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Effects on Geothermal Features Following the February 21, 2008 Wells, Nevada Earthquake

by

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ABSTRACT

Following the February 21, 2008 magnitude 6.0 earthquake near Wells, Nevada, we received reports of temporary temperature increases of thermal wells in the City of Wells. The increases were reported to be in the neighborhood of 9^{o}C. Temporary reduction in clarity of the wells was also reported primarily in the form of iron oxides. The function of several domestic wells was also lost. Changes in water quality, level, flow rate and temperature of wells and springs as a result of earthquakes are well documented (Huang and others, 1999; Yaltirak and others, 2005; Sneed et al, 2005 and others). These changes can occur both before and after an earthquake, and some effects can be noticed great distances from an epicenter. Thermal features in the Wells area consist of warm and hot springs associated with a normal range-bounding fault on the west side of the Snake Mountains approximately 12 km west of the epicenter of the February earthquake, and warm wells in the City of Wells approximately 9 km west of the epicenter. Several hot and warm springs, and wells were visited both one month and again eight months after the February earthquake. A mudslide near one of the hot spring sites appears to have occurred coincident with the earthquake, and a change in the nature of the flow of seeps or springs at this site is suspected. The elapsed time interval of 4 weeks between the earthquake and the time wells and springs were visited appears to have allowed temperatures and chemistry to return to a state similar to that preceding the earthquake, based on available historic data. However, more time may be required for deep aquifers to respond to changes caused by the February 2008 earthquake.

Wells Nevada Geothermal Features

Hot and warm springs are found at several locations in the Wells area, most of which are located approximately 12 km west of the earthquake epicenter (figure 1). From south to north the prominent hot springs are as follows: Threemile (Sulphur) Spring (W5), a group of springs marked by travertine mounds (W6), and a slump and mudslide feature approximately 2 km north of Threemile Spring (W7). Other features which were not active or were inaccessible include these: unnamed springs located 1.7 km south of Threemile Spring; and Twelvemile Spring located 9.5 km north of Threemile Spring, along Bishop Creek. The unnamed springs 1.7 km south of Threemile Spring were found to be largely dried up. The southernmost of these three springs appears to have been the most dominant, and consists of a bowl-shaped sapping feature in the hillside. The soil was locally damp and there was evidence of periodic flow, but no evidence to indicate that it was likely flowing immediately before the earthquake. Twelvemile Spring was not visited because of snow blocking the road. The hot springs in the Wells area are typical of thermal features in the Great Basin region, occurring near or along range-front faults. The springs are controlled by Late Quaternary normal faults along the western side of the Snake Mountains (figure 1). Faults related to springs offset Tertiary sedimentary and volcaniclastic rocks in the area of Threemile Spring at the south end of the spring trend and Mesozoic sedimentary rocks at Twelvemile Spring to the north. There are several warm wells in the City of Wells that are or have been used for residential, district, and commercial heating. The locations of three currently operating warm wells that were visited are shown in figure 1. Jewell and others (1994) describes the hydrology of thermal waters in the Wells area and suggests that while hot springs are fault controlled, warm wells in the City of Wells are dominantly supplied by upward movement of thermal waters in the porous sedimentary units of the Humboldt Formation. A shift in oil well temperature logs indicates that the upwardly migrating thermal waters mix with cold shallow waters (Jewell and others, 1994).

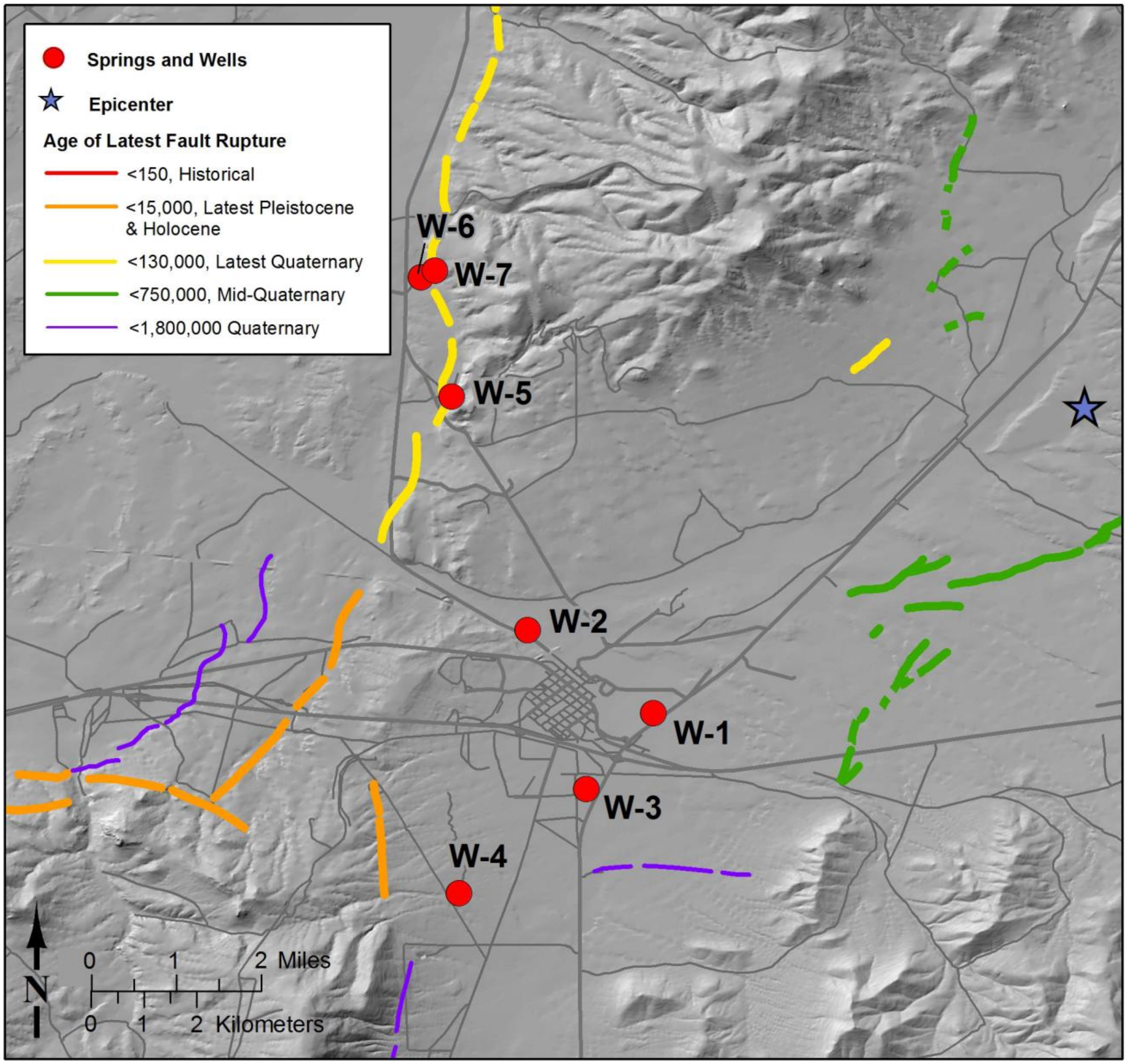

Figure 1. Map of the Wells, Nevada area showing locations of springs and wells sampled, the epicenter of the magnitude 6 earthquake of Feburary 12, 2008, and Quaternary faults (dePolo, 2008). The labeled spring and well locations are as follows: W-1: BTI Transloaders Well; W-2: Reynolds Ranch house well; W-3: Ray Reynolds well; W-4: Warm spring; W-5: Threemile Spring; W-6: Unnamed hot springs; and W-7: Mudslide area with warm springs.

The Wells, Nevada area was visited between March 26 and 27, 2008, approximately one month following the earthquake, and again on November 11, 2008. In March, three domestic and commercial warm wells in the City of Wells were visited and sampled. Three warm and hot spring areas west of the City of Wells in an area on the southwest side of the Snake Mountains were visited along with one warm spring south of the City of Wells (figure 1). A small recent mudslide was noted near one of mapped hot spring locations. All locations were revisited again during November, and two sites were selected and resampled at that time.

March 25 to 27, 2008 Visit

Well Samples

W-1: Warm well (32.8°C) at BTI (Bonneville Transloaders Inc.) used for heating and supplying water for a truck wash. The well reportedly experienced reduced clarity after the earthquake. Reduced clarity is most pronounced if the well is allowed to rest, and then pumped. Allowing the well to flow at a low volume improves the water clarity. At the time of sampling the clarity was said to be somewhat reduced.

W-2: Reynolds Ranch well. Warm (40.6°C) well used for heating and domestic and agricultural purposes. The well reportedly experienced a temperature increase of approximately 9 °C and reduced clarity following the earthquake. Clarity was good at the time of sampling.

W-3: Warm well at the house of Ray Reynolds (28.6°C). This is a domestic well that is used to supply several of the neighboring properties. The well reportedly experienced a temperature increase of approximately 9 °C and reduced clarity, similar to W-2, but had returned to normal conditions at the time of sampling.

Warm and Hot Spring Samples

W-4: Warm spring south of the City of Wells (19.3°C). The spring is located on the north side of a dirt road. A broken-off pipe near the spring suggests it may be an abandoned well. Flow rate is approximately 5 *l*/min.

W-5: Threemile Spring (Sulphur Spring). A number of small springs and seeps are present in this area, mostly south of the main spring. The main spring occurs at the base of a small cliff where the outflow has been dammed to form a 2- by 10-meter pool. The primary influx point into the pool is below the water level of the pool from an open fracture. Temperature measured in the inflow zone was 36.6 °C. Flow rate is approximately 180 *l*/min. A data logger was submerged in the inflow zone and set to log temperature once an hour.

W-6: Warm and hot springs marked by travertine mounds. Small springs in the travertine mounds have very low flow rates and high gas content. Temperatures of the small springs are in the 50 °C to 60 °C range. The main flow of the spring system is below the prominent travertine outcrop, in a grassy area. Temperature of the main flow is lower than the travertine springs at 48.7 °C. The main flow rate is approximately 40 *l*/min.

W-7: A series of warm springs approximately 200 meters northeast of the travertine springs mentioned above. A small mudslide (figures 2 and 3) recently occurred here exposing numerous springs in the scarp. It is uncertain if these springs are new or a better exposure of existing springs. The scarp is approximately 50 meters long and dips approximately 45° to the west. Debris extends approximately 70 meters downslope with mud in the drainage axis extending an additional 70 meters. Iron staining is present around the spring orifices and outflow zones of the scarp face. Spring temperatures are approximately 34 °C, and the flow rate is approximately 40 *l*/min. The lack of grass in the wet areas and the presence of arid-climate vegetation, such as sage and grass, only on displaced debris blocks, as well as the lack of algae around the spring orifices and outflows, suggest a recent nature to the feature. Although there is evidence of recent activity here, satellite and air photo images indicate there were likely seeps or a sapping feature in this location prior to the earthquake.

An attempt was made to visit some of the cold springs near the epicenter, however most were inaccessible due to snow and mud. The temperature of one spring, feeding a stock watering pond, 5 km north of the earthquake epicenter on the east side of U.S Highway 95 was measured and was below 10 °C. Since this was a cold spring and located in a drainage with melting snow in the upper reaches, no sample was collected.

Data for the samples collected along with historic data from some of the same locations are listed in table 1. Although the historic data are from approximately the same location, more than one spring or well are present at some of the locations, thus samples may be from a different spring or well that is in close proximity.

Figure 2. View looking east at the mudslide on the west side of the Snake Mountains. The scarp strikes roughly north-south for approximately 50 meters, and debris and mud extend for approximately 140 meters below the scarp. Warm springs issue from the foot of the scarp.

Figure 3. Views along mudslide scarp slide looking south. Left view is from March 2008, and right view is from November 2008 showing growth of cattails and algae. Scarp height is approximately 4 meters and length is approximately 50 meters. Numerous small springs and seeps issue from argillically altered rock in the scarp face and several springs percolate up through the mud at the toe of the scarp. The images show a significant change in vegetation from March to November. The lack of dead cattails and grass, and the absence of algae in the warm spring waters suggest the recent nature of the mudslide.

November 11, 2008 Visit

The sites visited in November appear to have experienced no significant changes since the March visit with the exception of some minor changes at the mudslide area. Communications with BTI personnel indicated that they had not seen a significant temperature change. At the time of the November visit, BTI was using the well for supplying the truck wash but not for heating purposes yet. The temperature of the Reynolds Ranch well was similar to the temperature measured in March, 2008. Water chemistry for water samples collected from the Reynolds Ranch well in March and November are also similar (table 1). Data from the data logger placed in Threemile Spring indicate a gradual increase of 1.6^{o}C between March and November with no temperature excursions. This gradual increase in temperature is most likely due to seasonal shift. The water discharge rate at the mudslide area is similar to the rate in March, but the temperature of springs at the mudslide area appears to have increased by approximately 15 ^{o}C. However, temperature measurements and samples were collected from different orifices than in March due to difficulties with access (deep mud at the scarp face). Geothermometer temperatures are also higher for the samples collected in November than for March, and there is a significant disagreement between the silica and cation geothermometers for both the March and November samples. The iron concentration has decreased by a factor of approximately 7 from March to November, and minor changes in other element concentrations have occurred (table 1). Gas bubbling can be seen in several of the spring orifices and is at a rate of several liters per minute, based on the size and rate of bubbling. Gas was less apparent in March, but may have been because of the general lack of pools to observe bubbling in at the toe of the scarp. Significant changes in vegetation have also occurred at the mudslide area (figure 3). Spring orifices are marked by green algae and cattails have vegetated some areas at the scarp. Cattails were also noted sprouting down gradient of the scarp in the mud flow area; as with the scarp area, no cattails were noted in this area during the first visit in March. Some minor additional sloughing has also occurred at the scarp.

CONCLUSIONS

Following the 2008 Wells, Nevada earthquake, a number of wells in the area were lost, most likely due to breakage of casings in the bore holes. Initially, temperatures of several wells in the City of Wells were reported to have increased up to 9 ^{o}C, but decreased to pre-earthquake levels in the weeks after the earthquake. Clarity was also reduced temporarily following the earthquake, likely due to descaling of iron oxides from well casings and pipes from the shaking. These are largely normal responses to earthquake activity. In general, the long-term temperature and chemistry of geothermal features in the Wells area appear similar to historical data, but comparison is difficult because precise location of historic samples is uncertain. Although collected from the same general area, different wells or springs may have been sampled. A recent mudslide noted at a warm spring area was likely triggered by earthquake activity. Although evidence indicated recent movement in this area, air photos taken prior to the earthquake indicate a slide or sapping feature was here previously. The noticeable change in vegetation suggests that flow of previous springs may have increased, or that surface versus subsurface flow may have shifted due to unearthing of spring orifices. The change in iron concentrations and the disequilibrium in geothermometer temperatures between March and November may indicate some hydrologic changes at the mudslide area, to which the system has not yet equilibrated. Between March and November, iron concentrations decreased by a factor of 7. However these differences could be related to collection from different spring orifices. The March sample was collected from an orifice issuing from the scarp face, whereas the November sample was collected from a spring in the sediment toe of the scarp. Reaction of the water with sediments in the spring could easily account for the minor differences in elements such as Ca, Mg, and K for the November sample with respect to the March sample. The higher iron concentrations observed in the March sample, however, are suspected be related to oxidation of pyrite in fluid pathways of the freshly exposed scarp face, which are more likely to be exposed to atmospheric oxygen than fluid pathways feeding springs in the sediments at the toe of the scarp. The presence of iron staining in the scarp face, but not in springs at the toe of the scarp, is consistent with this. If the mudslide merely altered the area from a sapping feature to exposed spring orifices in the scarp face, it may have concentrated the outflow over a smaller area, causing lower resistance to flow in the scarp face than in areas where soil covers the bedrock. The subsequent increase in flow locally could result in an increase in measured temperature. Alternatively mixing with meteoric water, which is more likely to occur during snow melt in March, could depress the temperatures and cause some of the observed chemical differences; however, the similarity of Na concentrations between March and November argue against this.

Because groundwater flow rates can be extremely low, some influences on the hydrology of thermal features in the Wells, Nevada area resulting from the earthquake may not be apparent over the relatively short period between the earthquake and times when samples were collected. This may especially be the case with respect to deep geothermal fluids.

Sample No.	Location	Temp	pH	Specific Conductivity	HCO_3	SO_4	NO_3	Cl	F	B	Ca	Fe	K	Li	Mg	Mn	Na	SiO2	Geothermometers		Sample date	Reference/Lab
																			SiO_2	Cation		
W-1	BTI well	32.8	7.08	903	301	30.1	0.16	15.3	2.47		37.3	0.00	16.4	0.00	9.8	0.00	92.4	89.7	104	68	3/26/2008	GBCGE
W-2	Reynolds Ranch well	40.6	6.90	619	190	22.3	3.43	10.6	1.01		29.9	0.00	18.3	0.05	5.2	0.00	53.2	108.5	115	110	3/26/2008	GBCGE
		40.0	6.80		295	20.0		16.0			33.0		20.0		5.0		58.0			121	3/16/1980	Jewell, 2008
			8.00		214	24.0		10.0			13.0		17.0		4.0		51.0			88	11/11/1991	Jewell, 2008
W-3	Ray Reynolds well	28.6	7.20	619	210	18.8	1.23	7.2	1.27		45.4	0.00	7.2	0.00	6.8	0.00	37.1	54.6	77	60	3/26/2008	GBCGE
	(2)				164	17.0		9.0			19.0		4.0		12.0		23.0			55	11/11/1991	Jewell, 2008
	(2)				177	14.0		7.0			22.0		6.0		8.0		28.0			66	11/11/1991	Jewell, 2008
	(2)	37.0	8.20		224	7.0		14.0			25.0		12.0		8.0		61.0			63	11/11/1991	Jewell, 2008
W-4	Spring SW of Wells	19.3	6.79	700	197	34.3	3.60	18.9	0.72		50.0	0.00	3.1	0.00	15.1	0.00	33.6	23.3	37	35	3/27/2008	GBCGE
	(1)	19.5	7.80	395	227	30.0		15.0			48.0		3.0		13.0		38.0			36	11/11/1991	Jewell, 2008
W-5	Threemile Spring area	36.6	6.36	1630	872	41.0	0.14	29.0	6.26		48.4	0.00	38.7	0.00	11.4	0.00	330	71.9	91	85	3/25/2008	GBCGE
	(1)	35.0	7.70	1800	1000	25.0		20.0			43.0		31.0		10.0		355			81	11/16/1991	Jewell, 2008
	(1)	36.0	6.30	1740	1150	29.0		34.0	7.00	0.80	51.0		36.0	0.65	13.0	0.12	340	76.0	94	76		Mariner et al., 1975
	Hot spring 0.5 km	45.0	7.80	2300	1080	12.0		20.0			38.0		35.0		10.0		390			78	11/16/1991	Jewell, 2008
	south of W-5	60.0	6.60	1730	1210	24.0		26.0	6.10	0.77	78.0	0.02	30.0	0.75	36.0		300		116	34		Mariner et al., 1975
W-6	Travertine spring area	48.7	6.53	1640	910	30.0	0.55	22.0	6.53		63.4	0.00	31.9	0.04	30.0	0.00	285	104	113	35	3/26/2008	GBCGE
	(1)	46.0	7.70	2255	950	28.0		15.0			56.0		10.0		30.0		290			38	11/12/1991	Jewell, 2008
	(2)	54.0	6.00	2100	1096	18.1	0.10	36.6	2.05	0.80	36.5	0.01	38.8	0.35	11.2	0.09	386	91.0	105	72	6/24/2002	GBCGE
	(2)	61.0	7.30	1650	1135	32.0		27.0	7.20	0.89	75.0		31.0		37.0		300	105	114	31		Mariner et al., 1974
	(2)	55.0	6.60	1820	1230	12.0		37.0	7.40	0.73	48.0		46.0		13.0		370	86.0	101	80		Mariner et al., 1975
W-7	Mud slide	34.2	6.44	1700	1016	14.0	0.12	21.5	5.53		78.4	1.58	34.7	0.68	37.1	0.19	338	85.0	102	39	3/25/2008	GBCGE

Comparison of March 08 and November 08 water chemistry(3). Cation analysis only by ICP OES (GBCGE). Samples were analyzed at the same time for accuracy of comparison.

Sample_No	Location	Ba	Ca	Fe	K	Li	Mg	Mn	Na	Rb	S	SiO_2	Geothermometers #		Sample date
													SiO_2	Cation	
W-1	Reynolds Rranch well	0.29	29.9		18.3	0.05	5.24		53.2	0.06	7.29	108	115	110	3/26/2008
		0.28	29.6		18.4	0.05	5.19		53.3	0.06	7.00	97	109	111	11/11/2008
W-7	Mud slide	0.71	89.9	1.58	34.7	0.68	37.1	0.19	338	0.26	5.23	85	102	39	3/25/2008
		0.65	78.4	0.22	40.8	0.70	32.9	0.12	335	0.36	7.17	111	117	42	11/11/2008

Table 1. Water chemistry and temperature of some thermal wells and springs near Wells, NV. Data are of samples collected in March and November of 2008 and historic data as referenced. Many historic locations are approximate and exact well or spring sampled is unclear. (1) Sample most likely collected from the same well or spring. (2) Spring or well in the same general area. For Travertine spring area, samples noted by (2) were collected from smaller springs in the travertine mound, while W6 was collected from the high outflow at the base. SiO2 geothermometer is chalcedony and cation geothermometer is Ca, K, Na with Mg correction. Fournier and Potter 1997, and 1982; Fournier and Truesdell, 1973.

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