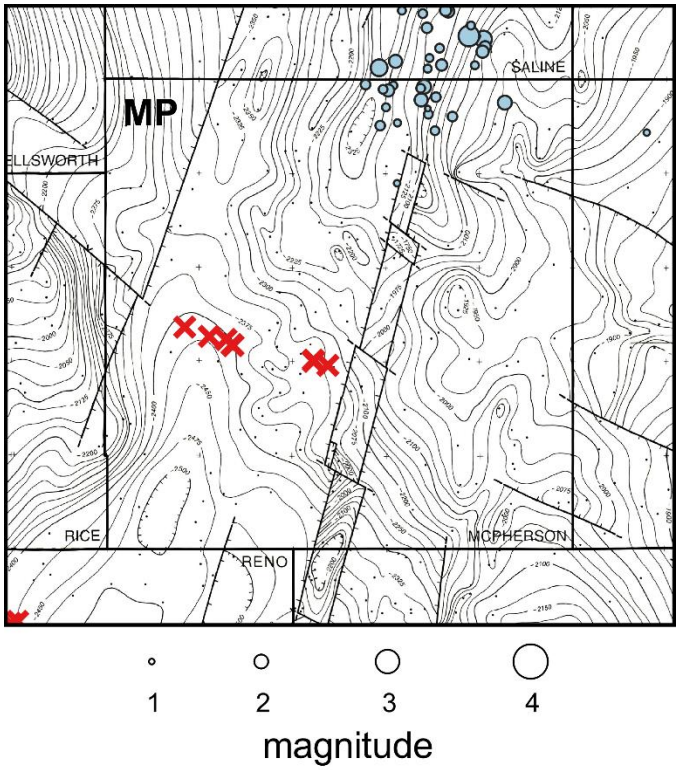

Figure 13. Earthquakes recorded in McPherson County from July 2018 through June 2019 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

Geophysical Anomaly along and east of the Salina Fault in Saline County. Seismicity in this area has been ongoing. Since installation of the KGS seismic network in 2015, nearly 100 M 2 or larger earthquakes have been recorded in this cluster and to the north along the same general structure. Historically, seismicity in this area is extremely sparse, with only one M 1.7 earthquake on February 9, 1983, about 10 mi to the west. Therefore, persistent seismicity in this area is somewhat unexpected.

Clustering of earthquakes and persistent seismicity can be an indicator that elevated pore pressures are influencing seismicity. Several dozen Class II saltwater disposal wells operate in the immediate vicinity of the McPherson–Saline earthquakes, more than 10 of which terminate in the Arbuckle Group. However, these wells are relatively low-rate, with the highest rate well injecting less than 3,000 bbl/day. Therefore, it is unclear what role nearby disposal may play in the elevated seismic activity.

Sedgwick County

Seismic activity in Sedgwick County primarily persisted in previously-identified areas in the southern half of the county (Figure 14), although, at a lower rate than previous years. About 80 earthquake were recorded in the Cheney cluster, most of which occurred in December 2018 leading up to a M 2.5 main shock on December 20, 2018. Sparse microearthquakes occurred throughout southern Sedgwick County, most of which occurred during the first half of 2019. The cause of the uptick in this microseismicity is unclear at this time. One of the more notable microearthquake clusters was a foreshock-mainshock-aftershock sequence near Wichita, the largest of which was a M 1.9 on March 6, 2019. A small cluster of about 10 earthquakes continued in northern Sumner County, the largest of which was a M 2.7 on December 17, 2018. About 30 earthquakes occurred in the first half of 2019 in previously-identified clusters in neighboring Butler County near Rose Hill and Andover 15- 20 mi to the east of Sedgwick County member wells.

The events recorded in and adjacent to Sedgwick County are likely induced as a result of elevated fluid pressure associated with the high-rate saltwater disposal near Kansas–Oklahoma border. Pore pressures have begun to stabilize, but have not yet started to decrease. While pressure remains elevated, the likelihood of continued seismicity remains high.

Butler County

In addition to the earthquakes near the Sedgwick–Butler county line discussed in the previous section, there were several earthquakes in Butler County primarily during the third quarter of 2018 (Figure 15). Most of these occurred on the steeply dipping western flank of the Nemaha Ridge, and one on the crest of the Ridge in norther-central Butler County. These earthquakes do not follow the northeasterly trend of induced earthquakes that have migrated progressively farther from the high-volume saltwater disposal near the southern Kansas border. Although it is possible that pore pressures may be elevated in Butler County, the earthquakes do not follow a clear temporal or spatial trend that would suggest these events were induced. While these events likely represent natural movement of critically-stressed faults, the influence of elevated pore pressures has not been confidently ruled out.

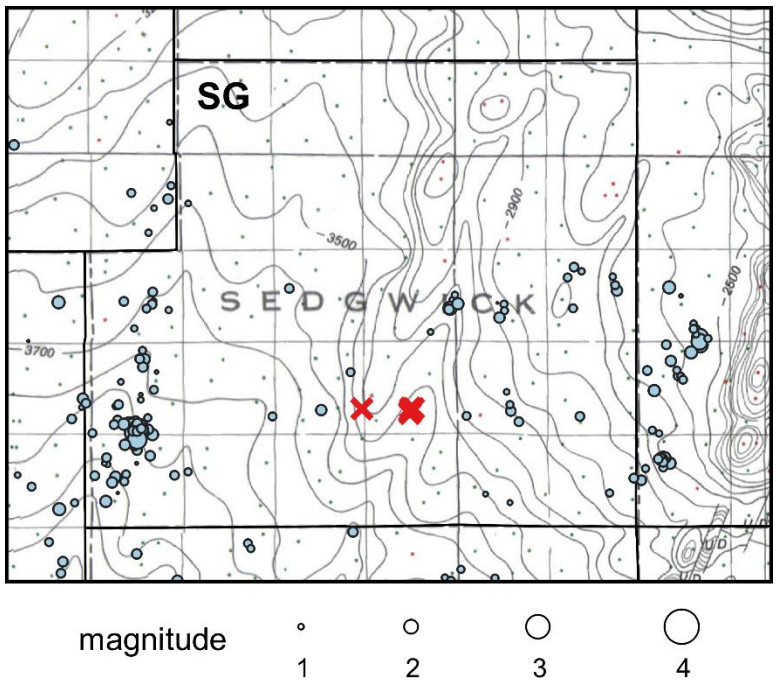

Figure 14. Earthquakes recorded in and adjacent to Sedgwick County from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976). CSTS member well(s) are indicated by a red X.

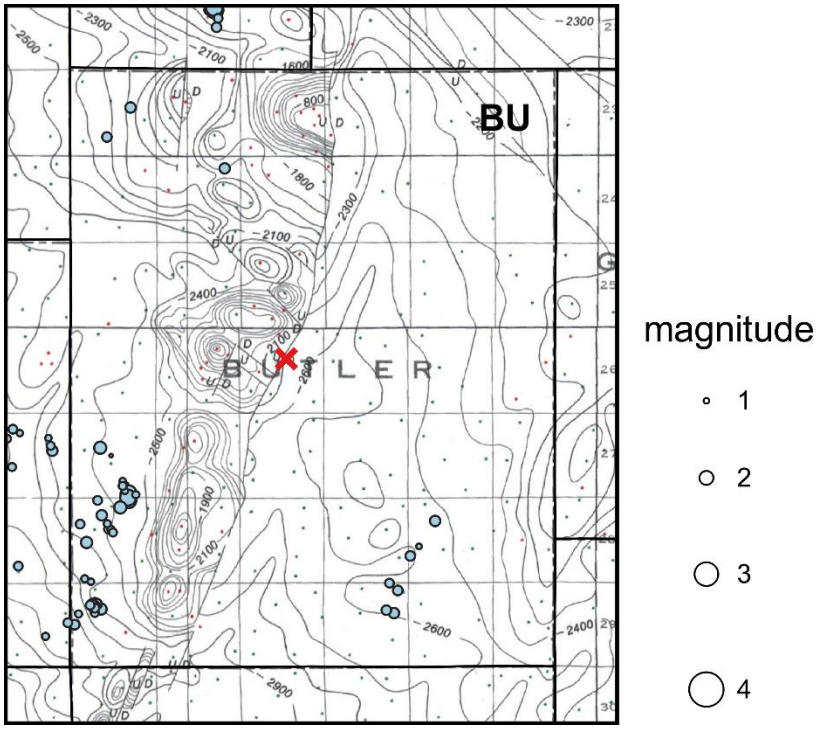

Figure 15. Earthquakes recorded in Butler County from July 2018 through June 2019 superimposed on Precambrian structural contours (from Cole, 1976). CSTS member well(s) are indicated by a red X.

Johnson County

No earthquakes were located within 20 mi of member wells in Johnson County.

Subnetwork Seismic Events

Locating the epicenter of an earthquake requires detecting P- or S-waves at three or more stations. Subnetwork events are only recorded on a single or at most two station (s) and therefore, the epicenter location cannot be determined uniquely. Rather, the epicenter exists somewhere on a circle centered on the seismic station with radius equal to the calculated distance to the earthquake epicenter. The magnitude of a subnetwork event is estimated from the coda, or duration—the time from the P-wave arrival until the energy is approximately equal to or drops below the noise floor at that time and station (background noise). More than 1,000 sub-network events were recorded at CSTS stations during this reporting period. Some events may have an anthropogenic origin (for example, underground blasting). However, the majority of these subnetwork events are low-energy microearthquakes that provide insight into the relative stability and stress conditions of faults in close proximity to the station (within about 12 mi).

Station KE01 near the Kearney–Finney County Line

No subnetwork events were recorded at station KE01 in Kearney County, adjacent to Finney County. This is unsurprising given the stable tectonic regime and extremely limited number of historic earthquakes recorded in this area.

Station KW01 in North-Central Kiowa County

No subnetwork events were recorded at station KW01 in Kiowa County. As discussed previously in this section, this likely indicates that pore pressure changes and crustal stresses are lower here and not enough time has passed to accumulate sufficient stress to trigger subnetwork earthquakes.

Station EW01 in Southwestern Ellsworth County

Two subnetwork events with magnitudes less than zero were recorded at a distance of about 4 mi from station EW01 in December 2018 (Figure 16). This may represent continued low-energy movement on the fault that produced the earlier M 1.4 earthquake about 5 mi southwest of EW01 or a historic 1983 M 2.0 earthquake about 4 mi west of EW01.

Station RC02 in Northeastern Rice County

Station RC02 is located in eastern Rice County near the center of the Geneseo Uplift, an eastern lobe of the Central Kansas Uplift that is bounded by faults mapped on the top of the Arbuckle Group to the north, west, and east (Berendsen and Blair, 1986). Eleven subnetwork events with magnitudes from M -1.5 to 0.7 were recorded at RC01 at epicentral distances ranging from about 3 to 8 mi away (Figure 17). This range of distances corresponds to all three fault zones bounding the Geneseo Uplift and, therefore, these events could have originated from any of them. Without detailed data on crustal stresses, it is unclear which of these faults may be active in the current stress regime.

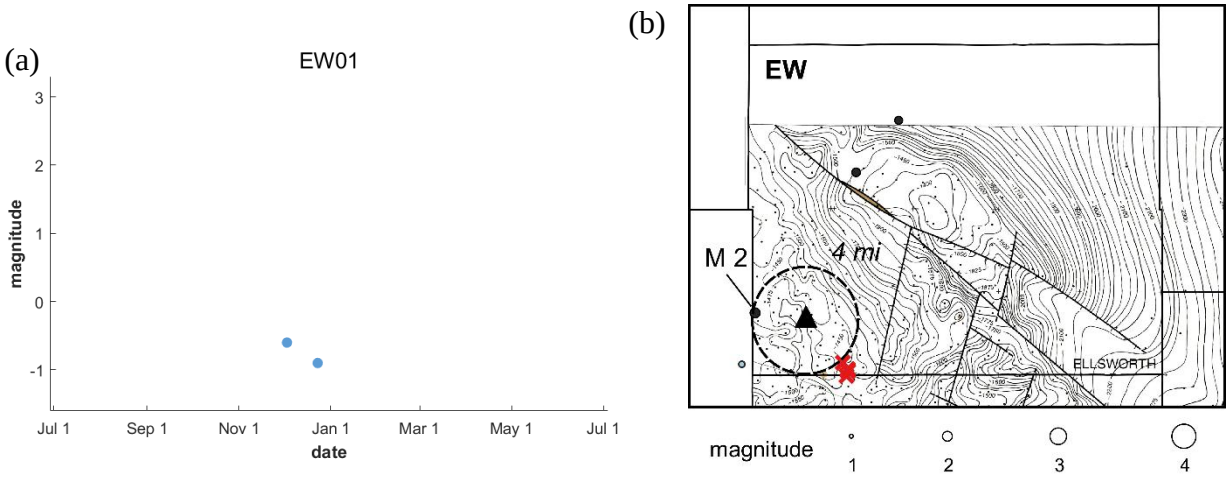

Figure 16. (a) Histogram of subnetwork events recorded at station EW01. (b) Map of historic seismicity (black) in Ellsworth County and epicentral distance of subnetwork events recorded at EW01 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

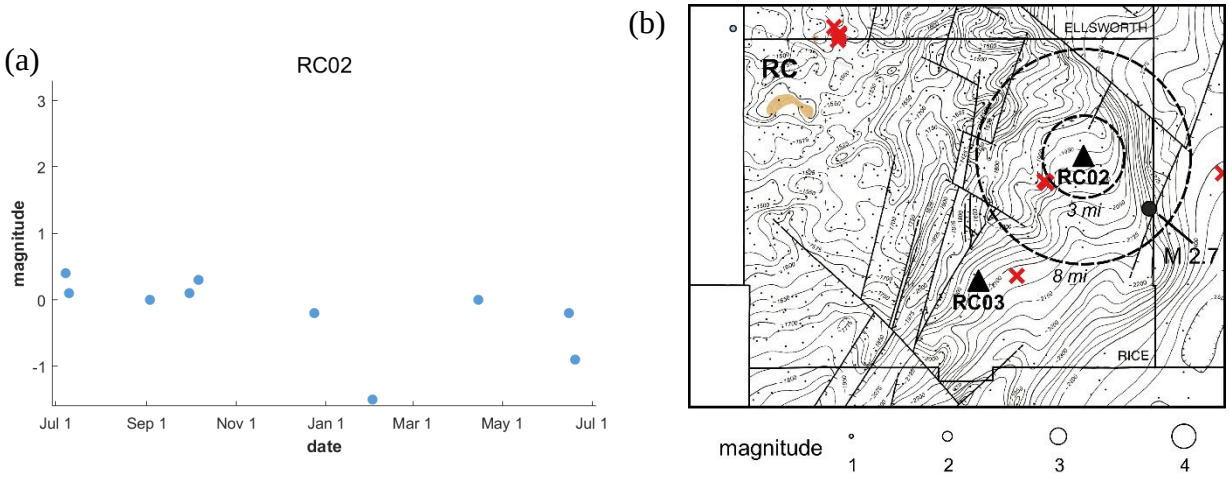

Figure 17. (a) Histogram of subnetwork events recorded at station RC02. (b) Map of historic seismicity (black) in Rice County and epicentral distance of subnetwork events recorded at RC02 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

Station RC03 in Southern Rice County

Station RC03 is located in south-central Rice County near the Peace Creek Fault Zone located on the western margin of the Geneseo Uplift. More than 500 subnetwork seismic events were recorded at RC03 with magnitudes ranging from -0.9 to 1.3. The vast majority of these events occur at regular times of day, corresponding to 5AM, 1PM, and 9 PM local time (Figure 18a). This regular timing and clustering at a distance of about 7 mi (Figure 18b) strongly suggest these events have an anthropogenic origin. The amplitude spectrum of small, close-by micro-earthquakes is typically dominated by higher frequencies. The majority of seismic events near RC03 have relatively large amplitudes toward the low frequency end of the amplitude spectrum (Figure 18c).

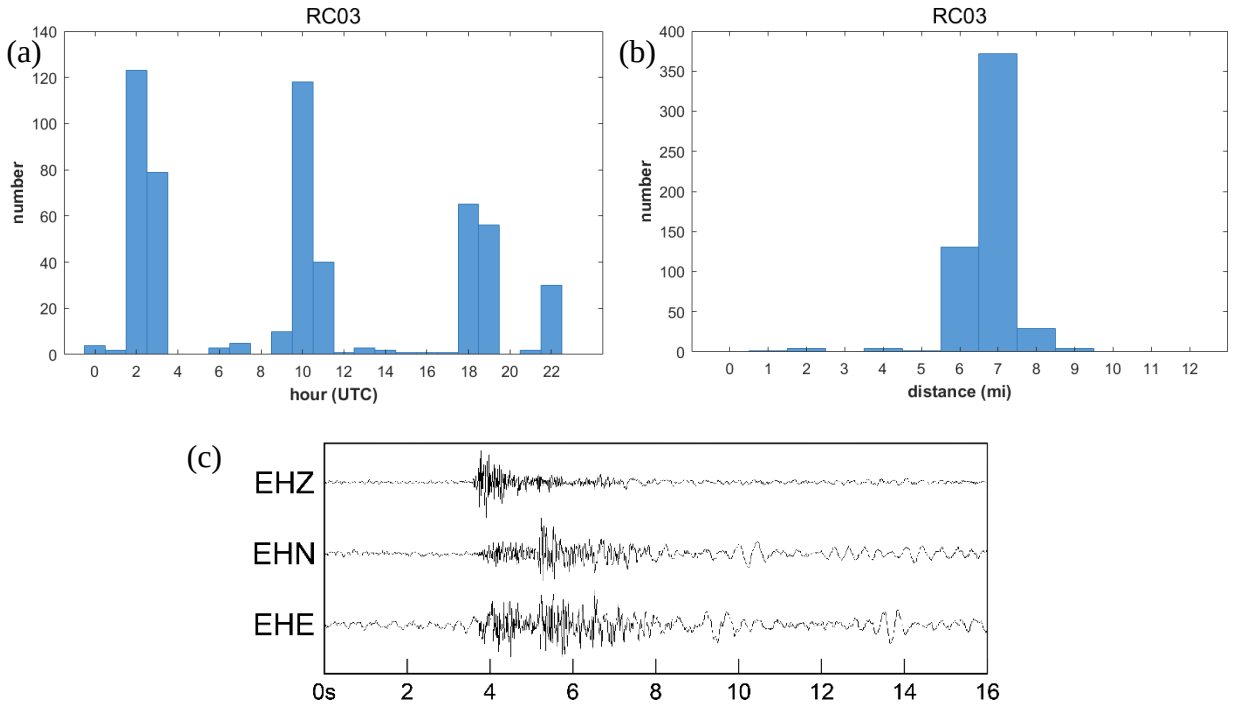

Figure 18. Histogram indicating the (a) time of day (UTC) and (b) epicentral distance of subnetwork events recorded at station RC03. (c) A representative waveform of a subnetwork event recorded at RC03.

Station RN01 in North-Central Reno County

Station RN01 is located 2-3 mi northwest of the dense cluster of earthquakes near Hutchinson. More than 350 subnetwork events were recorded at RN01 with magnitudes ranging from -1.5 to 1.3 (Figure 19a). Like the larger earthquake in the Hutchinson cluster located by the network, these events occurred regularly throughout the year. These events occur at all times of day and the estimated epicentral distances of nearly all these events is about 4.8 mi (Figure 19b). Although this is slightly larger than the 2.8 mi to the center of the Hutchinson earthquake swarm, these microearthquakes almost certainly originate from the same fault or set of faults. The epicentral distance was calculated assuming a fixed earthquake depth of 3 mi, which is a common assumption used to locate earthquakes in the midcontinental U.S. Earthquakes are likely occurring on faults within the shallow Precambrian basement, which is at a depth of about 1 mi in this part of Reno County. Recalculating the epicentral distance using a depth of 1 mi results in an average distance of 3 mi, which is consistent with the location of the swarm of earthquakes located by the KGS regional seismic network. These events are not only consistent with the accepted recursion relationship, but they have provided confidence in suggestions that the focus of the Hutchinson Swarm earthquakes is around 1 mile deep.

Station RN02 in Northeastern Reno County

More than 50 subnetwork events were recorded at station RN02 with magnitudes ranging from -0.9 to 1.0. These events largely occur around midnight local time (Figure 20a) at an epicentral distance of about 8.5 mi (Figure 20b), on average. Similar to RC03, the regular timing

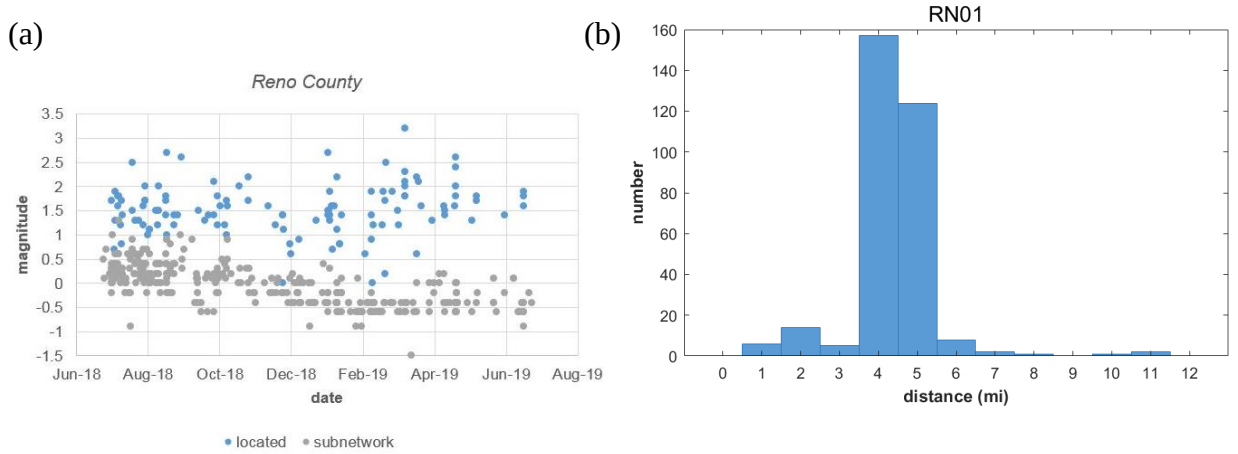

Figure 19. (a) Histogram of earthquakes in the Hutchinson cluster (blue) and subnetwork events recorded at station RN01 (gray). (b) Histogram of the epicentral distance of subnetwork events recorded at RN01.

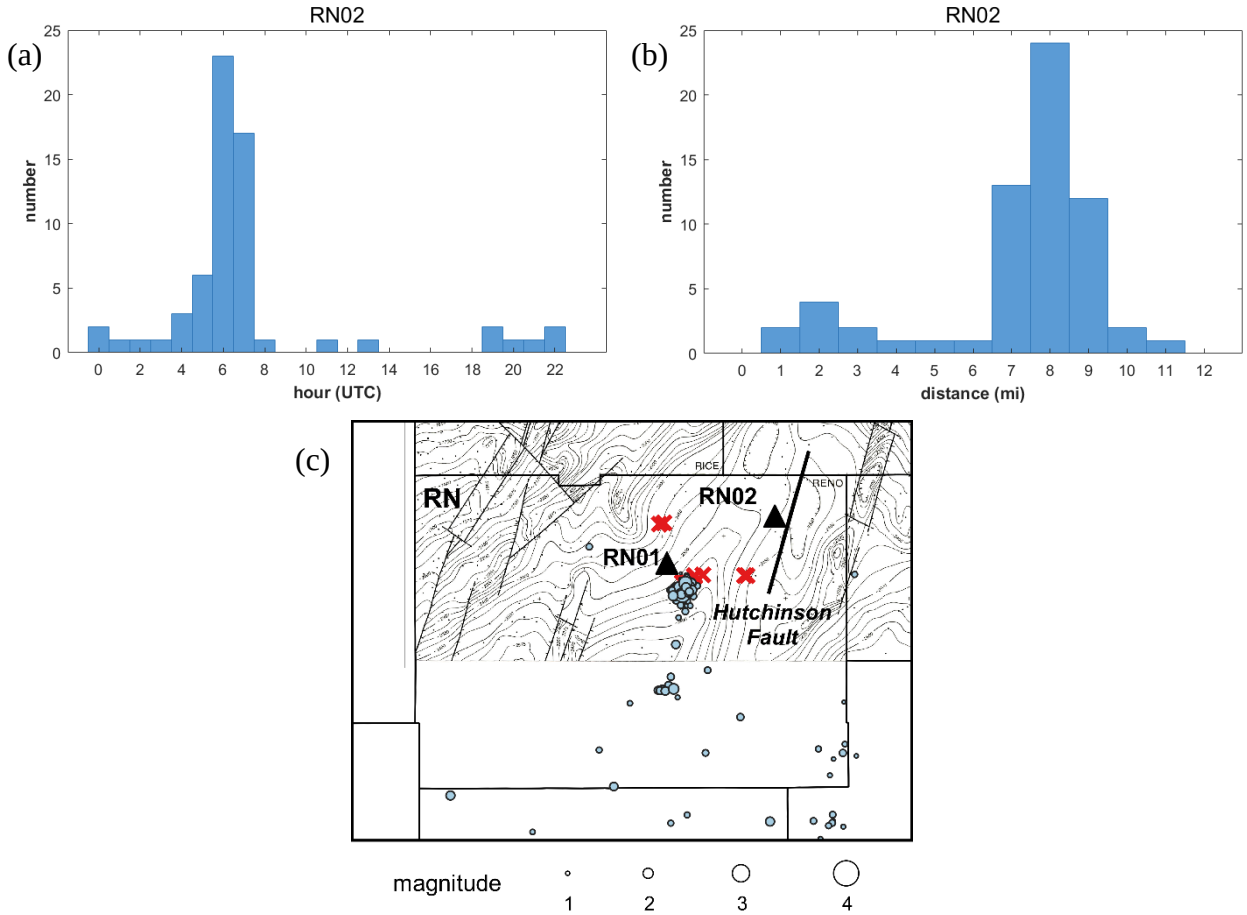

Figure 20. Histogram indicating the (a) time of day (UTC) and (b) epicentral distance of subnetwork events recorded at station RN02. (c) Map indicating epicentral distance of possible subnetwork earthquakes recorded at RN02 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

and clustering at a particular distance strongly suggest these events have an anthropogenic origin. The amplitude spectra for most of these events are characteristic of underground explosions. Based on the distance, timing, and frequency characteristics, the majority of seismic events recorded at RN02 are likely mining blasts.

About a dozen events recorded at RN02 occur outside the time and distance windows characteristic of mining blasts, and have frequency characteristics expected for microearthquakes. Many of these events occur at distances ranging from primarily ranging from 2 to 10 mi. The Hutchinson Fault, mapped from structural configuration of Arbuckle Group rocks, is oriented northeast about a mile east of RN02 (Figure 20c). Although this fault is mapped in the Arbuckle Group, it is expressed in underlying basement rocks and associated structures. The subnetwork events at RN02 that are not blasts may represent movement of this nearby basement fault. No historic earthquakes (within the detection threshold of regional networks, ~ M 3) were recorded along this fault. However, microearthquakes may indicate that elevated pore pressure (associated with deep saltwater disposal near the KS–OK border) has reactivated this and other basement faults near RN02 that have not experienced enough displacement to produce an earthquake measurable by the regional or subregional networks.

Station MP01 in Central McPherson County

Station MP01 is bounded to the west and east by northeast trending faults mapped in Precambrian and/or Arbuckle Group rocks associated with the Midcontinent Rift System. About 10 subnetwork events were recorded at MP01 with magnitudes ranging from -0.6 to 0.4 (Figure 21a). These events occurred at various times of day and most of which occurred at an epicentral distance of about 4 mi. This distance corresponds to the location of a M 2.6 earthquake that occurred on November 3, 2014 (Figure 21c). Therefore, these microearthquakes likely represent continued movement on this critically-stressed fault. Given the sparse and measured characteristics of this activity, these events are likely natural.

Station MP02 in Southern McPherson County

More than three dozen subnetwork events were recorded at station MP02 with magnitudes ranging from -0.9 to 0.6 (Figure 21b). These events occurred at epicentral distances ranging from 1 to 9 mi, the majority of which occurred 2-4 mi from the station. MP02 is bounded to the west by a system of faults associated with the Voshell Anticline, to the southeast by the Halstead Fault, and is surrounded by a number of anticlinal and synclinal structures. The majority of the subnetwork events probably occurred on the Voshell Anticline, which is less than a mile from the station. Given the sparse and measured characteristics of this activity, these events are likely natural. However, events that can be correlated to a mapped structure that has not produced an earthquake that can be located on the regional network suggests this area needs to be monitored with added attention to potential increases in the magnitude of microearthquakes.

Station SG02 in Southern Sedgwick County

About two dozen subnetwork events were recorded at station SG02 with magnitudes ranging from -1.5 to 0.6 (Figure 22a). These events occurred at epicentral distances ranging from 3-10 mi. The more distant subnetwork events likely originate from the cluster of earthquakes about 10 mi south of SG02 in northern Sumner County that has been active since 2016 (Figure 22b). These events largely occurred sporadically throughout the year, likely as a result of currently stabilizing pore pressures. Although pressure remains elevated, it levelled off in

2017 and 2018. Until pressure declines, earthquakes may continue albeit at lower rate than previous years. Because pressures are still well above the earthquake triggering threshold, even small fluctuations in pressure may generate seismicity in this area.

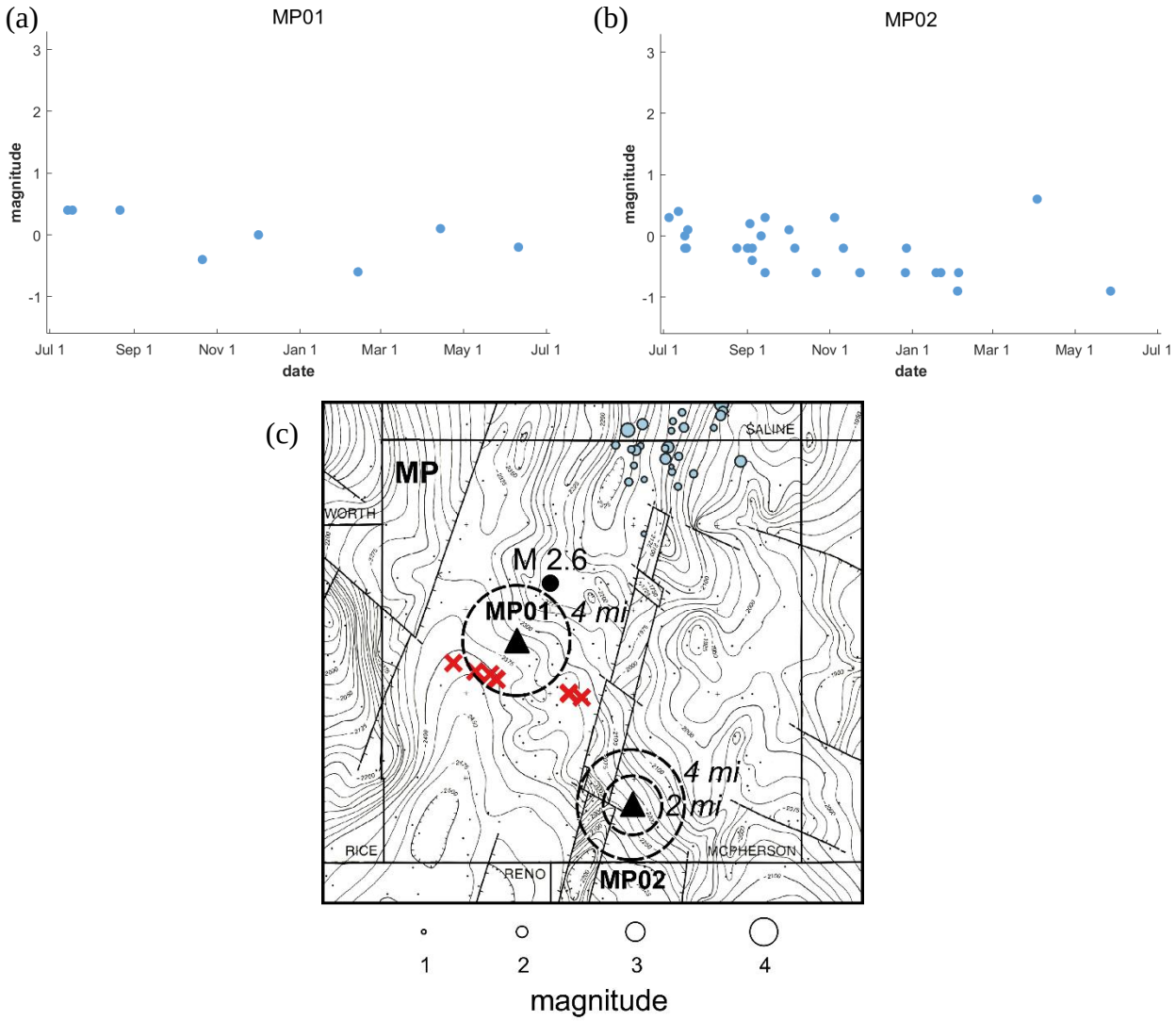

Figure 21. (a) Histogram of subnetwork events recorded at station MP01. (b) Histogram of subnetwork events recorded at station MP02. (c) Map of historic seismicity in McPherson County and epicentral distance of subnetwork events recorded at MP01 and MP02 superimposed on Arbuckle Group structural contours (from Berendsen and Blair, 1986). CSTS member well(s) are indicated by a red X.

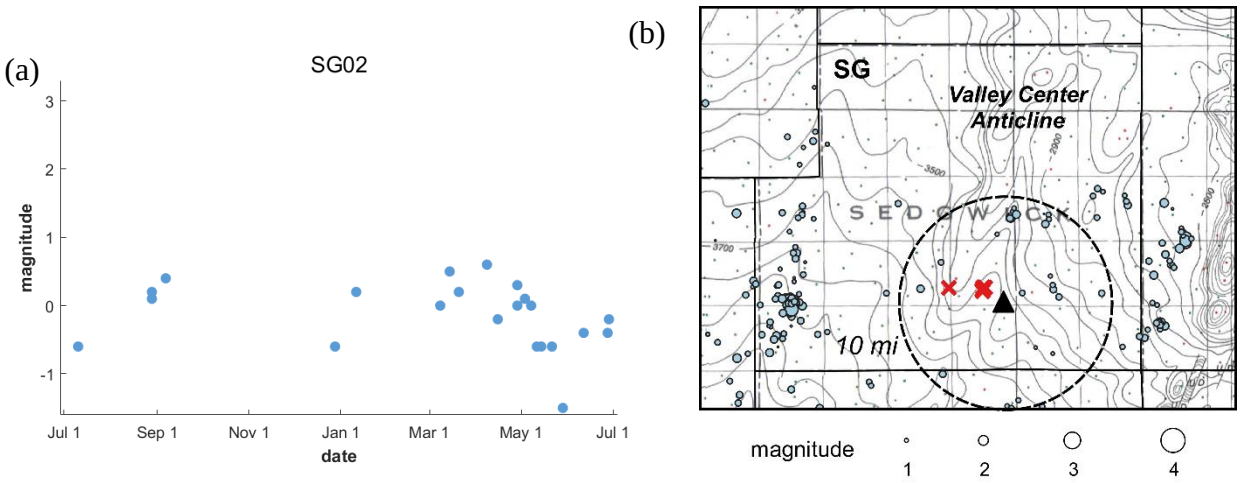

Figure 22. (a) Histogram of subnetwork events recorded at station SG02. (b) Map of earthquakes recorded in Sedgwick County by the KGS network and epicentral distance of subnetwork events recorded at SG02 superimposed on Precambrian structural contours (from Cole, 1976). CSTS member well(s) are indicated by a red X.

Station BU02 in Central Butler County

Less than 10 subnetwork events were recorded at station BU02 with magnitudes ranging -0.9 to 1.2 (Figure 23a). These events primarily occurred in two spatial groupings at about 4 mi and 11 mi. The 11 mi epicentral distance coincides with epicentral distances of subnetwork events from the previous reporting period as well as past earthquakes recorded by the KGS network about 11 mi northwest of BU02 along the Nemaha Ridge. The coincident location of these larger earthquakes and earlier subnetwork events strongly suggests the grouping of subnetwork events at 11 mi likely represent low-energy movement along the same fault, which is no doubt associated with the Nemaha Ridge. Likewise, the subnetwork event with an epicentral distance of 4 mi approximately corresponds with the location of a M 1.7 microearthquake on August 25, 2017, suggesting low-energy movement along a fault on the eastern margin of the Nemaha Ridge.

Station JO01 in Central Johnson County

No subnetwork events were recorded at station JO01. This is unsurprising given the stable tectonic regime and limited number of historic earthquakes recorded in this area.

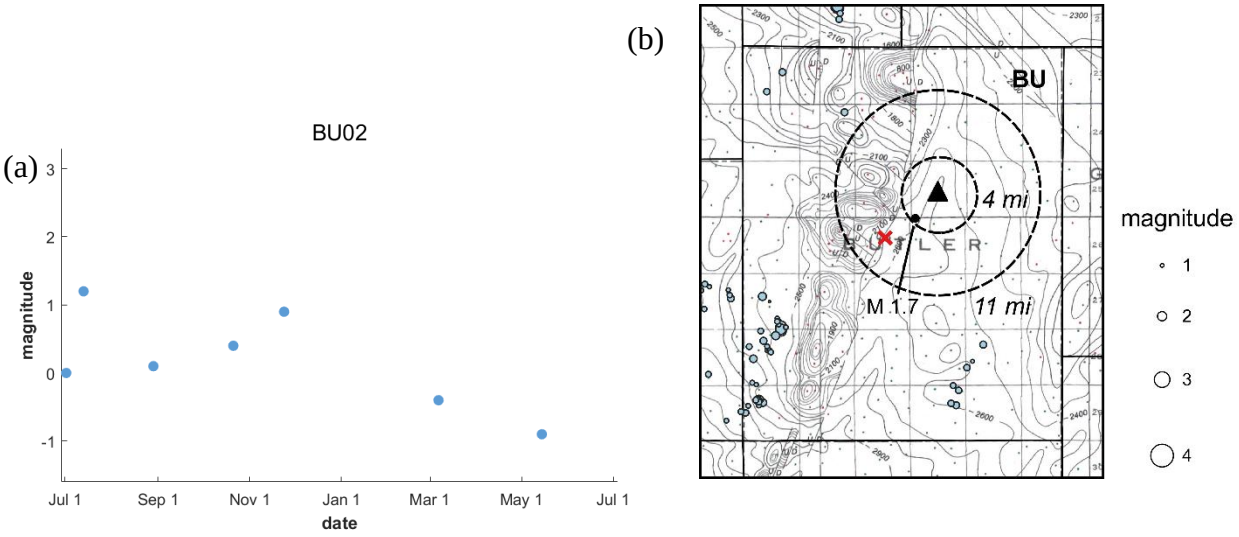

Figure 23. (a) Histogram of subnetwork events recorded at station BU02. (b) Map of earthquakes recorded in Butler County by the KGS network and epicentral distances of subnetwork events recorded at BU02 superimposed on Precambrian structural contours (from Cole, 1976). CSTS member well(s) are indicated by a red X.

DISCUSSION

The Arbuckle Group is a deep aquifer that serves as the injection zone for thousands of Underground Injection Control (UIC) wells in Kansas and neighboring Oklahoma. Widespread seismic activity across central Oklahoma and south-central Kansas is primarily attributed to elevated pore pressures along critically-stressed faults in the underlying hydraulically-connected basement. As injection volumes in south-central Kansas decreased, pressures in south-central Kansas began to stabilize in 2016 and the earthquake rate likewise levelled off (Figure 24). In 2018 (the most current year with complete pressure data), pore pressures within the Arbuckle Group (and, thus, basement) have stabilized but remained elevated above the earthquake triggering threshold (Figure 25). Therefore, earthquakes will likely persist as crustal stresses continue to load near-critical faults. Furthermore, injection practices that produce even small pressure fluctuations may contribute to triggering earthquakes on nearby faults.

Seismicity in Kansas has remained concentrated in six distinct areas with clustering activity ranging from concentrated earthquake events all within a few square miles, to earthquakes strung along apparent faults that extend over 50 miles. Active areas around Hutchinson, Nemaha Ridge, and Jewell/Smith/Republic counties seem to be consistent with years past in terms of locations and characteristics. Events in the Saline and Central Kansas Uplift (primarily Rooks County) have seen consistent to elevated activity along zones with inferred faults. South-Central (Harper/Sumner counties) area has experienced a reduction in seismicity consistent with the previous years' trend. Seismically active areas around Kansas remain active with volume of events in the last year varying from decreasing to increasing without a clear catalyst for either extreme. Some areas with swarms have experienced movement in the center of the clusters, but the concentrations of events have remained within the loosely defined groupings.

Rooks County was of the more notable seismically-active areas this year, with an unprecedented M 4.8 earthquake and more than 50 M 2 or larger earthquakes. Although disposal wells report monthly injection volumes, some of these are suspect (e.g., the monthly volumes are

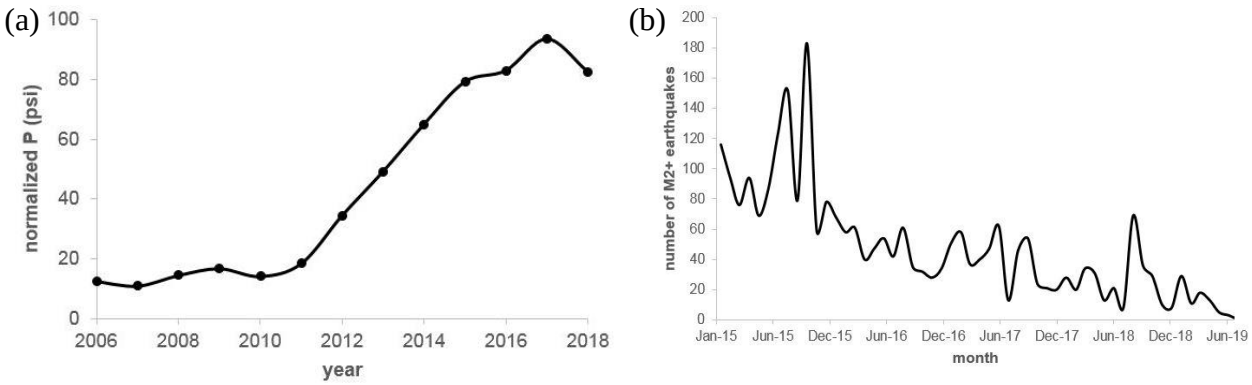

Figure 24. (a) Arbuckle Group pore pressure reported for a well in Harper County. (b) Monthly number of earthquakes M 2 or larger in central and southern Kansas.

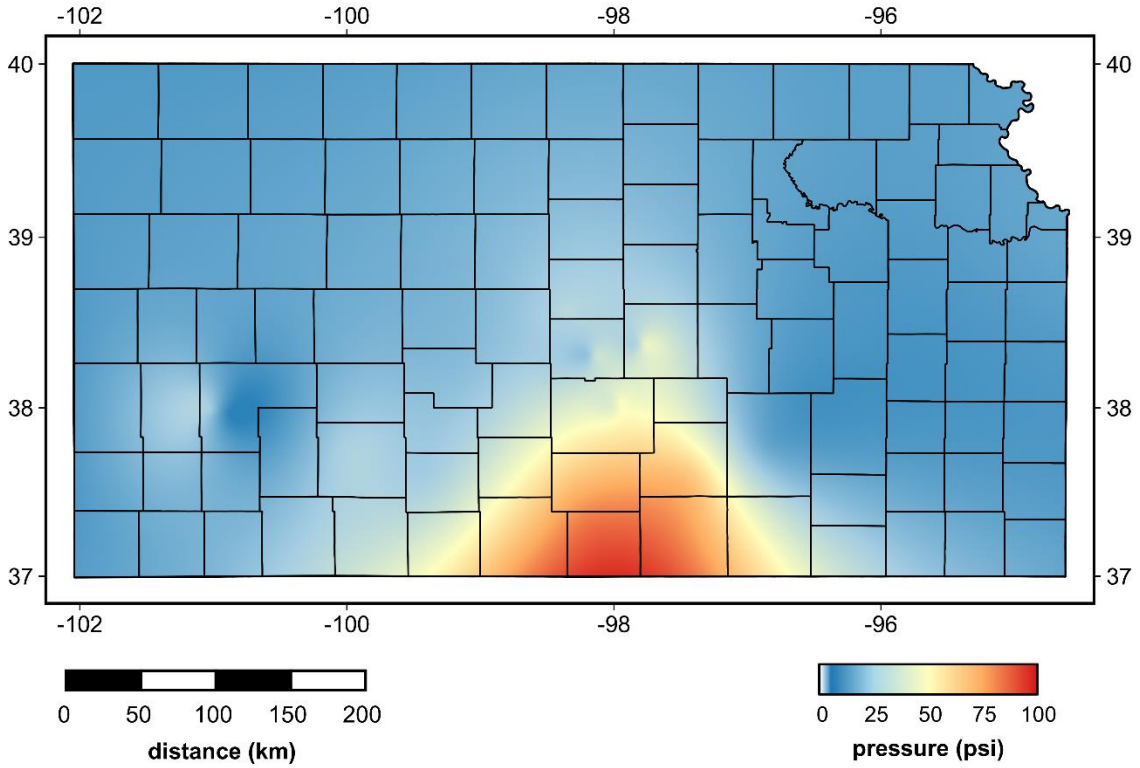

Figure 25. Change in Arbuckle Group pore pressure in 2018 (relative to baseline pressures reported in 2002, or first reported year thereafter).

one-twelfth of the annual volume) and large daily volume fluctuations (e.g. shut-in) would not be apparent from the monthly total. Furthermore, no well in this area regularly records or reports pressure measurements. Pore pressure estimates from drill stem tests (DSTs) from different wells completed in the Arbuckle Group in this area do not yield an identifiable long-term pressure trend. That is not to say that pore pressures have not changed over time, but that the uncertainty in the measurements and spatial sampling size are not conducive for determining whether or not pore pressures have changed. However, the decay rate for earthquakes in this

area appears to occur at a slower rate than natural earthquakes (most notably, the earthquake sequence in northeastern Trego County that began in 2016 and was discussed in the 2018 annual report). Considering these observations and the history of suspected induced seismicity resulting from fluid disposal in this area (Armbruster et al., 1989), it is possible earthquakes along the Central Kansas Uplift may be induced. This highlights the need for reliable and regular pressure (and static fluid level) measurements from wells in this area.

WEB PAGE CONTENT

The CSTS web page (http://www.kgs.ku.edu/Geophysics/CSTS/index.html) is operated by the KGS. It includes links to information about meetings, publications, network updates, and seismic updates (for Tier 1 members), and information about the seismic network for Tier 2 members. It includes semi-annual newsletters about earthquake activity, along with access to a comprehensive catalog of events, including time, location, magnitude, and the Seismic Action Score (based on evaluation criteria developed by the State's Induced Seismicity Task Force) for each event. The website also includes a series of pictures and accounts of the installation process and gives a feel for the environment and footprint of each consortium station. Currently at least one station has been installed within 20 miles of every Tier 1 member's well (Figure 2). A short discussion and set of pictures are posted on the website documenting the installation process.

OTHER ACTIVITIES

During the past three months, the 2019 annual meeting was scheduled for July 23 in Hutchinson. The aim is to visit Tier 1 member facilities, as appropriate, for this and future meetings. The agenda for that meeting is at the front of this report. In June 2019, Rick Miller participated in a panel on Seismic Monitoring, Regulation, and Challenges of Underground Waste Disposal as part of the KGS's annual field conference for legislators and other decision-makers. The session was held in Hutchinson at the Hutchinson Water Treatment Plant.

Also in June, David Newell was the lead author of a comprehensive article about Arbuckle disposal issues, published in the *Bulletin of the Kansas Geological Society*. Entitled "Will the Arbuckle Group Remain a Viable Disposal Zone in Kansas?", co-authors were Shelby Peterie, Michael Killion, Brandy DeArmond, Carrie Ridley, Rolfe Mandel, and Rex Buchanan.

Other activities from the past year that were discussed in previous quarterly reports include the following:

- 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.
- The KGS hosted a meeting to discuss Arbuckle disposal issues at the Kansas Corporation Commission offices in October 2018. Kyle Murray from the Oklahoma Geological Survey presented information on Arbuckle fluid levels and pressures in monitoring wells

in Oklahoma, along with an update on Oklahoma seismicity. Shelby Peterie of the KGS discussed seismic monitoring in Kansas and pressure changes related to seismic activity in south-central Kansas. Dave Newell from the KGS analyzed and summarized available data for Arbuckle fluid levels in Kansas, the need for additional data, and the challenges of obtaining that data. KGS researcher Geoff Bohling presented the results of a statistical analysis of available Arbuckle data. The meeting was attended by staff from the KGS, KCC, KDHE, and operators that utilize Class I and Class II disposal wells.

- The second annual CSTS meeting was held in Wichita on July 18, 2018. This meeting marked the first anniversary of the Consortium's creation and the first meeting since CSTS became fully operational. Eleven member companies were represented by 20 participants, along with staff from the Kansas Department of Health and Environment (KDHE) and the Kansas Corporation Commission (KCC). The morning session included presentations on national seismicity issues and responses, the Kansas monitoring network, the CSTS monitoring network, recent seismic activity, Arbuckle fluid issues, and an update from the KCC. The afternoon involved extensive discussion among Consortium members about CSTS activities and directions. Presentations from that meeting are available to Tier 1 and Tier 2 members on the CSTS webpage.

PLANS

With more than two years of recording on all stations, very preliminary searches for associations between subnetwork seismicity and operations at each site is a reasonable exercise. We plan to look at injection practices and seismicity at the 0.0 to 2.0 M levels within 10 miles of each facility to insure our general observations are in fact substantiated with actual well specific operations. We acknowledge that 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 to steer a more directed study of a trend as it continues to develop. We are starting that process a bit early just to insure our study begins at the onset of a correlation, understanding we are likely still a few years ahead of having enough data for this kind of detailed investigation.

As the Statewide network is expanded to its full strength over the next few months, infill stations around Salina will provide improved location accuracy as well as another station to help with event triangulation for earthquakes currently too small to be detected on three or more stations, which is necessary for unique epicenter locations for earthquakes.

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 year's trends in seismicity, as they relate to CSTS facilities, are generally consistent with observations reported over the year prior. 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. 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 micro levels 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 evidence they existed, except CSTS identified earthquake epicenters.

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Appendix A: CSTS Station Locations, Pictures, and Descriptions

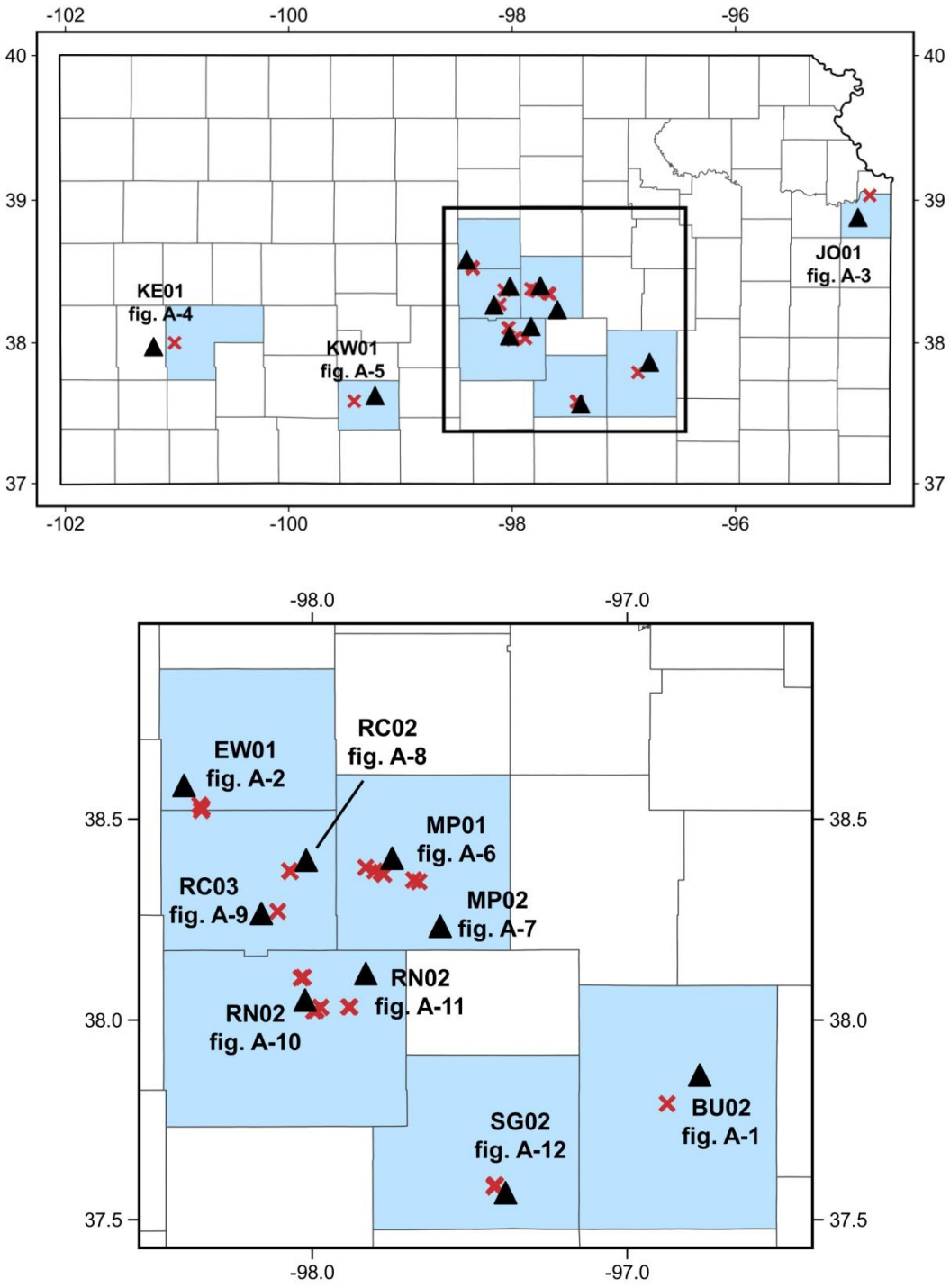

Figure A-0. Base map for pictures of equipment configuration at each station included in this appendix. Top figure is State of Kansas with the bottom figure enlargement of black box in upper figure. Black triangles are earthquake stations and red Xs are each member's injection facility location(s).

Figure A-1. BU02 is located in the El Dorado State Park in northern Butler County. This station is in a pasture near the El Dorado Lake about 4 mi from Interstate 35.

Figure A-2. EW01 is located in southwestern Ellsworth County near the city of Holyrood. The station is in a cemetery about 1 mi from highway Kansas Highway 156.

Figure A-3. JO01 is located on the grounds of the Olathe Prairie Center in Johnson County about 4 mi west of Kansas Highway 10. There is light traffic around the station and two rock quarries within about 5 mi.

Figure A-4. KE01 is located in eastern Kearny County between Lakin and Deerfield. The station is near the dam of Lake McKinney about a mile from US Highway 50.

Figure A-5. KW01 is located in northern Kiowa County near Greensburg. This station is within 1 mi a set of railroad tracks, US Highway 54, and an active construction site for a future airport. Due to unacceptable noise conditions and flooding, this station will be decommissioned and is scheduled to be moved to a pasture located between Mullinville and Greensburg more than 1 mi from the railroad and highway.

Figure A-6. MP01 is located in the McPherson Valley Wetlands Wildlife Area in McPherson County. The station is northwest of Conway about 2 mi from US Highway 56.

Figure A-7. MP02 is located in south-central McPherson County southeast of the McPherson. The station is in a pasture on the grounds of a local church about 3 mi from Interstate 135.

Figure A-8. RC02 is located in eastern Rice County near the city of Little River. This station is installed in a pasture more than 1 mi from US Highway 56 and Kansas Highway 46.

Figure A-9. RC03 is located in Rice County between Lyons and Sterling. This station is installed in a pasture about 2 mi from highway Kansas Highway 96 and is near a small landing strip.

Figure A-10. RN01 is located in Reno County west of Hutchinson. This station is installed in a cemetery about 2 mi from Kansas Highway 14.

Figure A-11. RN02 is located in Reno County northeast of Hutchinson in Sand Hills State Park. It is installed in a 2.5 mi from Kansas Highway 61.

Figure A-12. SG02 is located in Sedgwick County south of Wichita. This station is on the grounds of a local church about 3 mi from Interstate 35 and US Highway 81 and 2 mi from two sets of railroad tracks to the west and east.

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Appendix B: CSTS Earthquake Catalog 7/1/2018 – 6/30/2019

This catalog includes all earthquakes that were uniquely located and within 20 miles of a consortium member facility.

Origin Time (UTC)	Latitude	Longitude	Magnitude
2018-07-02 19:35:23	37.47046	-97.48942	1.5
2018-07-03 06:11:39	37.30675	-97.39395	1.2
2018-07-05 00:04:05	37.56561	-97.73238	1.6
2018-07-07 05:33:13	37.5755	-97.76898	1.4
2018-07-08 07:28:34	38.56645	-97.59936	1.5
2018-07-08 12:41:14	38.0093	-97.98938	1.7
2018-07-10 07:00:51	37.9891	-97.98029	0.7
2018-07-11 01:34:44	38.02234	-97.98054	1.9
2018-07-11 03:47:46	37.38449	-97.64938	1.3
2018-07-11 08:23:42	38.00803	-97.99276	1.3
2018-07-12 18:04:57	37.60395	-97.72581	1.3
2018-07-13 21:04:54	38.0155	-97.99225	1.6
2018-07-13 21:57:57	38.0102	-97.98826	1.8
2018-07-14 02:37:48	38.00773	-98.00269	1.8
2018-07-16 02:38:15	37.99066	-97.98731	1.2
2018-07-16 05:09:34	38.6044	-97.61665	1.5
2018-07-16 18:15:51	38.02627	-97.99055	0.8
2018-07-16 22:39:33	38.01529	-97.99018	1.7
2018-07-17 02:42:17	37.67872	-97.70824	1.1
2018-07-17 06:12:05	37.37996	-97.57008	1.3
2018-07-17 06:21:08	37.3628	-97.59678	1.9
2018-07-17 07:27:20	37.36825	-97.59663	1.2
2018-07-17 08:05:26	37.39653	-97.52659	0.9
2018-07-17 18:25:53	37.98196	-97.99014	1.4
2018-07-18 20:31:35	37.56191	-97.72742	1.7
2018-07-19 12:07:54	37.30059	-97.42576	1.8
2018-07-22 04:11:04	37.42459	-97.69792	1.6
2018-07-22 15:41:57	38.57703	-97.5424	1.4
2018-07-23 03:20:52	37.53086	-96.73402	1.6
2018-07-25 18:16:19	38.0106	-97.99627	2.5
2018-07-25 18:22:42	38.01777	-97.99193	1.5
2018-07-26 05:03:10	37.63272	-97.73684	1.6
2018-07-27 01:25:52	37.68702	-97.72618	1.0
2018-07-27 07:21:30	37.542	-97.73021	1.5
2018-07-27 13:32:26	37.6408	-97.73927	1.2
2018-07-27 14:43:26	37.6253	-97.73893	1.5
2018-07-28 04:53:00	38.01792	-97.96848	1.3
2018-07-30 15:46:38	37.60316	-97.13166	1.7
2018-07-31 06:52:44	38.00654	-98.0024	1.3
2018-07-31 23:02:53	37.50701	-97.18472	1.2
2018-08-01 00:52:35	37.41685	-97.68301	0.8
2018-08-01 01:15:55	37.41211	-97.70116	1.6
2018-08-01 04:38:09	37.7952	-97.70547	1.2
2018-08-02 07:33:48	37.70923	-97.23458	1.3
2018-08-02 21:16:57	37.41599	-97.63053	0.9
2018-08-04 00:48:23	37.99838	-98.00118	1.6
2018-08-04 01:18:31	37.97336	-98.00215	1.2
2018-08-04 02:27:34	37.40634	-97.50184	1.3
2018-08-04 09:06:40	37.61136	-97.76501	1.0
2018-08-04 11:15:39	37.40898	-97.49807	1.6
2018-08-05 01:42:07	38.01834	-97.99559	2.0
2018-08-05 04:01:58	38.00653	-97.99645	1.7
2018-08-05 04:04:44	37.39344	-97.49902	1.4
2018-08-05 04:14:46	38.01436	-97.9902	1.7
2018-08-06 01:53:11	37.40604	-97.48854	1.3
2018-08-06 14:27:55	37.78271	-97.70904	1.5
2018-08-06 18:12:12	37.37605	-97.60737	1.0
2018-08-07 14:52:52	38.00956	-97.99234	1.0
2018-08-09 00:07:41	37.68542	-97.31798	0.4
2018-08-09 01:07:05	38.0328	-97.98792	1.1
2018-08-09 01:15:43	38.013	-97.98363	1.1
2018-08-09 15:44:48	37.58939	-96.71295	1.5
2018-08-09 16:10:46	37.56149	-96.73987	1.4
2018-08-09 22:29:21	37.55403	-96.72912	1.5
2018-08-11 11:34:32	37.5666	-97.74351	1.8
2018-08-12 01:00:09	37.3224	-97.3883	1.3
2018-08-14 16:50:30	37.33133	-97.36295	1.3
2018-08-14 20:45:32	38.00418	-97.98887	1.5
2018-08-15 07:13:42	37.78691	-98.14397	1.3
2018-08-15 08:08:36	37.34102	-99.30653	1.0
2018-08-15 20:23:29	38.02191	-97.98631	1.2
2018-08-16 11:43:28	38.00944	-97.97871	1.5
2018-08-16 11:55:37	38.00838	-97.99149	2.0
2018-08-17 18:03:40	37.61692	-97.10332	1.4
2018-08-18 13:23:15	37.61651	-97.10007	1.2
2018-08-21 16:42:01	37.699	-97.565	1.4
2018-08-22 07:16:01	37.62233	-97.10487	1.2
2018-08-22 17:52:39	38.02173	-97.9789	1.8
2018-08-23 02:31:57	38.01059	-97.98779	1.7
2018-08-23 02:40:51	38.01374	-97.98833	1.4
2018-08-23 08:04:41	37.99448	-97.98555	1.0
2018-08-23 16:41:58	38.01168	-98.0057	2.7
2018-08-26 02:21:20	37.684	-97.728	1.4
2018-08-30 00:30:15	38.00719	-97.99003	1.2
2018-08-30 00:34:45	38.0144	-97.98685	1.4
2018-08-30 09:12:04	37.52373	-97.70129	1.4
2018-09-01 20:23:01	38.0293	-97.98765	1.4
2018-09-05 03:21:58	38.00741	-98.00117	2.6
2018-09-06 10:05:32	37.5992	-96.7017	1.0
2018-09-06 14:57:26	37.62044	-97.4923	1.3
2018-09-09 12:20:39	37.89002	-98.01602	1.5
2018-09-09 21:36:54	37.62519	-96.68082	1.6
2018-09-10 18:31:30	37.83329	-97.89189	1.5
2018-09-12 00:15:00	37.89932	-97.95033	1.4
2018-09-15 02:57:09	37.38497	-97.50085	1.7
2018-09-17 03:11:26	37.38461	-97.50298	1.0
2018-09-18 21:49:57	37.58859	-97.77107	1.1
2018-09-18 22:31:47	38.53332	-98.49467	1.4
2018-09-18 22:52:07	38.00476	-97.9852	1.5
2018-09-21 12:38:38	37.62061	-97.72268	0.7
2018-09-21 14:45:52	37.5901	-97.76774	1.4
2018-09-21 15:01:30	37.66146	-97.74902	1.1
2018-09-22 22:17:59	37.52695	-97.6852	1.2
2018-09-24 08:11:20	38.00618	-97.9937	1.3
2018-09-26 10:21:24	37.38804	-97.49767	1.4
2018-09-27 16:23:51	38.00214	-97.9902	1.4
2018-10-01 21:41:57	37.5994	-97.74133	0.7
2018-10-02 02:53:12	38.0122	-97.99657	2.1
2018-10-02 04:58:27	38.01339	-97.9909	1.4
2018-10-03 05:59:17	37.69566	-97.72719	1.4
2018-10-03 06:28:55	37.63292	-97.74265	1.4
2018-10-05 07:05:24	38.01097	-98.00009	1.8
2018-10-05 07:35:26	38.00067	-97.99415	1.2
2018-10-07 03:05:35	38.01815	-97.98103	1.6
2018-10-07 04:07:30	37.38653	-97.50552	1.5
2018-10-08 07:05:28	37.53388	-96.74388	1.5
2018-10-11 05:07:26	37.43525	-97.36121	1.2
2018-10-11 11:04:44	38.0143	-97.9874	1.2

Appendix B. Continued

Origin Time (UTC)	Latitude	Longitude	Magnitude
2018-10-12 20:10:46	37.45976	-97.61411	1.3
2018-10-12 20:47:27	37.45486	-97.61076	1.2
2018-10-12 22:56:47	38.01502	-97.99532	1.7
2018-10-12 23:48:18	38.00006	-97.99371	1.0
2018-10-13 04:36:38	38.00349	-97.98932	1.6
2018-10-14 04:16:01	37.52116	-97.76743	1.3
2018-10-18 09:16:27	37.38628	-97.50475	0.8
2018-10-18 14:44:28	37.93554	-98.00717	1.7
2018-10-21 02:18:56	38.58339	-97.59254	1.3
2018-10-21 10:23:19	38.60349	-97.58382	1.3
2018-10-23 16:28:38	38.01123	-97.9893	2.0
2018-10-27 03:57:28	37.61341	-97.09755	1.3
2018-10-27 04:50:32	37.64621	-97.11738	1.4
2018-10-30 14:55:35	37.51906	-99.75287	3.1
2018-10-30 17:11:48	38.01485	-97.99374	2.2
2018-10-30 18:06:37	38.00867	-97.99579	1.7
2018-11-01 20:44:31	37.39102	-97.48425	1.3
2018-11-05 07:33:54	37.68036	-97.22803	1.3
2018-11-08 09:00:52	37.37336	-97.50769	1.2
2018-11-15 00:48:54	37.41101	-97.39155	2.5
2018-11-16 07:50:11	38.0137	-97.99644	1.6
2018-11-17 02:59:41	37.42702	-97.32082	1.2
2018-11-18 21:36:47	37.48972	-99.2619	1.6
2018-11-20 15:33:20	37.41933	-97.38745	1.8
2018-11-20 17:33:51	37.42244	-97.37724	1.2
2018-11-22 16:14:51	38.01569	-97.99458	1.2
2018-11-23 12:55:47	37.34787	-97.62463	1.9
2018-11-27 05:31:37	37.32757	-97.44671	1.4
2018-11-27 17:49:00	37.4139	-97.49431	1.3
2018-11-27 18:56:41	37.6801	-97.73452	1.3
2018-11-28 17:24:50	37.4078	-97.48685	1.6
2018-11-28 23:41:15	37.40847	-97.48779	1.8
2018-11-29 01:22:24	37.41756	-97.47976	1.6
2018-11-29 01:32:30	38.00663	-97.99186	0.0
2018-11-29 02:17:20	38.00334	-97.97577	1.4
2018-11-29 02:19:39	38.00932	-97.98392	1.4
2018-11-29 06:03:04	37.40912	-97.49347	2.2
2018-11-29 10:30:49	38.01314	-97.9954	1.1
2018-12-03 15:25:40	37.78283	-97.95408	1.4
2018-12-04 08:53:09	37.87799	-98.01993	1.6
2018-12-04 20:48:32	38.0083	-97.99474	0.8
2018-12-05 22:55:23	38.0201	-97.98083	0.6
2018-12-06 11:39:51	37.41061	-97.49359	1.3
2018-12-12 08:07:28	38.00135	-97.99718	0.9
2018-12-15 01:02:28	37.50705	-97.76875	0.5
2018-12-16 19:14:41	37.56665	-97.74152	1.5
2018-12-16 19:58:09	37.56986	-97.75452	1.8
2018-12-16 20:13:40	37.569	-97.75191	2.1
2018-12-16 21:03:28	37.33812	-97.49522	1.7
2018-12-16 21:08:00	37.57412	-97.74762	1.6
2018-12-16 23:18:32	37.56937	-97.74203	2.1
2018-12-16 23:20:51	37.56803	-97.74973	1.6
2018-12-16 23:27:55	37.57287	-97.75556	1.7
2018-12-16 23:37:39	37.57187	-97.75118	1.7
2018-12-16 23:49:24	37.56871	-97.74284	1.6
2018-12-16 23:52:47	37.56887	-97.74461	2.2
2018-12-17 00:08:17	37.56495	-97.74078	2.1
2018-12-17 00:11:58	37.56019	-97.74163	1.8
2018-12-17 00:27:56	37.56672	-97.73231	1.5
2018-12-17 00:30:01	37.55996	-97.75073	1.5
2018-12-17 00:31:32	37.53493	-97.74638	0.6
2018-12-17 00:44:25	37.7786	-97.68507	1.0
2018-12-17 00:57:17	37.54735	-97.74574	1.5
2018-12-17 01:07:22	37.5653	-97.74393	2.0
2018-12-17 01:08:38	37.56714	-97.73971	1.6
2018-12-17 01:14:39	37.57764	-97.73307	1.2
2018-12-17 01:43:50	37.57118	-97.74544	1.1
2018-12-17 01:45:58	37.5721	-97.73898	1.1
2018-12-17 04:16:57	37.5706	-97.74229	1.2
2018-12-17 04:31:14	37.56338	-97.75024	2.3
2018-12-17 04:32:52	37.56362	-97.7379	1.5
2018-12-17 06:02:55	37.56044	-97.74892	1.7
2018-12-17 06:32:57	37.55116	-97.74892	1.4
2018-12-17 07:06:23	37.56551	-97.73988	1.6
2018-12-17 10:04:00	37.56166	-97.7454	1.8
2018-12-17 15:08:14	37.56235	-97.74257	1.6
2018-12-17 15:21:32	37.59456	-97.74134	1.0
2018-12-17 18:33:18	37.56648	-97.74198	1.5
2018-12-17 20:36:19	37.41992	-97.39233	2.9
2018-12-17 21:22:11	37.56416	-97.745	1.6
2018-12-18 00:24:16	37.56564	-97.73943	1.5
2018-12-18 06:05:23	37.56572	-97.74564	1.4
2018-12-18 19:44:29	37.85447	-97.70723	0.9
2018-12-19 04:09:24	37.56399	-97.74767	1.6
2018-12-20 09:52:59	37.56675	-97.7394	1.7
2018-12-20 11:17:27	37.56541	-97.75013	1.4
2018-12-20 19:59:33	37.57229	-97.74551	1.5
2018-12-20 20:56:57	37.5573	-97.74557	2.5
2018-12-20 20:59:15	37.56536	-97.75035	1.5
2018-12-20 22:41:22	37.55234	-97.76021	1.6
2018-12-20 23:14:02	38.60236	-97.54749	2.0
2018-12-21 01:02:16	37.56546	-97.74505	1.5
2018-12-21 01:03:07	37.56486	-97.74585	1.4
2018-12-21 01:49:49	37.56752	-97.74068	1.4
2018-12-21 08:10:45	38.59283	-97.53352	1.5
2018-12-21 08:26:58	37.52457	-97.75887	1.3
2018-12-21 09:43:35	38.58223	-97.54307	1.0
2018-12-23 02:45:50	37.33981	-97.48154	1.5
2018-12-27 00:36:22	37.99874	-97.99168	1.3
2018-12-29 07:26:10	37.42751	-97.38023	1.1
2018-12-29 12:32:47	37.39683	-97.67036	1.6
2018-12-30 08:41:49	37.42307	-97.38896	1.1
2018-12-30 16:54:04	37.51788	-97.76093	1.3
2019-01-03 06:16:32	37.42453	-97.37309	1.3
2019-01-04 07:00:56	37.36397	-97.65392	1.6
2019-01-05 05:23:06	37.31684	-97.5368	1.4
2019-01-05 14:10:53	37.99761	-98.00662	1.5
2019-01-05 15:01:09	37.99711	-97.99146	1.4
2019-01-06 02:18:33	38.01208	-98.00269	2.7
2019-01-06 04:02:56	37.31482	-97.52818	1.4
2019-01-06 04:53:19	38.00937	-97.99042	1.5
2019-01-07 07:13:58	38.00177	-97.99125	1.3
2019-01-07 09:46:23	37.99073	-97.99841	1.4
2019-01-07 12:40:14	38.01776	-97.99364	1.9
2019-01-08 13:09:57	38.00228	-97.99503	1.6
2019-01-08 20:34:26	38.59022	-97.55091	1.9
2019-01-09 17:37:01	38.03559	-97.9982	0.7
2019-01-10 05:53:24	38.60098	-97.55148	1.4
2019-01-11 04:15:22	38.00739	-97.99664	1.6
2019-01-11 04:51:57	37.57939	-97.35459	1.3
2019-01-13 09:48:14	38.01538	-97.99513	2.2
2019-01-13 12:50:49	38.01817	-97.98894	1.1
2019-01-15 07:25:41	38.00351	-97.99766	0.8
2019-01-15 10:49:51	38.02753	-97.99865	0.8

Appendix B. Continued

Origin Time (UTC)	Latitude	Longitude	Magnitude
2019-01-16 08:39:19	38.57483	-97.51392	1.5
2019-01-17 06:15:58	38.01791	-97.99731	1.4
2019-01-18 02:08:35	37.4204	-97.70404	1.5
2019-01-18 03:30:27	37.42215	-97.70969	1.3
2019-01-18 04:03:15	37.42004	-97.71095	1.2
2019-01-20 06:15:21	37.36437	-97.62672	1.2
2019-01-20 06:49:36	37.34668	-97.62775	2.1
2019-01-20 12:05:27	37.35976	-97.62536	1.2
2019-01-20 12:50:46	37.34577	-97.62738	1.8
2019-01-20 13:19:02	37.3536	-97.57007	1.4
2019-01-20 19:40:38	37.34905	-97.61725	1.6
2019-01-22 17:10:17	37.35425	-97.62146	2.2
2019-01-23 01:39:54	37.57167	-97.76158	1.7
2019-01-23 12:46:52	37.52235	-97.77142	1.6
2019-01-23 22:14:51	37.35536	-97.61736	1.4
2019-02-05 18:13:49	37.99946	-97.99119	0.6
2019-02-09 22:47:09	38.62591	-97.58125	1.9
2019-02-10 06:45:26	38.61992	-97.6007	2.3
2019-02-11 01:58:12	38.00999	-98.00016	1.4
2019-02-11 02:25:35	38.01304	-97.98222	1.9
2019-02-11 05:01:20	38.00174	-97.99576	0.9
2019-02-11 11:22:19	37.57398	-97.29246	1.4
2019-02-11 11:34:43	37.60199	-97.30696	1.0
2019-02-11 14:38:55	37.77422	-97.72559	1.0
2019-02-12 04:14:55	38.00386	-97.98818	0.0
2019-02-12 16:37:11	38.00541	-97.99506	1.2
2019-02-16 12:11:26	37.42178	-97.3808	1.3
2019-02-19 21:11:08	37.57129	-97.77303	1.4
2019-02-20 06:50:15	37.98994	-97.98137	1.2
2019-02-21 07:02:12	38.00688	-98.00407	1.9
2019-02-22 05:56:30	37.78838	-97.75261	1.3
2019-02-22 07:13:24	37.57895	-97.58499	1.3
2019-02-22 18:17:30	38.01167	-98.00489	0.2
2019-02-22 19:07:12	38.01466	-97.99031	1.7
2019-02-23 12:21:23	38.01445	-98.00026	2.5
2019-02-28 09:56:55	37.68421	-97.31015	1.2
2019-02-28 09:57:39	37.67813	-97.30951	1.2
2019-02-28 12:55:56	38.56174	-97.53454	1.4
2019-02-28 13:32:57	38.51313	-97.57944	1.1
2019-02-28 20:16:55	38.01314	-97.98861	1.9
2019-03-04 06:35:16	37.68788	-97.37019	1.3
2019-03-04 10:14:59	37.67168	-97.31549	1.6
2019-03-04 22:43:28	38.00863	-97.99236	1.5
2019-03-05 06:27:43	37.6929	-97.36845	1.1
2019-03-06 06:05:05	37.99669	-97.98591	1.2
2019-03-06 18:17:02	37.68032	-97.37424	1.9
2019-03-09 04:20:36	37.87101	-98.03558	1.7
2019-03-10 11:22:40	37.85275	-98.08903	1.2
2019-03-10 11:37:21	37.87106	-98.03886	1.6
2019-03-10 15:58:02	37.87245	-98.03087	1.7
2019-03-10 16:05:10	37.87429	-98.00941	1.4
2019-03-11 05:35:14	38.01032	-97.99574	3.2
2019-03-11 09:47:09	38.02081	-97.98683	1.8
2019-03-11 12:18:07	38.00735	-97.99329	2.3
2019-03-11 14:40:37	38.00512	-98.00154	1.8
2019-03-11 15:13:07	38.01511	-97.99073	2.1
2019-03-11 16:06:34	38.01302	-97.99883	2.0
2019-03-11 17:23:12	37.87053	-98.03539	1.6
2019-03-12 05:48:29	37.8728	-98.00847	1.4
2019-03-13 10:32:43	37.375	-97.37624	1.4
2019-03-14 07:50:05	37.68459	-97.36481	1.7
2019-03-15 20:26:40	37.87007	-98.02596	1.7
2019-03-20 06:12:12	37.67939	-97.37542	1.5
2019-03-20 10:05:33	37.65813	-97.3973	1.0
2019-03-21 06:14:39	38.01564	-98.00021	2.2
2019-03-21 06:22:01	38.02837	-97.99566	0.6
2019-03-22 22:53:36	38.01307	-97.98839	2.1
2019-03-23 19:32:13	37.5849	-97.52711	1.6
2019-03-25 03:33:20	38.0133	-97.99133	1.6
2019-04-03 09:04:00	38.009	-97.994	1.3
2019-04-08 08:46:00	37.861	-98.004	1.1
2019-04-10 14:26:00	38.599	-97.59	1.8
2019-04-12 16:30:00	38.01	-97.99	1.6
2019-04-13 20:30:00	38.009	-97.992	1.5
2019-04-13 23:39:00	38.009	-97.986	1.4
2019-04-14 10:35:33	38.07291	-98.16174	1.4
2019-04-14 18:49:00	37.661	-97.082	1.3
2019-04-15 00:47:00	37.653	-97.078	2.1
2019-04-15 00:47:10	37.646	-97.077	2.1
2019-04-15 13:02:00	37.422	-97.382	1.7
2019-04-18 12:36:00	38.569	-97.579	1.2
2019-04-20 18:49:53	37.873	-98.011	2.0
2019-04-21 11:55:00	37.579	-97.22	1.4
2019-04-21 22:50:00	37.584	-97.302	1.5
2019-04-22 02:27:00	38.014	-97.989	1.6
2019-04-22 22:04:00	38.004	-98.01	2.0
2019-04-22 22:04:46	38.012	-97.978	1.8
2019-04-22 22:06:00	38.005	-97.995	2.6
2019-04-22 22:06:53	38.022	-97.99	2.4
2019-04-25 13:58:00	37.719	-97.227	1.4
2019-04-27 01:15:00	37.715	-97.218	1.1
2019-04-27 12:28:00	38.6	-97.596	1.4
2019-04-28 07:31:00	37.506	-97.332	0.9
2019-04-28 09:51:00	37.59	-97.303	1.2
2019-05-03 06:38:00	37.498	-97.303	0.9
2019-05-06 02:52:00	38.012	-98.018	1.3
2019-05-06 06:35:00	37.692	-97.1	0.7
2019-05-07 03:30:00	37.985	-96.953	1.6
2019-05-09 19:34:00	37.654	-97.077	2.1
2019-05-09 19:34:53	37.649	-97.078	2.2
2019-05-10 02:35:23	37.639	-97.088	1.8
2019-05-10 15:24:00	38.006	-97.997	1.8
2019-05-10 15:24:10	38.008	-97.984	1.7
2019-05-12 04:39:00	37.666	-97.085	1.1
2019-05-13 06:23:00	37.411	-97.406	1.0
2019-05-19 10:12:00	37.656	-97.082	1.1
2019-05-20 10:00:00	37.652	-97.068	1.2
2019-05-20 21:58:00	37.535	-97.113	1.7
2019-05-20 22:43:00	37.7	-97.114	1.8
2019-05-21 05:24:00	37.54	-97.118	1.5
2019-05-21 06:32:00	37.622	-97.14	1.4
2019-05-21 19:41:00	37.539	-97.123	1.9
2019-05-22 04:58:00	37.541	-97.121	1.6
2019-05-22 12:21:00	37.631	-97.112	1.6
2019-05-22 14:24:00	37.541	-97.118	1.4
2019-05-22 16:54:00	37.661	-97.085	1.3
2019-05-22 20:10:00	37.53	-97.142	1.2
2019-05-26 18:46:00	37.563	-97.126	1.1
2019-05-26 18:52:00	37.538	-97.122	1.7
2019-05-28 00:15:00	37.54	-97.124	1.4
2019-05-28 07:16:00	37.566	-97.134	1.2
2019-05-28 10:32:00	37.531	-97.121	1.3
2019-05-28 10:59:00	37.536	-97.121	1.4
2019-05-30 12:31:00	37.519	-97.147	1.5

Appendix B. Continued

Origin Time (UTC)	Latitude	Longitude	Magnitude
2019-06-02 20:10:00	38.012	-98.014	1.4
2019-06-03 13:06:00	37.539	-97.127	1.4
2019-06-05 23:16:36	37.598	-99.065	2.1
2019-06-07 19:50:00	37.71	-97.181	1.1
2019-06-07 21:18:00	37.697	-97.176	1.6
2019-06-07 21:23:00	37.702	-97.178	1.3
2019-06-08 05:09:00	37.521	-97.156	1.4
2019-06-10 05:15:00	38.034	-97.688	1.3
2019-06-18 14:43:00	38.004	-98.012	1.9
2019-06-18 14:43:58	38.016	-97.989	1.8
2019-06-18 16:46:00	38.01	-97.983	1.6
2019-06-30 21:04:00	37.332	-97.428	1.5
2019-06-30 21:20:00	37.334	-97.407	1.3

Appendix C: Subnetwork Events Catalog

Subnetwork events recorded from July 1, 2018, to June 30, 2019, with epicentral distance within 12 miles of member wells. Epicentral distance is the estimated distance from the earthquake epicenter to the seismic station where it was recorded.

Station	Origin Time (UTC)	Distance (mi)	Magnitude
BU02	2018-07-01 19:51:35	5.4	0.0
BU02	2018-07-13 09:05:03	10.8	1.2
BU02	2018-08-28 20:28:28	4.8	0.1
BU02	2018-10-21 00:49:30	3.0	0.4
BU02	2018-11-23 20:23:02	11.8	0.9
BU02	2019-03-06 14:18:13	1.5	-0.4
BU02	2019-05-14 09:38:56	3.7	-0.9
EW01	2018-12-02 20:29:34	2.7	-0.6
EW01	2018-12-23 05:15:29	2.2	-0.9
MP01	2018-07-14 01:21:25	8.1	0.4
MP01	2018-07-17 11:03:31	7.7	0.4
MP01	2018-08-21 11:32:35	3.2	0.4
MP01	2018-10-21 01:32:29	3.7	-0.4
MP01	2018-12-01 07:00:10	5.1	0.0
MP01	2019-02-12 11:23:42	4.4	-0.6
MP01	2019-04-14 03:23:07	8.3	0.1
MP01	2019-06-10 10:57:04	5.9	-0.2
MP02	2018-07-04 22:55:49	5.2	0.3
MP02	2018-07-11 20:55:03	4.1	0.4
MP02	2018-07-16 14:56:04	3.0	0.0
MP02	2018-07-16 15:27:50	2.9	-0.2
MP02	2018-07-17 17:19:34	1.7	-0.2
MP02	2018-07-17 17:53:48	2.8	-0.2
MP02	2018-07-18 20:22:15	3.2	0.1
MP02	2018-08-24 02:11:11	2.5	-0.2
MP02	2018-08-31 21:00:16	1.7	-0.2
MP02	2018-09-01 02:06:22	1.4	-0.2
MP02	2018-09-02 18:35:36	4.5	0.2
MP02	2018-09-04 10:35:55	2.9	-0.4
MP02	2018-09-04 11:23:09	1.7	-0.2
MP02	2018-09-10 23:47:27	2.1	0.0
MP02	2018-09-13 22:46:22	1.8	-0.6
MP02	2018-09-13 23:18:49	4.3	0.3
MP02	2018-10-01 15:12:50	3.0	0.1
MP02	2018-10-05 22:40:42	4.7	-0.2
MP02	2018-10-21 18:42:36	2.0	-0.6
MP02	2018-11-04 09:02:00	9.2	0.3
MP02	2018-11-10 19:31:31	2.9	-0.2
MP02	2018-11-22 23:33:48	1.8	-0.6
MP02	2018-11-23 05:17:35	1.6	-0.6
MP02	2018-12-26 15:15:35	1.6	-0.6
MP02	2018-12-27 10:53:14	3.8	-0.2
MP02	2019-01-18 08:48:05	3.8	-0.6
MP02	2019-01-21 19:31:19	3.0	-0.6
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 22:57:20	4.4	-0.6
MP02	2019-04-03 00:46:22	4.9	0.6
MP02	2019-05-27 07:13:14	4.2	-0.9
RC02	2018-07-07 20:07:00	8.6	0.4
RC02	2018-07-10 03:17:25	2.2	0.1
RC02	2018-09-03 03:53:15	2.9	0.0
RC02	2018-09-30 01:42:05	3.3	0.1
RC02	2018-10-06 05:14:37	6.9	0.3
RC02	2018-12-23 23:30:52	5.0	-0.2
RC02	2019-02-01 13:38:50	1.5	-1.5
RC02	2019-04-14 12:56:54	7.1	0.0
RC02	2019-06-15 03:45:41	7.0	-0.2
RC02	2019-06-15 04:28:08	4.3	-0.2
RC02	2019-06-19 09:40:40	2.7	-0.9
RC03	2018-07-02 10:08:22	7.4	0.6
RC03	2018-07-03 18:00:53	9.7	0.6
RC03	2018-07-03 18:00:53	7.3	0.3
RC03	2018-07-09 10:36:39	7.0	0.9
RC03	2018-07-09 10:36:39	6.6	0.6
RC03	2018-07-10 02:22:46	7.8	0.8
RC03	2018-07-10 11:55:25	7.4	0.7
RC03	2018-07-10 18:19:48	7.4	1.0
RC03	2018-07-11 02:17:59	7.0	0.6
RC03	2018-07-11 02:22:13	7.0	0.5
RC03	2018-07-11 10:14:04	7.0	0.6
RC03	2018-07-11 10:19:34	8.4	0.3
RC03	2018-07-13 02:18:23	6.8	0.6
RC03	2018-07-13 02:19:39	7.2	0.5
RC03	2018-07-14 10:00:49	6.5	0.6
RC03	2018-07-17 13:18:54	4.9	0.1
RC03	2018-07-17 14:09:46	8.7	1.3
RC03	2018-07-18 02:22:43	9.2	0.6
RC03	2018-07-18 18:11:05	7.2	1.2
RC03	2018-07-19 02:17:21	7.9	0.8
RC03	2018-07-19 18:20:22	7.6	0.8
RC03	2018-07-20 10:15:53	7.2	0.8
RC03	2018-07-20 10:17:02	6.7	1.2
RC03	2018-07-21 02:24:31	7.4	0.4
RC03	2018-07-21 10:18:29	6.8	1.2
RC03	2018-07-24 02:18:47	7.4	0.4
RC03	2018-07-24 02:19:18	7.1	0.4
RC03	2018-07-24 10:10:27	7.2	0.5
RC03	2018-07-24 10:11:30	7.5	0.7
RC03	2018-07-25 10:13:23	6.7	0.8
RC03	2018-07-26 02:17:57	7.2	0.1
RC03	2018-07-26 02:18:32	7.4	0.1
RC03	2018-07-27 10:10:54	7.8	0.6
RC03	2018-07-29 02:12:11	8.0	0.8
RC03	2018-08-01 10:24:57	7.8	0.3
RC03	2018-08-01 10:26:05	7.3	0.1
RC03	2018-08-01 18:20:07	7.6	0.7
RC03	2018-08-01 18:20:47	6.7	0.4
RC03	2018-08-02 02:20:26	7.3	0.8
RC03	2018-08-02 18:23:32	7.6	0.3
RC03	2018-08-02 18:24:21	7.5	0.1
RC03	2018-08-07 10:16:27	6.5	0.4
RC03	2018-08-07 18:32:22	8.3	0.5
RC03	2018-08-07 18:32:22	7.5	0.5
RC03	2018-08-07 18:35:13	8.3	0.7
RC03	2018-08-07 18:36:06	7.6	0.4
RC03	2018-08-08 02:16:55	7.6	0.3
RC03	2018-08-08 02:17:54	7.5	0.4

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RC03	2018-08-08 02:21:32	8.1	0.3
RC03	2018-08-08 18:16:30	7.3	0.1
RC03	2018-08-08 18:17:14	8.4	0.3
RC03	2018-08-09 02:18:52	7.1	0.3
RC03	2018-08-09 02:19:40	7.3	0.4
RC03	2018-08-09 02:20:53	6.5	0.0
RC03	2018-08-10 10:12:01	7.3	0.4
RC03	2018-08-10 10:13:08	6.8	0.8
RC03	2018-08-12 01:55:08	7.2	0.3
RC03	2018-08-12 01:55:58	6.7	0.3
RC03	2018-08-14 11:42:24	2.6	0.2
RC03	2018-08-17 00:41:03	1.8	0.0
RC03	2018-08-30 02:22:21	8.0	0.8
RC03	2018-08-31 02:20:24	7.1	0.4
RC03	2018-09-01 02:16:15	7.9	0.4
RC03	2018-09-01 02:17:08	7.6	0.7
RC03	2018-09-05 02:21:13	6.8	0.7
RC03	2018-09-05 02:21:59	7.1	0.8
RC03	2018-09-06 02:17:37	7.3	0.4
RC03	2018-09-06 18:35:14	7.4	0.7
RC03	2018-09-07 18:19:25	7.1	0.8
RC03	2018-09-07 18:21:35	7.2	0.7
RC03	2018-09-08 02:17:43	7.2	0.5
RC03	2018-09-08 02:18:32	6.9	0.4
RC03	2018-09-08 18:21:47	7.3	0.7
RC03	2018-09-08 18:22:43	7.8	0.9
RC03	2018-09-10 18:09:24	7.3	0.4
RC03	2018-09-12 10:20:01	7.7	0.7
RC03	2018-09-12 18:21:54	7.0	0.3
RC03	2018-09-13 02:19:59	7.3	0.7
RC03	2018-09-13 03:58:43	7.2	0.2
RC03	2018-09-13 10:15:15	7.6	0.7
RC03	2018-09-16 02:30:57	7.3	0.5
RC03	2018-09-17 10:14:24	7.9	0.1
RC03	2018-09-17 10:14:56	7.0	0.1
RC03	2018-09-18 02:23:16	7.2	-0.2
RC03	2018-09-18 02:23:21	7.4	0.1
RC03	2018-09-18 10:14:10	7.1	0.1
RC03	2018-09-19 10:17:46	7.3	0.3
RC03	2018-09-20 10:19:15	7.2	0.1
RC03	2018-09-20 18:20:28	7.1	0.1
RC03	2018-09-20 18:21:34	7.9	0.2
RC03	2018-09-20 18:22:14	6.9	0.2
RC03	2018-09-21 10:11:15	7.6	0.0
RC03	2018-09-21 10:11:45	7.8	0.4
RC03	2018-09-22 10:07:38	6.8	0.5
RC03	2018-09-22 10:08:12	6.3	0.4
RC03	2018-09-22 10:08:33	6.7	0.2
RC03	2018-09-22 10:10:06	7.8	0.7
RC03	2018-09-22 10:11:56	7.7	0.4
RC03	2018-09-22 11:08:32	4.0	0.2
RC03	2018-09-25 10:21:55	7.2	0.4
RC03	2018-09-25 10:22:27	7.2	0.8
RC03	2018-09-25 18:21:30	7.5	0.1
RC03	2018-09-27 02:17:45	7.9	0.4
RC03	2018-09-27 09:45:04	7.2	0.4
RC03	2018-09-29 10:12:09	7.2	0.7
RC03	2018-09-29 10:13:18	7.1	1.0
RC03	2018-10-02 02:17:46	7.1	0.6
RC03	2018-10-02 10:06:44	7.5	1.0
RC03	2018-10-03 02:18:38	7.3	0.3
RC03	2018-10-03 02:20:15	8.1	-0.2
RC03	2018-10-03 18:22:14	7.2	0.4
RC03	2018-10-04 18:17:25	8.6	0.1
RC03	2018-10-04 18:17:58	7.1	0.2
RC03	2018-10-05 02:16:57	7.4	0.2
RC03	2018-10-05 17:29:05	2.0	-0.4
RC03	2018-10-06 02:14:14	7.1	0.2
RC03	2018-10-06 02:15:17	7.3	0.3
RC03	2018-10-07 07:42:51	5.2	0.2
RC03	2018-10-09 10:03:30	7.4	0.2
RC03	2018-10-10 10:23:05	6.5	0.2
RC03	2018-10-11 02:20:32	7.9	0.2
RC03	2018-10-11 02:22:49	7.7	0.4
RC03	2018-10-11 10:14:35	8.6	1.0
RC03	2018-10-12 02:18:33	7.5	0.5
RC03	2018-10-12 10:23:20	6.9	0.3
RC03	2018-10-12 10:23:43	7.7	0.4
RC03	2018-10-13 02:13:58	7.4	0.6
RC03	2018-10-13 02:22:35	7.4	0.1
RC03	2018-10-15 10:01:32	8.5	0.2
RC03	2018-10-15 10:02:01	8.7	0.2
RC03	2018-10-15 10:02:37	7.6	0.3
RC03	2018-10-15 18:22:17	6.8	0.2
RC03	2018-10-16 02:17:59	7.2	0.3
RC03	2018-10-16 02:18:13	7.4	0.2
RC03	2018-10-17 18:15:51	7.5	0.4
RC03	2018-10-18 10:18:40	7.1	0.3
RC03	2018-10-18 18:20:53	7.4	0.4
RC03	2018-10-19 09:29:35	7.7	0.3
RC03	2018-10-19 09:30:06	7.3	0.0
RC03	2018-10-20 02:17:09	7.4	0.1
RC03	2018-10-20 02:17:58	7.4	0.2
RC03	2018-10-20 18:19:14	8.0	0.4
RC03	2018-10-22 10:22:43	7.8	0.0
RC03	2018-10-22 10:23:33	7.0	0.1
RC03	2018-10-22 18:18:58	7.5	0.5
RC03	2018-10-23 10:13:57	7.0	0.2
RC03	2018-10-23 18:30:51	7.2	0.4
RC03	2018-10-23 18:35:15	7.8	0.3
RC03	2018-10-24 10:04:37	7.4	0.4
RC03	2018-10-25 10:13:10	7.8	0.1
RC03	2018-10-26 18:18:57	6.8	0.1
RC03	2018-10-27 10:06:29	9.1	0.3
RC03	2018-10-27 15:54:51	7.0	0.3
RC03	2018-10-29 10:22:04	6.9	0.3
RC03	2018-10-31 10:13:27	7.3	0.3
RC03	2018-10-31 10:13:56	6.8	0.3
RC03	2018-11-01 02:16:47	7.4	0.6
RC03	2018-11-01 10:21:06	7.5	0.5
RC03	2018-11-01 18:12:31	7.1	0.4
RC03	2018-11-02 02:20:15	7.2	0.1
RC03	2018-11-05 19:19:40	7.0	0.1
RC03	2018-11-06 03:21:53	7.5	0.3
RC03	2018-11-06 03:22:39	7.6	0.3
RC03	2018-11-06 11:14:02	8.2	0.4
RC03	2018-11-06 11:15:09	8.0	0.1
RC03	2018-11-06 19:17:50	8.2	0.2
RC03	2018-11-06 19:19:03	8.0	0.2
RC03	2018-11-07 19:24:25	7.0	0.2

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RC03	2018-11-07 19:25:23	7.2	0.1
RC03	2018-11-08 03:20:54	7.3	0.4
RC03	2018-11-08 11:26:51	7.5	0.0
RC03	2018-11-08 11:27:18	8.1	0.1
RC03	2018-11-08 19:23:04	6.6	-0.4
RC03	2018-11-08 19:23:23	6.1	0.1
RC03	2018-11-09 11:15:46	7.1	0.1
RC03	2018-11-10 03:22:12	7.2	0.1
RC03	2018-11-10 03:23:50	6.7	0.2
RC03	2018-11-10 03:29:10	7.0	0.2
RC03	2018-11-11 03:12:51	6.7	0.0
RC03	2018-11-11 03:13:44	7.3	-0.2
RC03	2018-11-11 03:13:58	7.0	0.0
RC03	2018-11-13 19:00:54	7.4	1.1
RC03	2018-11-14 19:15:18	7.2	0.0
RC03	2018-11-14 19:15:56	7.2	0.0
RC03	2018-11-14 19:16:52	7.2	0.1
RC03	2018-11-15 03:20:07	7.0	0.1
RC03	2018-11-15 03:21:05	7.3	0.1
RC03	2018-11-15 19:08:34	7.1	0.1
RC03	2018-11-15 19:09:37	6.6	0.4
RC03	2018-11-15 19:10:44	7.0	0.3
RC03	2018-11-16 11:14:17	7.6	-0.2
RC03	2018-11-16 11:14:44	7.6	0.0
RC03	2018-11-17 03:21:48	7.1	0.2
RC03	2018-11-18 21:47:58	7.2	0.1
RC03	2018-11-18 21:48:52	7.6	0.4
RC03	2018-11-20 03:15:30	7.5	0.4
RC03	2018-11-20 03:16:14	7.0	0.3
RC03	2018-11-20 19:28:50	7.3	0.0
RC03	2018-11-20 19:29:27	7.1	-0.2
RC03	2018-11-21 03:06:00	7.1	0.0
RC03	2018-11-21 03:07:34	7.2	0.4
RC03	2018-11-21 19:12:36	7.2	0.1
RC03	2018-11-21 19:13:18	6.9	0.1
RC03	2018-11-26 23:25:19	7.1	0.3
RC03	2018-11-26 23:26:32	6.7	0.0
RC03	2018-11-26 23:27:09	6.8	0.0
RC03	2018-11-27 19:21:20	6.5	-0.2
RC03	2018-11-28 03:19:34	7.3	-0.2
RC03	2018-11-28 03:21:35	7.0	0.2
RC03	2018-11-28 23:50:25	7.5	0.4
RC03	2018-11-30 03:25:19	7.4	0.2
RC03	2018-11-30 23:00:57	7.4	0.3
RC03	2018-11-30 23:01:19	7.3	0.4
RC03	2018-12-01 03:13:26	7.0	0.1
RC03	2018-12-03 23:07:08	7.6	0.4
RC03	2018-12-04 03:20:07	6.2	0.9
RC03	2018-12-04 03:21:19	7.3	1.0
RC03	2018-12-05 03:21:27	6.5	1.0
RC03	2018-12-05 23:26:16	7.7	0.2
RC03	2018-12-05 23:27:07	7.8	0.2
RC03	2018-12-05 23:28:09	7.1	-0.2
RC03	2018-12-06 03:20:08	6.9	0.1
RC03	2018-12-07 03:11:26	7.0	0.4
RC03	2018-12-07 03:12:25	7.1	0.4
RC03	2018-12-07 11:21:41	6.9	0.7
RC03	2018-12-08 11:17:21	7.1	0.0
RC03	2018-12-08 14:11:13	2.1	-0.9
RC03	2018-12-09 03:12:40	7.0	0.9
RC03	2018-12-10 11:23:12	6.8	-0.2
RC03	2018-12-10 11:23:34	6.4	-0.2
RC03	2018-12-10 11:24:14	6.9	0.9
RC03	2018-12-11 03:25:14	7.2	0.7
RC03	2018-12-11 03:27:07	6.9	0.9
RC03	2018-12-11 23:30:24	7.7	0.3
RC03	2018-12-11 23:31:19	7.5	0.1
RC03	2018-12-12 03:11:11	6.9	0.4
RC03	2018-12-12 03:12:10	7.1	0.0
RC03	2018-12-13 03:09:58	7.2	0.2
RC03	2018-12-13 03:11:15	7.1	0.2
RC03	2018-12-13 11:13:44	7.2	0.0
RC03	2018-12-13 23:26:50	7.2	-0.4
RC03	2018-12-15 00:01:07	7.4	0.3
RC03	2018-12-15 00:02:43	7.2	0.0
RC03	2018-12-17 10:23:03	7.3	0.0
RC03	2018-12-17 10:23:49	7.6	0.2
RC03	2018-12-18 03:16:18	7.6	0.0
RC03	2018-12-18 03:17:07	6.7	0.3
RC03	2018-12-18 03:17:51	6.9	0.4
RC03	2018-12-18 09:49:34	6.9	0.0
RC03	2018-12-18 09:49:34	6.5	0.2
RC03	2018-12-19 03:13:11	6.8	0.2
RC03	2018-12-19 03:14:13	6.6	0.0
RC03	2018-12-19 23:34:06	6.9	0.0
RC03	2018-12-20 03:18:29	7.1	-0.2
RC03	2018-12-20 23:35:35	7.6	0.0
RC03	2018-12-20 23:38:14	6.5	0.1
RC03	2018-12-21 07:43:27	7.1	0.4
RC03	2018-12-21 07:44:28	7.4	0.4
RC03	2018-12-21 19:17:13	7.0	0.2
RC03	2018-12-22 11:17:11	7.0	0.1
RC03	2018-12-22 11:17:48	7.2	0.3
RC03	2018-12-27 09:12:11	6.8	-0.2
RC03	2018-12-29 11:19:35	7.7	0.0
RC03	2018-12-29 19:16:50	7.1	0.4
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

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
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
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

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
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
RC03	2019-04-01 10:14:36	8.1	0.7
RC03	2019-04-01 10:14:56	6.9	1.0
RC03	2019-04-03 10:17:39	6.6	0.3
RC03	2019-04-03 10:17:57	6.8	0.2
RC03	2019-04-03 18:15:45	7.0	0.3
RC03	2019-04-03 18:17:49	7.0	0.1
RC03	2019-04-04 18:18:12	9.4	0.2
RC03	2019-04-04 18:19:06	7.7	0.1
RC03	2019-04-05 02:17:47	8.0	0.2
RC03	2019-04-05 02:18:02	7.6	0.2
RC03	2019-04-05 10:19:15	7.8	0.1
RC03	2019-04-06 10:19:11	8.2	-0.2
RC03	2019-04-06 10:19:42	6.9	0.1
RC03	2019-04-07 02:16:25	7.0	0.9
RC03	2019-04-08 18:16:10	7.2	-0.2
RC03	2019-04-08 18:17:05	8.0	-0.4
RC03	2019-04-09 02:07:26	7.5	0.3
RC03	2019-04-09 02:08:23	6.6	0.7
RC03	2019-04-10 10:19:58	7.1	0.1
RC03	2019-04-10 18:13:57	6.9	-0.2
RC03	2019-04-12 18:21:04	6.8	0.6
RC03	2019-04-13 06:11:03	6.8	0.6
RC03	2019-04-13 06:11:53	7.0	0.0
RC03	2019-04-17 10:22:54	7.1	0.2
RC03	2019-04-18 02:28:31	6.7	0.0
RC03	2019-04-23 02:18:56	6.7	0.0
RC03	2019-04-23 02:19:34	6.8	-0.2
RC03	2019-04-23 10:24:30	7.3	0.0
RC03	2019-04-23 10:25:57	6.9	0.0
RC03	2019-04-25 02:13:38	7.3	0.4
RC03	2019-04-25 02:14:05	7.2	0.0
RC03	2019-04-25 10:23:04	6.8	0.1
RC03	2019-04-28 02:19:41	7.1	0.4
RC03	2019-05-01 10:23:42	7.1	0.1
RC03	2019-05-01 18:22:37	7.0	0.2
RC03	2019-05-02 18:22:32	2.2	0.0
RC03	2019-05-03 02:19:19	7.0	-0.2
RC03	2019-05-03 02:19:46	6.9	0.0
RC03	2019-05-03 10:20:24	8.2	0.1
RC03	2019-05-04 02:20:23	7.4	0.6
RC03	2019-05-06 10:16:30	6.6	0.0
RC03	2019-05-07 02:18:45	6.6	-0.2
RC03	2019-05-07 02:19:57	7.3	-0.2
RC03	2019-05-07 16:30:43	7.6	0.1
RC03	2019-05-08 02:17:23	7.4	-0.2
RC03	2019-05-08 02:18:26	7.1	-0.4
RC03	2019-05-08 13:27:47	7.1	-0.2
RC03	2019-05-08 13:28:35	7.3	-0.2
RC03	2019-05-08 18:19:05	7.5	0.1
RC03	2019-05-10 02:18:54	7.2	-0.2
RC03	2019-05-10 02:20:43	7.8	0.0
RC03	2019-05-10 18:15:19	7.2	-0.2
RC03	2019-05-10 18:15:55	7.4	-0.2
RC03	2019-05-10 18:18:14	7.4	0.1
RC03	2019-05-13 10:23:34	7.0	-0.2
RC03	2019-05-14 10:20:32	7.2	-0.2
RC03	2019-05-15 02:15:25	7.3	-0.2
RC03	2019-05-15 02:16:11	7.7	0.0
RC03	2019-05-15 10:22:15	7.0	0.0
RC03	2019-05-16 10:22:13	7.2	-0.2
RC03	2019-05-16 10:22:47	7.4	-0.4
RC03	2019-05-17 10:26:48	7.2	-0.2
RC03	2019-05-17 10:27:36	7.2	-0.4
RC03	2019-05-20 10:25:45	4.5	0.0
RC03	2019-05-22 10:19:47	8.0	0.1
RC03	2019-05-22 10:20:16	6.8	0.0
RC03	2019-05-23 10:18:46	8.4	0.0
RC03	2019-05-24 02:14:16	7.6	-0.4
RC03	2019-05-24 10:19:38	7.0	0.0
RC03	2019-05-27 06:02:59	6.4	-0.4
RC03	2019-05-30 10:11:42	7.6	-0.2
RC03	2019-05-30 10:12:15	6.9	-0.4
RC03	2019-05-31 02:04:18	8.0	0.0
RC03	2019-06-01 10:18:10	6.8	-0.2
RC03	2019-06-01 10:18:09	7.3	-0.4
RC03	2019-06-01 10:18:20	7.2	0.0
RC03	2019-06-01 10:18:20	6.8	-0.4
RC03	2019-06-02 02:10:01	7.3	-0.2
RC03	2019-06-02 02:10:22	7.9	-0.2
RC03	2019-06-02 02:10:46	7.1	-0.2
RC03	2019-06-02 02:11:16	7.5	-0.2
RC03	2019-06-03 10:18:13	7.2	-0.2
RC03	2019-06-05 10:15:08	7.3	-0.4
RC03	2019-06-05 10:15:36	6.7	-0.2
RC03	2019-06-06 02:17:51	7.0	-0.2
RC03	2019-06-06 02:18:21	7.6	0.0
RC03	2019-06-06 02:18:52	7.1	0.0
RC03	2019-06-07 18:14:08	7.2	-0.2
RC03	2019-06-07 18:14:25	7.3	0.0
RC03	2019-06-07 18:18:08	7.1	-0.2
RC03	2019-06-10 10:19:53	6.4	0.3
RC03	2019-06-11 02:24:42	7.1	0.0
RC03	2019-06-11 10:22:14	6.9	-0.4
RC03	2019-06-11 10:22:22	6.9	-0.2
RC03	2019-06-11 10:22:50	7.1	0.0
RC03	2019-06-12 09:07:48	7.1	0.1
RC03	2019-06-12 10:14:39	7.4	0.0
RC03	2019-06-12 10:14:46	7.1	-0.4
RC03	2019-06-13 02:08:32	7.3	0.0
RC03	2019-06-13 02:09:03	7.4	0.0
RC03	2019-06-13 10:17:07	7.2	-0.2
RC03	2019-06-13 10:17:41	7.2	0.0
RC03	2019-06-13 18:14:53	7.4	-0.2
RC03	2019-06-13 18:15:02	7.2	-0.2
RC03	2019-06-14 02:12:30	6.8	0.0
RC03	2019-06-14 02:13:27	7.0	0.0
RC03	2019-06-18 02:09:08	6.9	0.0
RC03	2019-06-18 10:16:15	7.2	-0.4
RC03	2019-06-18 18:12:13	7.5	-0.6
RC03	2019-06-18 18:12:20	6.7	-0.4

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RC03	2019-06-19 10:11:40	7.3	0.1
RC03	2019-06-19 10:12:17	8.9	-0.2
RC03	2019-06-20 02:06:52	6.9	-0.2
RC03	2019-06-20 10:20:15	4.7	-0.4
RC03	2019-06-20 10:20:22	7.2	-0.4
RC03	2019-06-21 02:05:39	6.9	-0.2
RC03	2019-06-21 02:06:13	7.2	-0.4
RC03	2019-06-21 02:06:21	7.1	-0.4
RC03	2019-06-22 02:16:57	7.4	-0.2
RC03	2019-06-22 18:10:31	7.6	0.1
RC03	2019-06-22 18:11:23	7.1	0.1
RC03	2019-06-25 02:21:12	6.4	-0.2
RC03	2019-06-26 02:18:45	7.1	-0.2
RC03	2019-06-26 10:07:10	7.1	-0.4
RC03	2019-06-26 10:07:36	7.1	-0.4
RC03	2019-06-26 10:19:30	6.7	-0.2
RC03	2019-06-27 02:20:37	7.4	-0.2
RC03	2019-06-27 02:21:12	7.3	0.0
RN01	2018-07-01 19:23:38	5.3	0.5
RN01	2018-07-02 08:02:49	4.9	0.1
RN01	2018-07-03 09:47:53	5.5	0.7
RN01	2018-07-07 02:16:21	4.9	0.2
RN01	2018-07-08 03:06:29	4.9	0.0
RN01	2018-07-08 05:49:17	5.0	-0.2
RN01	2018-07-08 06:57:49	4.8	0.3
RN01	2018-07-08 12:40:51	5.0	0.0
RN01	2018-07-08 12:42:06	5.1	0.4
RN01	2018-07-08 12:44:28	4.9	0.1
RN01	2018-07-08 14:02:17	5.0	0.3
RN01	2018-07-08 19:04:24	5.2	1.0
RN01	2018-07-08 21:11:33	5.3	0.0
RN01	2018-07-10 07:02:25	5.1	0.1
RN01	2018-07-10 08:15:04	3.3	0.2
RN01	2018-07-10 08:49:38	4.8	0.4
RN01	2018-07-10 11:04:45	4.9	0.2
RN01	2018-07-11 01:37:34	4.9	0.1
RN01	2018-07-11 01:44:16	4.9	0.3
RN01	2018-07-11 02:05:33	4.9	0.1
RN01	2018-07-11 02:05:59	4.8	0.3
RN01	2018-07-11 03:46:45	4.9	0.2
RN01	2018-07-11 05:20:58	4.7	0.4
RN01	2018-07-11 08:33:39	4.8	0.6
RN01	2018-07-11 08:46:21	4.9	0.4
RN01	2018-07-12 22:11:08	2.2	0.2
RN01	2018-07-13 06:44:50	4.8	0.4
RN01	2018-07-13 22:35:43	5.0	0.6
RN01	2018-07-14 06:31:50	7.7	1.3
RN01	2018-07-14 15:42:08	5.1	0.6
RN01	2018-07-14 19:24:22	5.5	0.2
RN01	2018-07-16 03:25:40	4.5	0.0
RN01	2018-07-16 08:57:36	5.5	0.2
RN01	2018-07-16 18:42:13	5.3	0.3
RN01	2018-07-17 04:03:54	5.2	0.1
RN01	2018-07-17 04:33:58	4.9	0.2
RN01	2018-07-17 05:31:43	5.1	0.3
RN01	2018-07-17 05:33:38	5.0	0.2
RN01	2018-07-18 12:08:22	4.6	0.1
RN01	2018-07-19 07:36:58	2.2	0.1
RN01	2018-07-19 22:36:40	1.8	0.0
RN01	2018-07-19 22:36:40	2.0	-0.2

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RN01	2018-07-20 05:23:19	5.0	0.0
RN01	2018-07-20 09:47:19	4.9	0.0
RN01	2018-07-20 10:38:03	4.4	0.1
RN01	2018-07-22 06:56:51	5.1	0.6
RN01	2018-07-22 18:13:57	4.7	-0.2
RN01	2018-07-23 08:58:43	6.1	0.3
RN01	2018-07-24 01:00:13	1.4	-0.9
RN01	2018-07-24 10:12:05	5.7	-0.2
RN01	2018-07-24 13:20:59	4.9	0.5
RN01	2018-07-25 18:27:50	5.2	0.7
RN01	2018-07-25 20:35:37	5.2	0.9
RN01	2018-07-26 02:26:42	4.8	0.7
RN01	2018-07-26 03:52:29	4.6	0.6
RN01	2018-07-26 05:00:29	4.9	0.6
RN01	2018-07-27 05:16:48	5.2	0.2
RN01	2018-07-27 21:48:51	4.6	0.2
RN01	2018-07-27 23:08:48	3.8	0.4
RN01	2018-07-28 18:13:35	4.8	0.0
RN01	2018-07-29 03:54:52	5.4	0.6
RN01	2018-07-30 00:04:31	5.0	0.5
RN01	2018-07-31 18:10:56	4.9	0.4
RN01	2018-08-01 06:51:11	5.0	0.3
RN01	2018-08-01 10:07:28	4.9	0.6
RN01	2018-08-01 11:16:20	4.6	0.2
RN01	2018-08-01 14:30:58	5.2	0.1
RN01	2018-08-02 20:24:54	2.5	0.4
RN01	2018-08-03 04:53:05	5.0	0.4
RN01	2018-08-03 09:37:18	5.1	0.1
RN01	2018-08-03 13:03:29	4.7	0.2
RN01	2018-08-04 00:42:11	5.2	0.3
RN01	2018-08-04 01:18:31	4.9	0.7
RN01	2018-08-04 09:54:22	5.4	0.2
RN01	2018-08-04 11:13:04	5.1	0.0
RN01	2018-08-05 01:45:00	5.0	0.2
RN01	2018-08-05 09:47:26	3.9	0.4
RN01	2018-08-05 12:08:36	5.3	0.4
RN01	2018-08-06 08:31:32	5.7	0.4
RN01	2018-08-06 19:04:13	6.9	0.7
RN01	2018-08-06 23:11:40	5.1	0.1
RN01	2018-08-07 04:06:12	4.7	-0.2
RN01	2018-08-08 09:20:58	4.7	0.0
RN01	2018-08-08 16:03:18	4.9	0.2
RN01	2018-08-09 01:17:53	5.3	0.0
RN01	2018-08-09 04:49:15	4.8	0.6
RN01	2018-08-10 04:54:21	4.3	0.0
RN01	2018-08-10 14:27:45	4.7	0.1
RN01	2018-08-11 01:55:02	4.7	0.2
RN01	2018-08-14 07:16:32	5.1	0.4
RN01	2018-08-14 07:22:11	5.2	0.0
RN01	2018-08-14 17:18:19	4.8	0.2
RN01	2018-08-15 02:02:39	5.0	0.4
RN01	2018-08-15 07:01:24	5.1	0.2
RN01	2018-08-16 18:28:32	4.8	0.0
RN01	2018-08-16 19:46:46	5.1	0.2
RN01	2018-08-17 04:55:46	5.0	0.4
RN01	2018-08-17 23:31:10	4.7	-0.2
RN01	2018-08-18 05:24:12	4.9	0.4
RN01	2018-08-19 04:10:12	5.1	0.0
RN01	2018-08-22 13:53:48	6.0	0.6
RN01	2018-08-23 03:00:04	5.4	0.4

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RN01	2018-08-23 07:04:41	4.7	0.2
RN01	2018-08-23 14:47:17	5.2	0.9
RN01	2018-08-23 14:47:17	5.3	0.9
RN01	2018-08-23 14:57:13	4.5	0.1
RN01	2018-08-23 14:57:46	5.1	0.0
RN01	2018-08-23 15:10:54	5.3	0.4
RN01	2018-08-23 16:46:15	5.2	-0.2
RN01	2018-08-23 16:58:28	5.2	0.2
RN01	2018-08-24 01:49:31	5.3	0.2
RN01	2018-08-25 11:32:26	5.5	0.2
RN01	2018-08-25 19:01:56	4.5	0.2
RN01	2018-08-25 23:44:42	2.1	-0.2
RN01	2018-08-26 20:14:07	4.9	0.3
RN01	2018-08-26 22:59:26	5.9	0.8
RN01	2018-08-27 23:45:58	2.0	-0.2
RN01	2018-08-28 22:11:41	2.2	0.4
RN01	2018-08-29 09:49:29	2.9	0.2
RN01	2018-08-30 02:58:11	4.9	0.4
RN01	2018-09-03 20:04:17	10.6	1.0
RN01	2018-09-05 05:10:53	4.3	0.5
RN01	2018-09-05 07:13:01	6.3	0.3
RN01	2018-09-07 04:21:09	4.9	0.7
RN01	2018-09-13 13:18:11	5.0	0.9
RN01	2018-09-16 09:27:45	1.4	-0.4
RN01	2018-09-17 20:45:39	5.0	0.2
RN01	2018-09-18 00:19:25	4.5	0.1
RN01	2018-09-18 01:53:52	5.4	0.1
RN01	2018-09-18 02:03:10	4.7	0.0
RN01	2018-09-18 02:09:03	4.8	-0.2
RN01	2018-09-18 05:17:20	2.6	-0.4
RN01	2018-09-21 06:21:48	1.5	-0.6
RN01	2018-09-21 06:26:26	6.0	-0.4
RN01	2018-09-25 04:06:06	2.0	0.1
RN01	2018-09-26 11:40:49	3.7	0.2
RN01	2018-09-26 21:20:46	1.9	-0.6
RN01	2018-09-30 19:30:02	5.0	0.1
RN01	2018-10-02 03:51:05	5.3	0.2
RN01	2018-10-02 10:59:40	4.9	-0.6
RN01	2018-10-03 11:51:11	5.0	0.0
RN01	2018-10-04 02:26:30	2.6	-0.2
RN01	2018-10-04 22:40:56	5.1	0.3
RN01	2018-10-05 13:22:43	4.9	0.1
RN01	2018-10-05 13:22:43	4.8	0.2
RN01	2018-10-05 13:24:50	4.8	0.2
RN01	2018-10-05 18:30:18	4.9	-0.2
RN01	2018-10-08 21:21:57	4.9	0.5
RN01	2018-10-09 16:04:00	4.9	0.2
RN01	2018-10-11 11:04:44	4.8	0.4
RN01	2018-10-11 15:02:30	5.7	0.1
RN01	2018-10-13 00:42:46	4.9	0.3
RN01	2018-10-13 04:00:15	5.1	0.9
RN01	2018-10-13 04:01:04	4.9	0.5
RN01	2018-10-16 21:40:01	4.8	0.2
RN01	2018-10-22 06:39:37	4.7	0.0
RN01	2018-10-24 03:25:13	5.0	0.3
RN01	2018-10-25 00:15:07	4.8	0.0
RN01	2018-10-29 12:03:53	5.2	0.3
RN01	2018-10-30 16:11:57	4.8	0.0
RN01	2018-10-31 09:05:40	5.0	0.3
RN01	2018-10-31 20:08:28	5.1	-0.2
RN01	2018-11-03 04:27:06	4.6	0.1
RN01	2018-11-04 03:12:17	5.1	-0.2
RN01	2018-11-04 23:31:54	4.7	-0.2
RN01	2018-11-06 02:32:57	4.8	-0.4
RN01	2018-11-13 07:12:04	4.9	0.0
RN01	2018-11-18 06:03:56	4.4	-0.2
RN01	2018-11-19 13:43:25	5.0	0.1
RN01	2018-11-20 07:38:29	4.8	-0.2
RN01	2018-11-23 10:32:18	4.9	-0.2
RN01	2018-11-24 09:20:23	4.9	0.0
RN01	2018-11-24 15:43:31	4.5	0.1
RN01	2018-11-28 00:19:01	5.0	-0.2
RN01	2018-11-29 07:30:23	5.6	-0.2
RN01	2018-12-02 10:50:43	4.9	-0.2
RN01	2018-12-03 09:40:27	1.9	-0.4
RN01	2018-12-05 02:39:13	4.9	0.1
RN01	2018-12-06 10:21:40	4.3	-0.4
RN01	2018-12-06 22:03:45	4.8	0.2
RN01	2018-12-08 07:44:28	5.0	-0.4
RN01	2018-12-08 09:22:48	5.2	0.0
RN01	2018-12-10 01:31:55	4.6	0.0
RN01	2018-12-10 16:10:01	5.2	-0.2
RN01	2018-12-12 00:18:27	4.9	-0.2
RN01	2018-12-12 01:17:32	5.5	-0.2
RN01	2018-12-12 06:55:01	4.8	-0.4
RN01	2018-12-12 20:42:12	5.2	0.1
RN01	2018-12-12 23:07:10	4.7	0.0
RN01	2018-12-13 20:35:50	4.8	-0.4
RN01	2018-12-14 04:21:07	5.0	-0.4
RN01	2018-12-16 08:15:21	4.7	0.0
RN01	2018-12-20 23:50:56	4.6	0.0
RN01	2018-12-21 01:28:54	4.8	-0.4
RN01	2018-12-21 08:40:19	2.7	-0.9
RN01	2018-12-22 22:37:30	4.8	-0.4
RN01	2018-12-23 03:05:44	4.7	0.0
RN01	2018-12-25 01:21:13	3.4	-0.4
RN01	2018-12-26 10:17:21	4.5	-0.4
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

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
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
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
RN01	2019-04-01 01:07:31	4.8	0.0
RN01	2019-04-01 01:07:32	4.9	-0.4
RN01	2019-04-04 13:35:27	4.7	-0.2
RN01	2019-04-04 17:36:48	6.9	0.0
RN01	2019-04-09 08:23:45	11.8	0.2
RN01	2019-04-09 09:19:46	4.7	0.0
RN01	2019-04-12 16:41:04	5.1	-0.4
RN01	2019-04-12 20:15:49	5.0	0.2
RN01	2019-04-13 08:00:30	4.7	-0.6
RN01	2019-04-15 02:28:29	4.6	-0.4
RN01	2019-04-17 21:19:35	5.3	-0.4
RN01	2019-04-22 02:44:34	5.0	-0.4
RN01	2019-04-22 11:58:52	4.9	-0.6
RN01	2019-04-22 11:59:00	4.9	-0.6
RN01	2019-04-22 11:59:10	4.9	-0.6
RN01	2019-04-22 11:59:20	5.0	-0.4
RN01	2019-04-22 14:03:10	4.8	0.0
RN01	2019-04-22 15:05:18	4.9	-0.6
RN01	2019-04-22 22:14:12	4.8	-0.4
RN01	2019-04-23 08:35:46	4.9	-0.2
RN01	2019-04-23 11:57:38	5.0	0.0
RN01	2019-04-23 18:21:41	4.8	-0.4
RN01	2019-04-23 20:33:35	5.0	-0.2
RN01	2019-04-23 22:55:12	5.0	-0.6
RN01	2019-04-24 03:58:49	4.8	-0.4
RN01	2019-04-24 06:04:17	4.9	-0.4
RN01	2019-04-24 11:36:44	4.9	-0.4
RN01	2019-05-02 22:20:33	5.1	-0.4
RN01	2019-05-06 06:00:06	5.0	-0.6
RN01	2019-05-10 15:38:05	4.7	-0.4
RN01	2019-05-11 02:24:12	4.9	-0.2
RN01	2019-05-24 15:51:04	4.7	0.1
RN01	2019-05-24 16:47:50	4.7	-0.4
RN01	2019-05-24 17:16:14	5.2	-0.4
RN01	2019-05-27 02:41:15	4.9	-0.6
RN01	2019-06-03 00:29:02	4.7	-0.2
RN01	2019-06-10 15:25:53	8.3	0.1
RN01	2019-06-10 15:25:53	11.3	0.1
RN01	2019-06-14 06:48:30	4.0	-0.6
RN01	2019-06-15 22:29:26	4.8	-0.6
RN01	2019-06-17 08:11:15	5.0	-0.4
RN01	2019-06-18 11:30:35	5.0	-0.4
RN01	2019-06-18 11:36:55	5.1	-0.6
RN01	2019-06-18 21:22:53	5.2	-0.6
RN01	2019-06-19 02:40:11	2.8	-0.9
RN01	2019-06-23 09:28:30	6.3	-0.2
RN01	2019-06-25 22:36:58	4.8	-0.4
RN02	2018-07-04 05:50:12	9.3	0.1
RN02	2018-07-07 04:58:23	8.6	0.5
RN02	2018-07-10 04:54:02	8.5	0.5
RN02	2018-07-10 04:57:02	8.6	0.3
RN02	2018-07-10 05:00:19	8.7	0.4
RN02	2018-07-11 05:08:38	6.5	0.8
RN02	2018-07-11 05:37:10	7.5	0.2
RN02	2018-07-11 05:41:39	8.5	0.1
RN02	2018-07-24 02:13:30	11.8	0.6
RN02	2018-08-16 00:32:57	7.4	0.3
RN02	2018-09-18 06:30:57	7.8	0.0
RN02	2018-09-18 06:31:46	8.5	0.4
RN02	2018-09-18 06:32:38	9.7	0.1
RN02	2018-09-29 23:13:37	7.6	0.7
RN02	2018-09-30 06:29:57	8.5	0.1
RN02	2018-09-30 06:30:13	8.6	0.2
RN02	2018-10-02 06:58:16	8.2	0.1
RN02	2018-10-09 03:37:21	7.5	1.0
RN02	2018-10-16 06:55:51	8.9	0
RN02	2018-10-18 06:40:49	8.8	0.4
RN02	2018-10-19 06:24:33	8.2	0.3
RN02	2018-10-20 06:08:23	9.5	0.0

Appendix C. Continued

Station	Origin Time (UTC)	Distance (mi)	Magnitude
RN02	2018-10-20 06:08:23	2.3	-0.4
RN02	2018-10-23 06:11:55	8.9	0.0
RN02	2018-10-25 06:50:28	8.2	0.1
RN02	2018-10-26 06:47:27	8.8	0.2
RN02	2018-10-31 11:06:30	1.9	-0.9
RN02	2018-11-02 07:23:02	8.3	0.1
RN02	2018-11-03 07:20:05	9.2	0.1
RN02	2018-11-13 13:04:43	3.5	-0.6
RN02	2018-12-01 05:43:09	3.6	-0.4
RN02	2018-12-01 08:47:07	9.0	0.0
RN02	2018-12-05 19:20:05	5.5	0.0
RN02	2018-12-05 21:16:38	1.7	-0.9
RN02	2018-12-10 06:42:12	8.2	-0.2
RN02	2018-12-10 06:43:18	9.3	0.0
RN02	2018-12-15 07:08:56	9.0	0.0
RN02	2018-12-15 07:10:11	7.9	0.0
RN02	2018-12-15 07:11:28	8.0	0.1
RN02	2018-12-15 07:12:24	7.5	0.0
RN02	2018-12-15 07:13:32	9.4	0.0
RN02	2018-12-18 00:49:07	10.1	0.4
RN02	2018-12-26 01:39:15	4.0	-0.4
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
RN02	2019-04-26 06:11:11	9.1	0.0
RN02	2019-04-26 06:12:44	7.6	0.2
RN02	2019-04-26 06:13:09	8.4	-0.2
RN02	2019-04-26 06:13:09	7.7	-0.2
RN02	2019-04-26 06:15:01	8.7	-0.4
RN02	2019-04-26 06:16:16	8.0	-0.2
RN02	2019-04-26 06:17:14	7.3	0.1
SG02	2018-07-10 09:09:07	3.1	-0.6
SG02	2018-08-28 09:20:26	5.3	0.1
SG02	2018-08-28 09:23:21	5.1	0.2
SG02	2018-09-06 14:57:26	8.0	0.4
SG02	2018-12-28 03:40:30	4.2	-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
SG02	2019-04-08 03:03:21	9.5	0.6
SG02	2019-04-15 07:59:35	8.2	-0.2
SG02	2019-04-28 07:12:28	6.0	0.3
SG02	2019-04-28 07:49:23	6.1	0.0
SG02	2019-05-03 08:36:26	9.9	0.1
SG02	2019-05-07 12:27:27	9.0	0.0
SG02	2019-05-11 05:27:26	2.9	-0.6
SG02	2019-05-14 04:11:23	3.0	-0.6
SG02	2019-05-21 07:09:45	4.6	-0.6
SG02	2019-05-28 13:40:50	3.1	-1.5
SG02	2019-06-11 09:46:11	6.2	-0.4
SG02	2019-06-27 08:47:21	6.5	-0.4
SG02	2019-06-28 05:18:43	6.3	-0.2