Observations and Reported Effects of the February-April 2008 Mogul-Somersett, Nevada Earthquake Sequence

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Introduction

In February 2008, small earthquakes began in Mogul-Somersett area located in the western Reno, Nevada region (**Figure 1**). These grew in size and frequency over time until on February 28, the first earthquake was widely felt (magnitude 2.2). These small earthquakes made the news because it had been very quiet seismically in western Nevada prior to this and the magnitude 6, Wells, Nevada earthquake had occurred only seven days earlier on February 21. The earthquakes in western Reno continued to grow in size and a little in frequency until April 15, when a remarkable increase in activity occurred, including four magnitude 3 events (largest M3.6) within 12 hours. The earthquake swarm's character changed on this day and it became more aggressive and active. The swarm's character changed again on April 24 with the occurrence of two magnitude 4 events (largest M4.2) and yet another increase in earthquake activity.

Figure 1 Two communities directly overlie the earthquake zone, Mogul in the foreground, and Somersett shown in the distance in the upper part of the image. Interstate 80 is shown at the bottom. The view is to the northwest.

On April 25, 2008 a moment magnitude 5 (local magnitude 4.7) earthquake occurred at about 11:38 pm PST, rousing people out of their beds and causing violent up-and-down shaking at Mogul and Somersett. The earthquake was very shallow, perhaps reaching to within 0.5 mi (~1 km) of the surface. Shaking was generally reported to be 10 to 12 seconds long, but an immediate foreshock eleven seconds earlier made this seem longer to some people, particularly in Mogul.

This report covers the effects of the Mogul-Somersett Earthquake Sequence up through the April 25 magnitude 5 earthquake, even though activity has continued past this date. I've included the effects of the earthquake and some lessons that can be learned from the sequence, including the response of Nevadans to this extraordinary sequence.

Earthquakes are the natural laboratory for earthquake science, preparedness, and engineering. We sincerely do not wish earthquakes on anybody, but we are committed to learning everything we can from these natural events so we can be safer and more resilient in future earthquakes. We want to break any cycles of recurring loss from earthquakes through knowledge and application of that knowledge. This is why this report was written and why some of the commentary was inserted.

A note about earthquake magnitudes. Earthquake magnitudes can be calculated using different kinds of seismic data, and different laboratories are set up to use different seismic stations because of the areas they are designed to located earthquakes in. Thus, magnitude values vary a bit and this is to be expected. They vary at the time of the event when estimated by different seismic laboratories and there are different types of magnitudes based on different types of measurements. Earthquake catalogs are collected in systematic ways and at this time the Nevada Seismological Laboratory routinely calculates "local magnitudes." The local magnitude for the mainshock is M_L 4.7; this number is commonly cited and is accurate for the kind of magnitude it is. I have used a moment magnitude in this report for this event, a magnitude M_w 5. This is the result of more detailed studies of the earthquake and consideration of the physical size of the earthquake rupture. I use moment magnitude because it is a little better sampling of the overall earthquake and allows a comparison in earthquake size between different kinds of data (for example, seismic and geologic). The other magnitudes used in this report are from the Nevada Seismological Laboratory catalog and are local magnitudes, and are referenced with a simple "M" to make the text read easier (e.g., "M2.7" is a local magnitude 2.7).

Geologic Setting

The Mogul-Somersett Earthquake Sequence occurred in the Verdi-Mogul basin, a small, east-west sub-basin on the western side of Reno that lies between the Carson Range to the south, Peavine Mountain to the north, and the Verdi Range to the west. The general geology has been mapped by Bell and Garside (1987). More recent mapping has been conducted in the area that has benefited from new road cuts and exposures identified additional faults; this work is mostly unpublished research by Professors Pat Cashman and Jim Trexler from the University of Nevada, Reno.

The Verdi-Mogul basin is a shallow basin mostly filled with late Tertiary sediments, some Miocene basalt, a few Cretaceous granitic rock outcrops, and limited Quaternary deposits and terrace landforms. The volcanic system that produced the basalts has been extinct for millions of years.

There are several well-developed bedrock faults mapped in the Mogul and Somersett areas (e.g., Bell and Garside, 1987; Cashman and Trexler, unpublished mapping). Some of these have been monitored through this sequence to watch for any movement or cracking. A preliminary sketch map of local bedrock faults that might be important in understanding the earthquakes is presented in **Figure 2**. This is a compilation of faults that are not necessarily active and may or may not be related to modern earthquakes; when we try to understand earthquakes, a compilation of faults is a common first step. This is a bedrock fault map at the surface (remember the earthquakes are at a mile plus depth, down in the granitic rocks), but the map gives us an important structural grain to investigate. Many of the shorter faults are from Bell and Garside (1987) and the more continuous faults are from Cashman and Trexler (unpublished mapping). Some of the main faults have been named in this report for easier reference.

Details about the Mogul east fault are not known; this is the fault the Mw 5 earthquake occurred along and its existence is mostly inferred from that event and its northwest alignment of aftershocks. Other northwest-striking faults have also been mapped in the area. Although the details of the Mogul-Somersett Earthquake Sequence are being carefully examined for “new” faults and information, **this sequence is not a scientific surprise and similar earthquake sequences can occur anywhere in Nevada**.

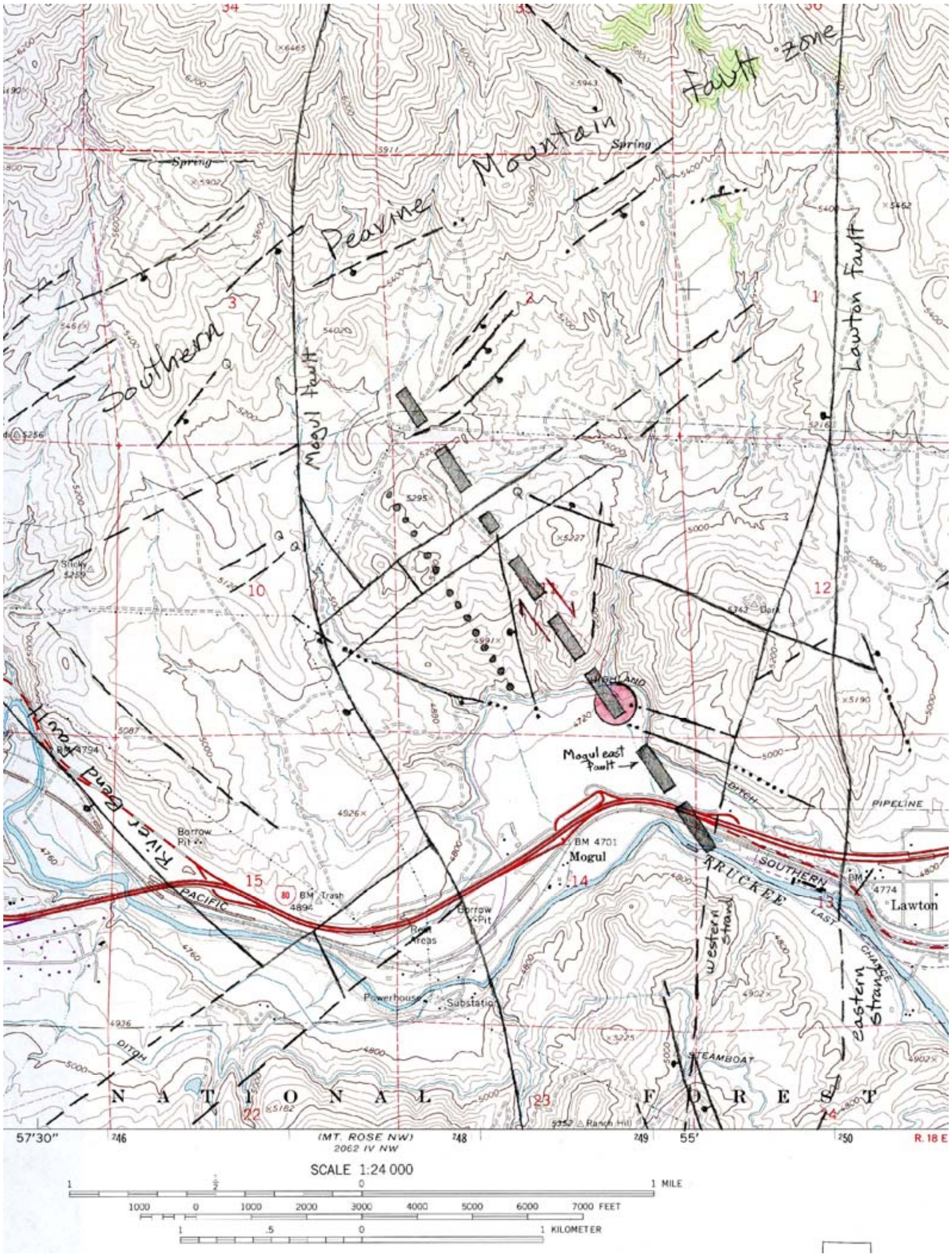

Figure 2 Preliminary sketch map of faults from Bell and Garside (1987) and Cashman and Trexler (unpublished research) compiled on the Verdi Quadrangle. These bedrock faults are solid lines where mapped and are dashed where inferred. The thick, solid gray dashed line is the upper part of the moment magnitude 5 earthquake rupture (herein named the "Mogul east fault"). The red circle is the epicenter (from Ken Smith, Nevada Seismological Laboratory). The alignment of dots is a second, early trend of seismicity, is called the western strand of the Mogul east fault. The southern Peavine Mountain fault zone is a structural trend or zone of faults near the southern flank of Peavine Mountain, shown as the northeast striking faults near the top of the map (taken from Bell and Garside, 1987) that dip to the southeast (indicated by the balls). The eastern continuous, north-south fault is from Cashman and Trexler (unpublished research) and is herein named the Lawton fault; this fault splays to the south into eastern and western strands. The magnitude 5 earthquake rupture appears to have nucleated near the intersection of the Mogul east fault and a more westerly set of faults mapped by Bell and Garside (1987). The southern end of the rupture may be an intersection with the western strand of the Lawton fault and the northern end may be a dipping intersection with the southern Peavine Mountain fault zone (a view of the relocated aftershocks shows a possible southeast-dipping truncation to the seismicity). Thus, there was structural control to the hypocenter of the Mw 5 event, its endpoints, and its size.

Historical Earthquakes

There has been quite a bit of discussion about the uniqueness of this earthquake sequence, and it has been extraordinary in many aspects (such as its shallow nature), but aside from details, it is also not altogether dissimilar to local historical earthquakes, in particular the 1950 Fort Sage Earthquake Sequence that occurred about 35 miles (56 km) north of the Mogul-Somersett area (**Figure 3)**. The 1948 Verdi, Nevada and California Earthquake occurred nearby (just to the west of the current sequence) and is also briefly reviewed (**Figure 3**).

<u>1950 Fort Sage Mountains, California Earthquake Sequence</u>

The 1950 sequence began at least 24 days before the mainshock with sustained activity recorded for several weeks and a pronounced ramp up of activity preceding the main event. There were twice as many magnitude ≥4 foreshocks as aftershocks (6 versus 3), whereas there were 10 magnitude ≥3 foreshocks versus 50 M≥3 aftershocks. Considering only the larger events (M≥2.9) the foreshock sequence for the Fort Sage Mountains, California Earthquake Sequence was:

Nov. 22: M2.9, M3.9,
Nov. 23: M3.0
Nov. 26: M3.1
Dec. 10: M2.9
Dec. 11: M4.1
Dec. 12: M2.9
Dec. 14: M4.5, M4.0, M4.0, M3.4, M2.9, M2.9, M4.0, M4.0, **M5.6**

Dec. 14: 15 M3s and M4.1

A vigorous aftershock sequence followed, but these tapered off notably after January 1951. There was a small normal dip-slip rupture along the western base of the Fort Sage Mountains following the mainshock. The earthquake and fault rupture are described by a local University of Nevada, Reno legend, Dr. Vincent P. Gianella, in his paper published in the Bulletin of the Seismological Society of America (v. 47, p. 173-177). Damage from the Fort Sage Mountains Earthquake was considerable in the town of Herlong (located on soft, water saturated sediments), where underground water mains, electric conduits, and sewers were broken, but was less at Doyle, where merchandise was thrown from shelves and a few windows were broken.

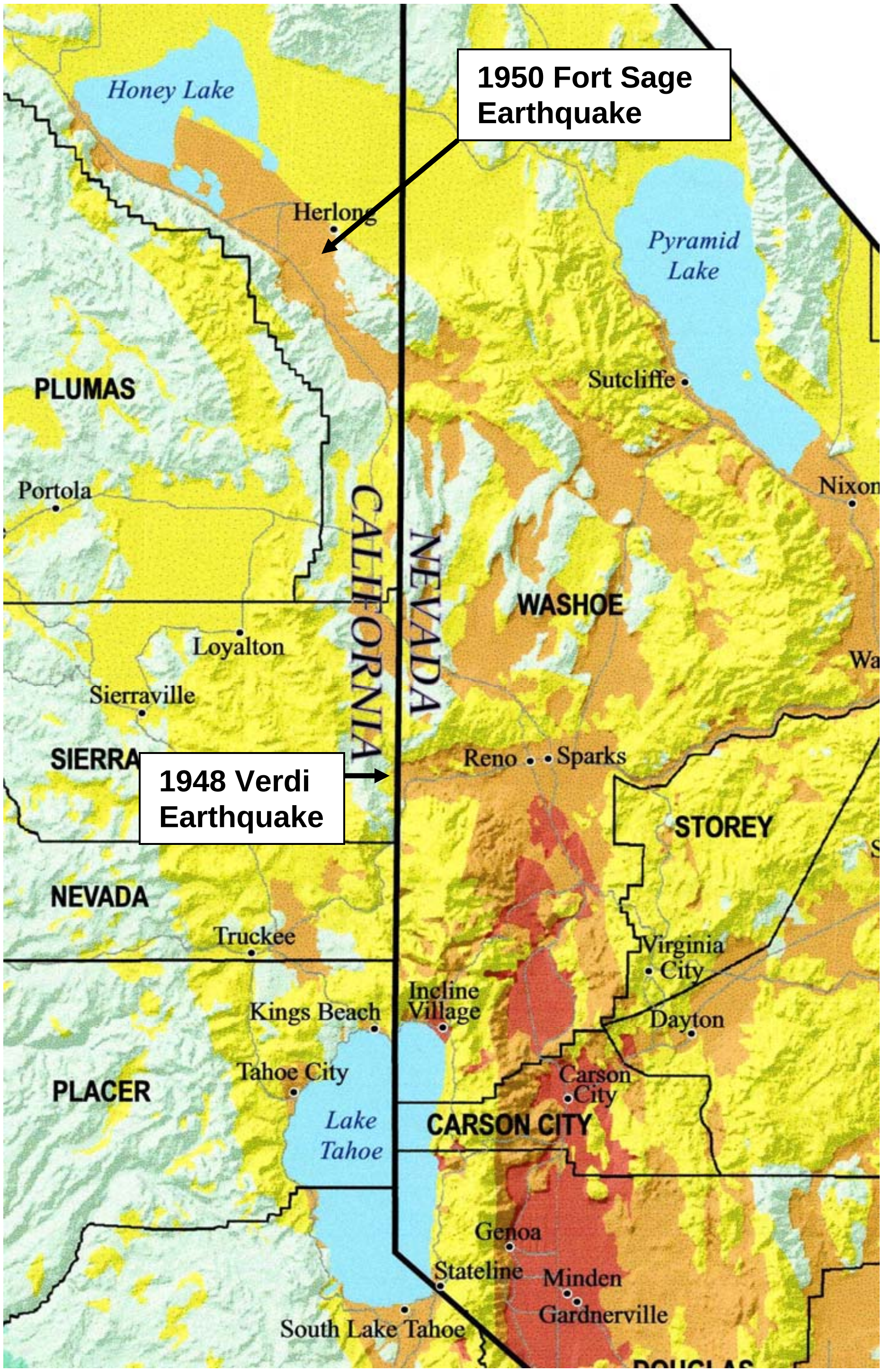

Figure 3 Earthquake Hazard Map of western Nevada and eastern California by Branum and others (2005). The approximate locations of the 1948 Verdi, Nevada and the 1950 Fort Sage, California Earthquakes are indicated.

On this map, the redder areas have the highest potential for strong shaking and the cooler colors have a lower potential. Mogul and Somersett have the same level of indicated hazard as Reno, and many surrounding basins.

The 1948 Verdi, Nevada Earthquake

One of the closest historical earthquakes to the 2008 Mogul-Somersett Earthquake Sequence was the 1948 Verdi, Nevada Earthquake. Similarities between these events include the area affected, foreshock activity, subterranean rumbles, and many Reno visitors checked out of hotels early. Differences include the location of the earthquakes, the duration of the foreshocks, the building code setting, and in a rather dramatic way, the ability to monitor the earthquakes with seismic instrumentation.

The effects of the1948 Verdi, Nevada Earthquake are best detailed by the December 29 *Reno Evening Gazette* which states:

> "Half of the west wall of the old Verdi general store, the brick and concrete landmark in the center of town, collapsed in a roar during this morning's earthquake.
>
> Plaster in other homes was cracked, chimneys were broken down or twisted out of line, appliances such as hot water heaters and electric stoves were wrenched from their foundations, and the foundations of several homes were damaged.
> …
>
> Dishes, canned goods, vases and other movable objects crashed to the floors in dozens of Verdi homes."

The 1948 Verdi Earthquake has several similarities to the recent 2008 Wells, Nevada earthquake, which isn't entirely surprising because the earthquake magnitudes were the same. In Verdi, there was severe damage to an unreinforced wall, many chimneys were damaged, and the walls of homes were cracked. Another aspect that was similar to the Wells Earthquake was the weather; Verdi and the surrounding region were in a very cold set of days and were entering a snowy period and like Wells, the loss of a primary heat source, wood fires, was a serious issue. In late December 1948, the evening temperatures were below zero.

In 1948 there was one seismometer in western Nevada, which was located in Reno, and that was all. Professor Vincent Gianella at the University of Nevada could see that the event wasn't far away by comparing the S-wave arrival time to the P-wave arrival time (the number of seconds between these arrivals is multiplied by ~5 miles (8 km) to give the distance the earthquake is from the seismometer). He knew where the epicenter roughly was when he heard about the damage at Verdi, and surmised the earthquake occurred along the Verdi fault. When the foreshocks were occurring, people in Reno didn't seem to have a very good idea where they were coming from, guessing their origin might be the "Steamboat Springs Fault." Bell and others (1977) compared the arrival times of the 1948 earthquake at distant stations to those of the 1966 Boca Valley Earthquake (M6) and suggest the epicenter is to the north of Verdi at 39° 33' North latitude and 120° 03', at the "intersection of the northwest trending Last Chance fault and the a northeast trending lineament in Dog Valley which was detected on aerial photographs and side-looking radar."

For about a year before the 1948 earthquake, "mysterious rumbles" or subterranean roars were heard in Reno and Verdi (Bell and others, 1977). Professor Gianella hypothesized that they were due to vertical motions without seismic activity (Reno Evening Gazette, 1/4/49). His hypothesis indicates that he believed these sounds were occurring (likely involving his having heard them first hand) and that he found no corresponding seismic signature on the seismometer in Reno.

The formal earthquake list from Slemmons and others (1965) includes these events:

11/13/48 M3.8 two sharp jolts, plaster fell, church window broken
12/28/48 two M4.3s occurred; distant moaning and subterranean sounds heard
12/29/48 **M6** damage to buildings in Verdi; "75 houses damaged"

At least four earthquakes are indicated to have shaken Reno the day before the mainshock. The two M4.3 foreshocks were widely felt and caused some cracking of wall plaster in Reno.

Progression of the February-April 2008 Mogul-Somersett Earthquake Sequence

Data and maps provided by the Nevada Seismological Laboratory (NSL) were used to track the general progression of the sequence through April 25. The seismic data presented was relocated by Ken Smith (NSL) and was plotted for this report by Yui Miyata (NSL). Magnitudes have been rounded to the nearest tenth and come from the Nevada Seismological Laboratory Catalog. The observations are still preliminary, and are meant to serve as a working model.

<u>February 28 – February 29</u>

One of the first felt earthquakes, a magnitude 2.2, occurred on February 28th in the northern part of the Mogul embayment (**Figure 4**); this epicenter is just a little to the west of the mainshock epicenter. A few small microearthquakes were also located close to this event.

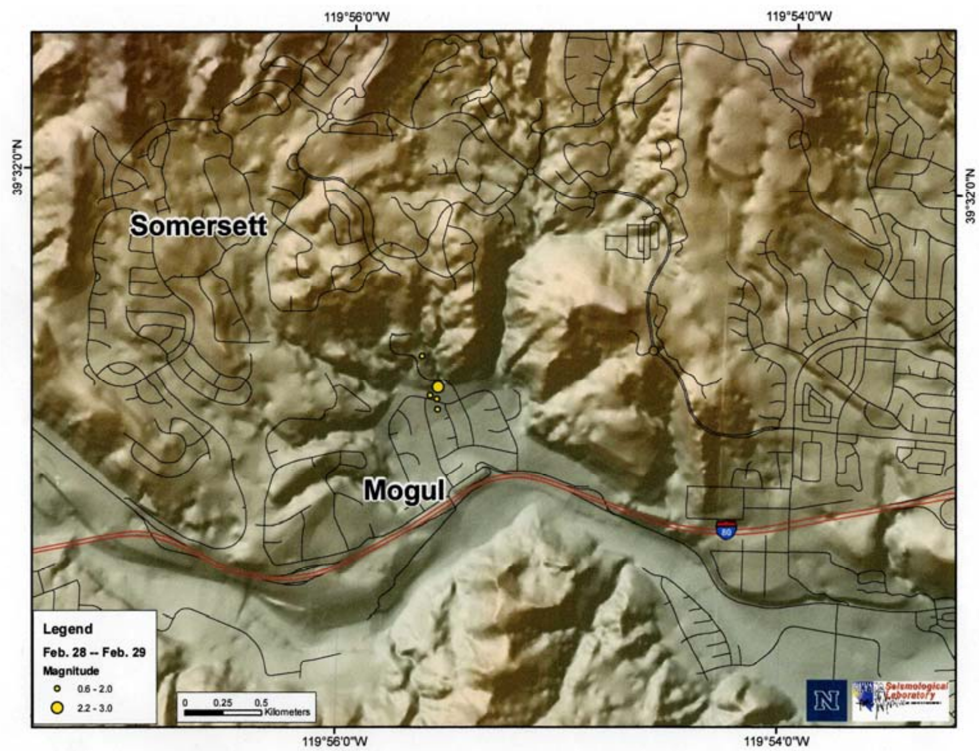

Figure 4
February 28th and 29th seismicity. (K. Smith - seismicity relocation; Y. Miyata - cartography)

March 1 – March 31

During March a northwest alignment about 0.5 km wide and about 1.25 km long developed (**Figure 5**). A magnitude 3.4 earthquake (March 8) occurred just northwest of the February 28th event. This was the first magnitude 3 sized event of the sequence. Activity expanded the swarm area mostly to the northwest, but other small micro-earthquakes occur in Mogul and as far south as just south of the Truckee river. Three other magnitude 3 events occurred in the hills just north of Mogul, a magnitude 3 earthquake on March 15, a magnitude 3.1 earthquake on March 24, and a magnitude 3.1 earthquake on March 26. Most of this activity is on a western strand of the Mogul east fault, although the width of the activity might indicate multiple fault traces were active.

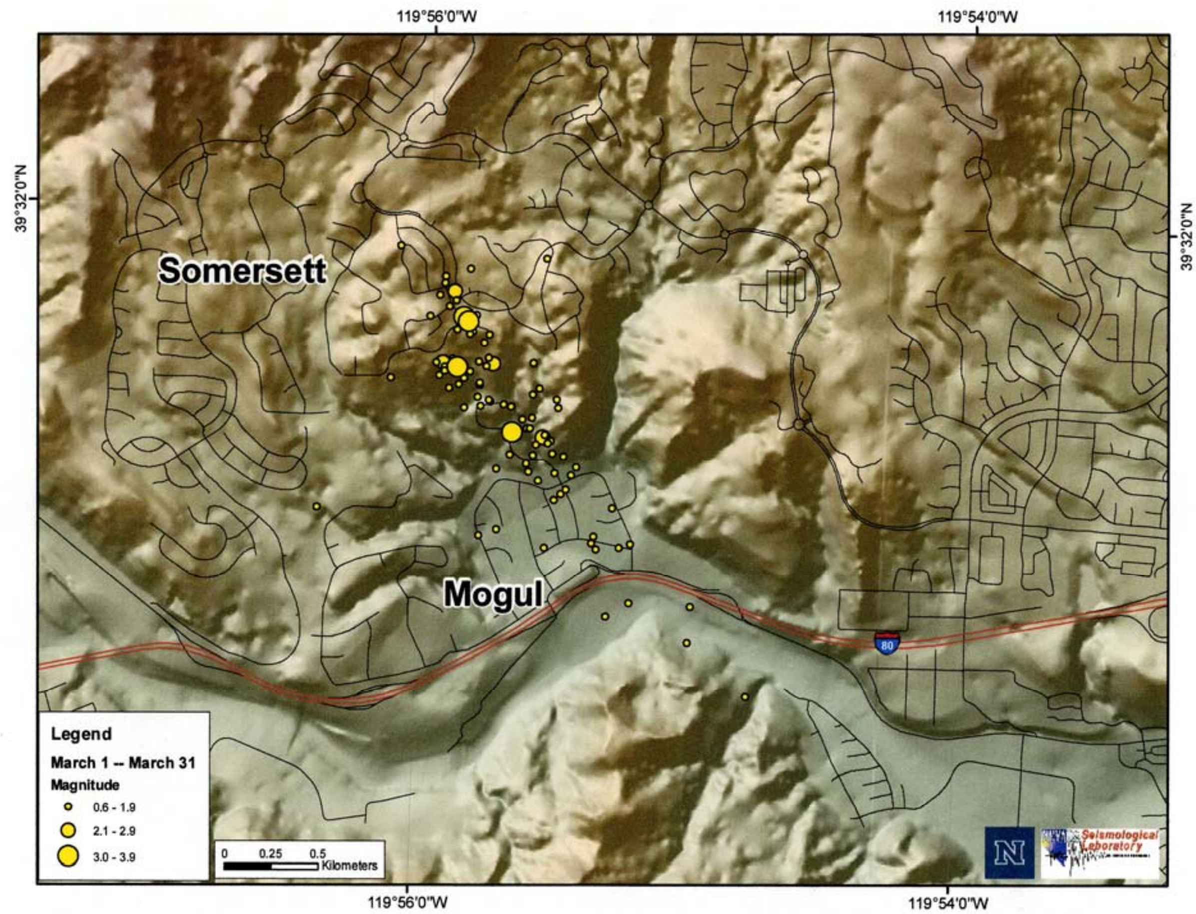

Figure 5 March seismicity mostly occurring along the western strand of the Mogul east fault (K. Smith - seismicity relocation; Y. Miyata - cartography)

April 1 – April 14

An April 1st magnitude 3.0 earthquake and magnitude 2.5 event occurred just northwest of Mogul, on the western strand of the Mogul east fault, but overall this was a quieter time period for the sequence although activity continued at a low microearthquake level.

April 15

On April 15 there was a significant increase in the activity of the earthquake sequence and it began to grow in a more threatening fashion (Anderson and others, 2008, Personal Communication; **Figure 6**). The activity was generally concentrated in the northern half of the sequence, with a surge of four magnitude 3.2 – 3.6 earthquakes occurring within seven hours (a M 3.4 earthquake in the morning and three events, M3.2, M3.4, M3.6, within seven minutes in the afternoon); most of these events appear to have clustered along the northern part of the Mogul east fault.

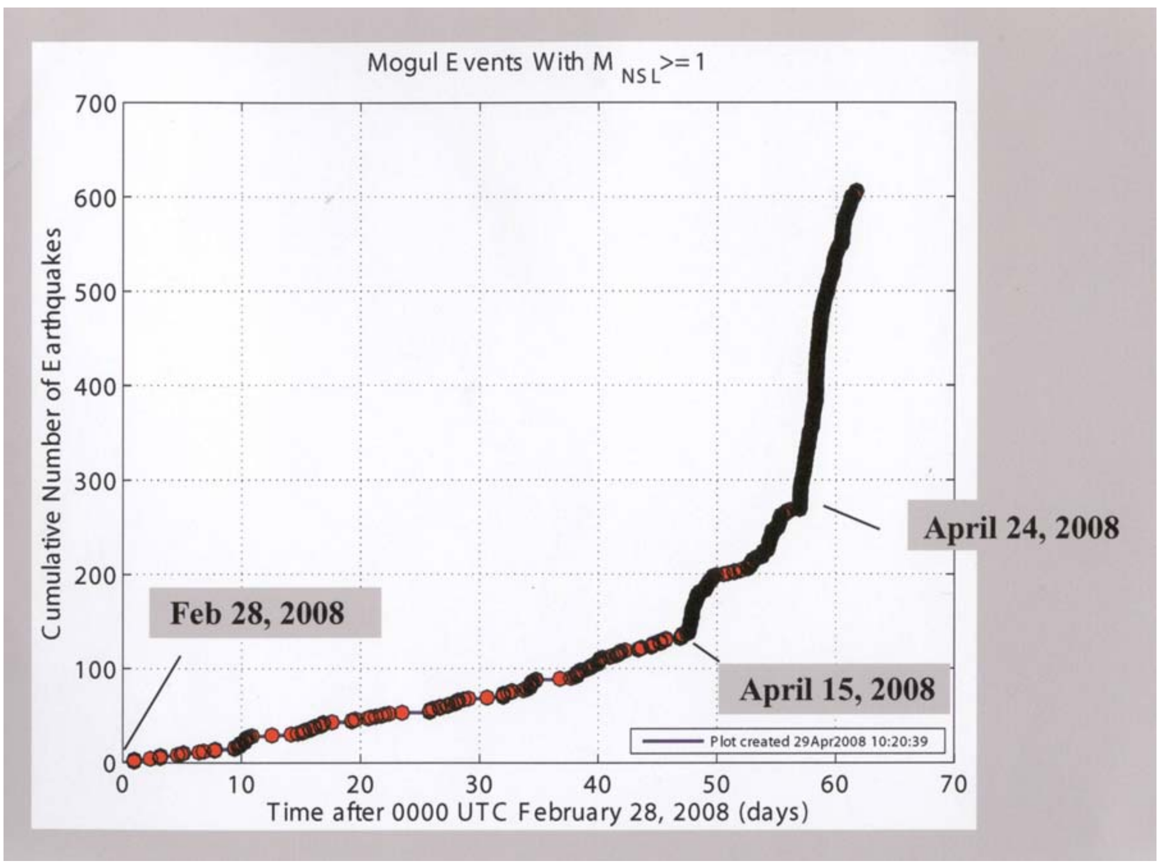

Figure 6 Earthquake activity graph produced by John Anderson and the Nevada Seismological Laboratory. It shows the total number of earthquakes with time and the three phases of earthquake activity, when activity increased on April 15th and again on April 24th.

April 15 is the first day that the eastern strand of the Mogul east fault, the one that ruptured with the magnitude 5 event, began to show significant activity (**Figure 7**). A preliminary relocation of seismicity showed that earthquakes also began to occur deeper with the April 15 activity (David von Seggern, 2008, Personal Communication).

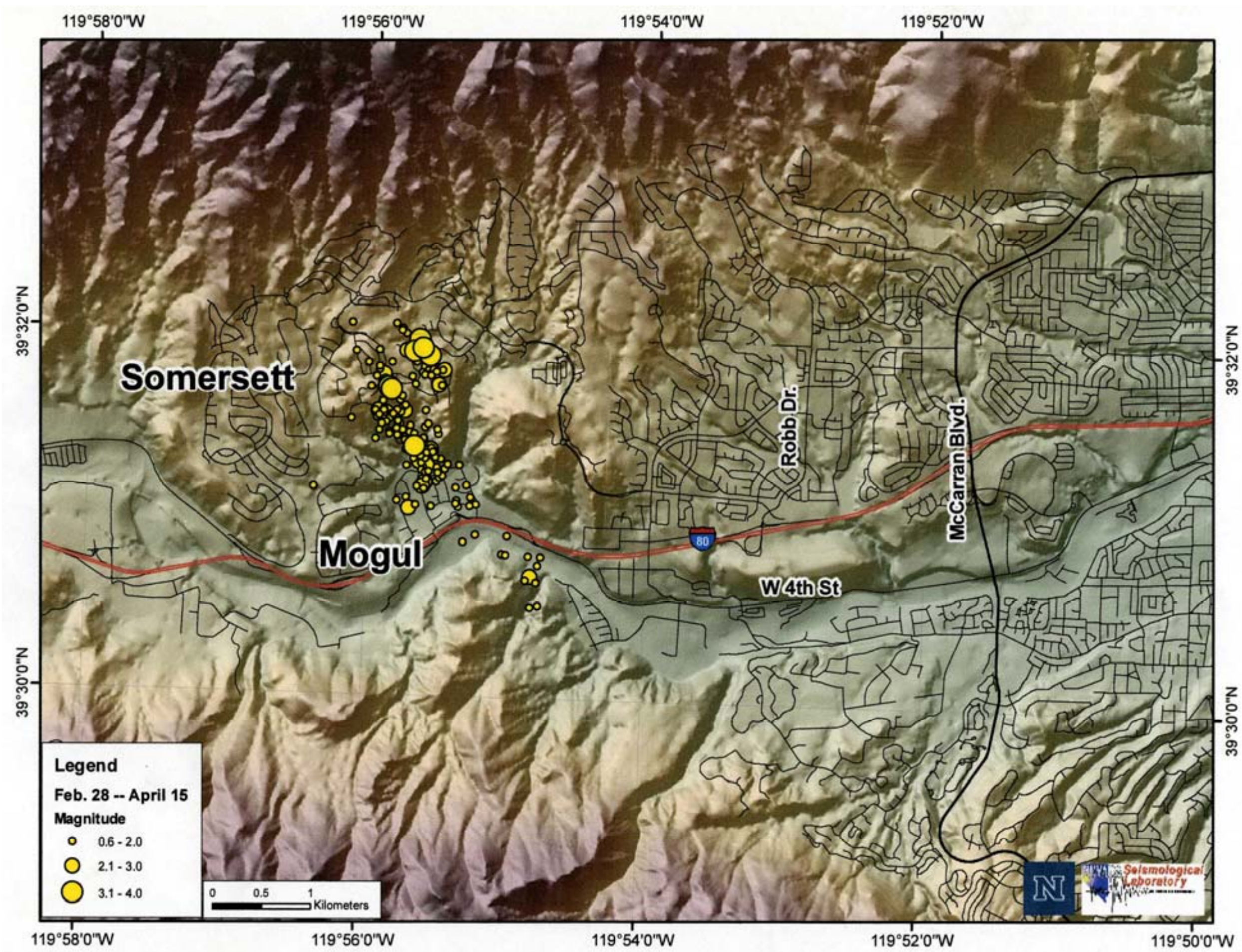

Figure 7 Seismicity April 1st through April 15th. The magnitude 3 earthquakes that occurred on April 15th clustered near the northern part of the earthquake swarm, on the Mogul east fault (K. Smith – seismicity relocation; Y. Miyata - cartography).

April 20 – April 24

This time period is a ramp up in activity that became more extreme on April 24, the day before the magnitude 5 earthquake (Anderson and others, 2008, Personal Comm.; **Figure 7**). Activity was focused on the Mogul east fault. On April 24 was a magnitude 4.1 at 3:47 pm PST along the eastern strand of the Mogul east fault followed eight minutes later by a magnitude 4.2 which occurred just to the west near the western strand of the fault. There were magnitude 3 and 2.9 events within seven minutes of the M4.1. The M4.2 was also followed by a two events, a M2.6 within 5 minutes and a M2.7 within the hour. A final M3.3 earthquake finished off the day, located a little to the south of, and about two hours after, the M4.2 event.

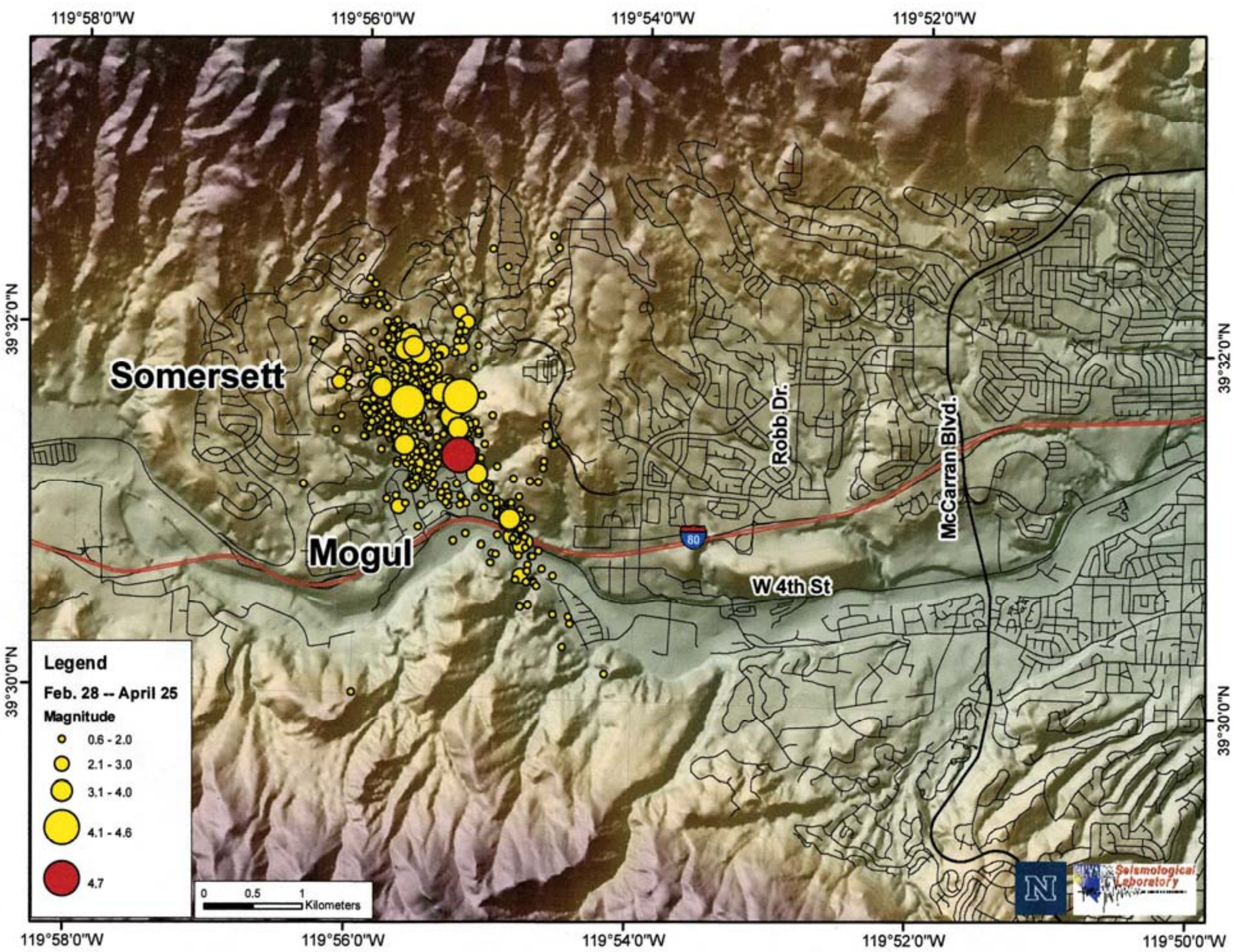

Figure 8 Seismicity up through April 25. The two M4 foreshocks are shown just above the red circle for the M5 (K. Smith – seismicity relocation; Y. Miyata - cartography).

April 25

Most of the activity of the larger earthquakes on April 25 occurred in the northern part of Mogul and near the area of the April 15 cluster of activity. A M3.3 event occurred in northeast Mogul about 22 hours before the main event, a M2.9 event occurred near the northern cluster about 19 hours before, a M3.3 event occurred near the northern cluster about 13 hours before, a M2.8 event occurred in northeast Mogul about 12 hours before, and a M3.7 occurred off the trend in Somersett about 5 hours before.

An immediate foreshock of magnitude 3.3 occurred 11 seconds before the mainshock that was located in southern Mogul. Then at 11:40 pm PST the mainshock nucleated in northern Mogul and based on the aftershock pattern, ruptured bilaterally a little over a half a mile (1 km) to the southeast and almost 1½ mile (2.2 km) to the northwest, and at depths of ~1 to ~3 miles (2 – 4.5 km). The orientation of the earthquake was about 33 degrees to the west of north, and it was on a fault (the Mogul east fault) that dips 85° to the southwest (Echinosa – http://www.seismo.unr.edu/feature/2008/Summary.html) based on a waveform-modeled earthquake focal mechanism. Three-dimensional aftershock representations (http://www.seismo.unr.edu/feature/2008/mogul_3D.html) indicate a west-dipping fault may intersect or truncate the Mogul east fault near the bottom of the Mw 5 rupture surface, giving a possible structural control to the base of the rupture. The rupture surface is also constrained by two close GPS stations installed by the Nevada Geodetic Laboratory. One station to the south of the river limits the rupture's southeastern extent and its horizontal position (Geoff Blewitt, 2008, personal communication).

Combining these data indicates the section of fault (or faults), that moved during the Mw 5 event was about 2 miles long and about 1½ miles vertical extent at depth (3.2 x 2.5 km).

On the technical side, the geologic moment is estimated to be 2.4 x 10^{23} dyne-cm. This assumes the rupture was 3.2 km long, 2.51 km wide (down-dip width based on near-term aftershock spread - uses an 85° dip), had an average displacement of 15 cm, and had a shear modulus of 3 x 10^{11} dynes/cm^2. The moment magnitude for these parameters is Mw 5.0. Keep in mind that at these magnitude values, small changes in parameters can have a significant effect on the moment magnitude estimate. For example, using a 10-cm-average displacement yields an Mw 4.9 and using a 20-cm-average displacement yields an Mw 5.1 (these magnitude values are rounded to the nearest tenth). A moment magnitude of Mw 5 is reasonable considering the likely physical parameters of the earthquake rupture.

A magnitude 3.4 aftershock occurred three minutes later in the area of the mainshock, and a fairly vigorous aftershock sequence followed. Aftershocks of the magnitude 5 earthquake are shown in **Figure 9** with all events through June 8.

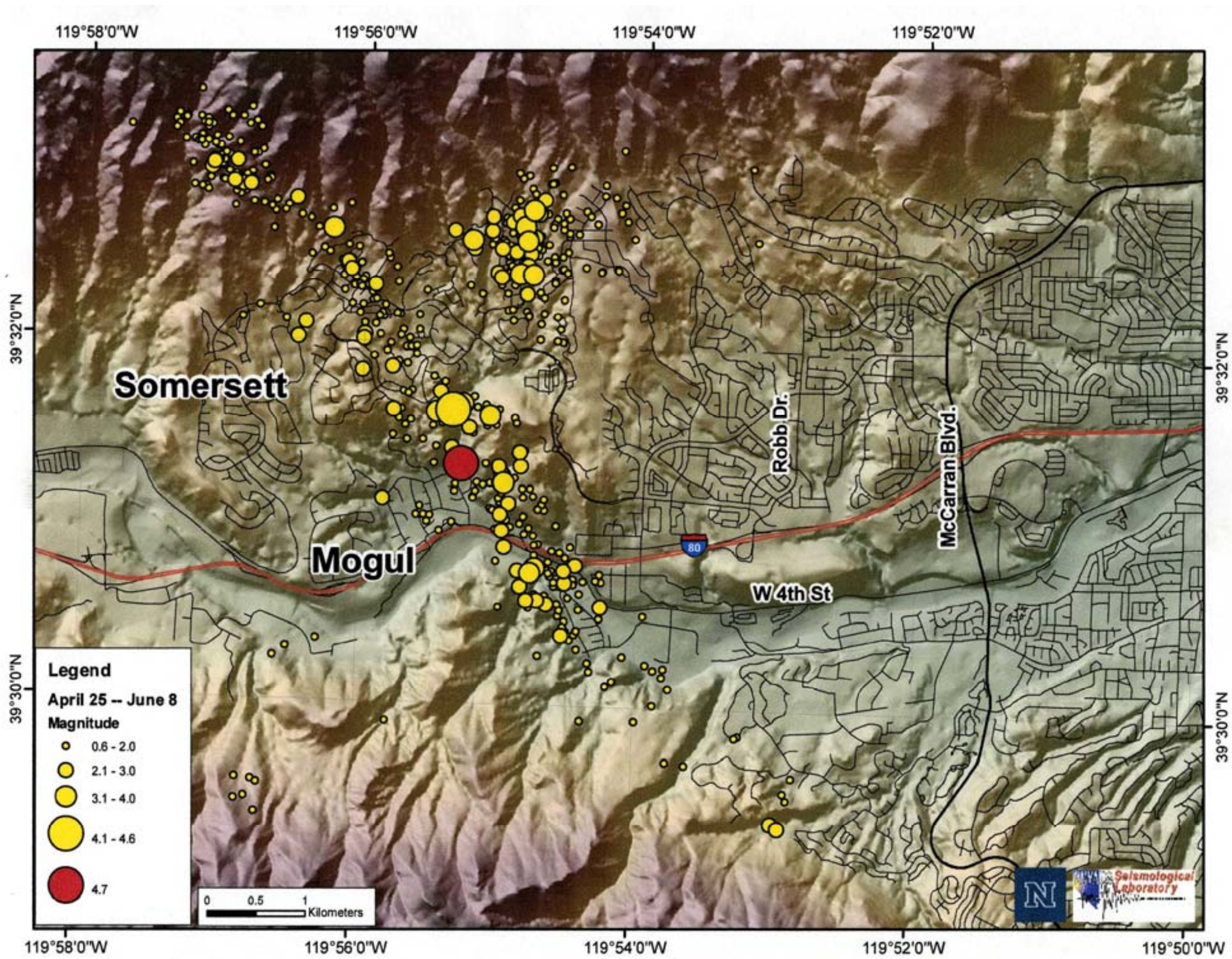

Figure 9 Aftershocks of the April 25 magnitude 5 event. (K. Smith - seismicity relocation; Y. Miyata - cartography)

There were two magnitude 4+ foreshocks versus only one magnitude 4+ aftershock thus far in the 2008 Mogul-Somersett Earthquake Sequence, similar to the greater number of magnitude 4+ foreshocks versus aftershocks during the 1950 Fort Sage Mountains Earthquake. This indicates very vigorous, swarming foreshock sequences preceded both of these earthquakes.

A separate, curious phenomenon reported as occurring Friday afternoon (April 25), about 4 p.m. PST, was a blast of air through the Truckee River in the River Bend area near Verdi (just west of Somersett). The blast of air carried a gush of water spray twenty feet into the air as observed by one man. A few others nearby noticed the mist in the air and when they arrived at the river bank, the river was bubbling where the air blast occurred, and continued to bubble for 10 to 15 minutes.

The April 25, 2008 Mogul-Somersett Earthquake occurred on a very high-order or secondary structure, which may have limited its size and yields a hypothesis for the shallow, swarm-like nature of the sequence. If the major range-front faults and longer strike-slip faults are the first order structures, and cross-structures to these or elements of these are second-order structures, then the largest faults in the Mogul-Somersett areas (southern Peavine Mountain fault zone or the Lawton fault) are probably third-order or higher structures. The Mogul east fault is secondary to these local faults, so it is an even higher-order fault (at least at this time – detailed research might change this view). The earthquake may have been bound between the southern Peavine Mountain fault zone (the southeast-dipping north end) and Lawton fault which crosses the earthquake trend at its southern end. Near the surface most mapped northwest-striking faults appear discontinuous and intersected and offset by northeast-striking faults; this complex setting may have led to many small faults being needed to move to accommodate offset, or many small earthquakes occurring as a swarm.

The epicenter of the Mw 5 earthquake is at the intersection of the earthquake fault and west-northwest striking faults mapped by Bell and Garside (1987), and it is likely that other fault intersections have been the location of several foreshocks to this event. It is also likely that the Mogul east fault is not a single continuous fault plane, but rather is a zone of faults itself. Earthquakes began to the southwest of the Mogul east fault, along the western strand, then largely shifted to the Mogul east fault alignment and swarmed for 10 days (there was also some off-fault activity to the northeast). This seems to have been a preparation for the Mw 5 event, whether is was small discontinuities breaking, cross faults shifting, or something else. Eventually, the instability that led to the Mw 5 earthquake nucleated and propagated along the Mogul east fault, allowing a rectangular patch of the fault to slip. Although it is possible this was a new fault, this is probably unlikely; there is a significant gravity gradient coincident with this fault (Mike Widmer, 2008, personal communication), and if related, repeated earthquakes or development of structures would be needed to create this feature.

Descriptions of the Earthquake

There are a couple of observations that were made by residents about the ground motion from the moment magnitude 5 event.

The duration of the event is slightly complicated by a magnitude 3.3 that preceded the mainshock by 11 seconds. Ten to 12 seconds of shaking was a common estimate, although in Mogul a slightly longer duration of 15 seconds has been estimated by some. After the event, nearly continuous aftershocks were reported felt in Somersett.

A resident in Mogul described the mainshock as follows:

“As to the big one, here is how it went: I believe I was awakened immediately prior to the main shock by a smaller one. The main shock came and went very quickly and was immediately followed by another one. The motion during the main shock was vertical, followed by a kind of rolling motion which traveled from northwest to southeast. The noise was incredible but very short lived. I thought either a bomb had gone off or that a giant was standing outside the house with a baseball bat banging on the side of the house. The house also seemed to sway back and forth but very violently and this was also very short lived."

Many who were apparently right over the rupture in Somersett said there was a loud roar during the event. They were impressed with the level of noise and likened it (reluctantly) to the sound from the original movie "Earthquake". They noted that much of the shaking seemed up-and-down (the waves felt as if they were coming directly from below rather than coming in from the side; hanging lights were vibrating up-and-down versus swaying side-to-side). Cracking of their homes walls indicated some significant lateral motion occurred as well.

One comment from a person near the base of Peavine Mountain was that unlike many of the preceding events that seemed to hit with a bang, like a truck hitting the building, the large event built up in intensity, had a stronger central portion, and then gradually died away.

Emergency Response

There was a light emergency response to the April 25 magnitude 5 event. Most people were ok and just observed what had happened and checked on one another. There were a couple dozen calls for assistance in Mogul, Somersett, and western Reno. Most were related to water heaters moving or falling. In two reported cases the gas lines were leaking at water heaters and the fire department turned the gas off, and in all the other cases, water lines were broken and were leaking. In one case the owner turned the water off, and in the other cases, firemen turned off the water. Fire personnel commented that it took people about 15 minutes to realize and assess what had happened before they started calling in. There were other cases of broken water pipes and damaged water heaters where the owners turned the water off and handled the situation themselves.

Rocks fell in and partially blocked a water canal and section of its flume was broken by a rock fall, both instances sending water flowing through the backyards of homes (**Figure 10** -see utilities section). Quick action by local water company employees diverted the canal water upstream into a drainage ditch and turned the canal off to avoid further damage.

Figure 10 A rock fall broke the water flume and caused water to flow near houses.

As earthquake magnitudes increased in the sequence, so did the response readiness, as emergency responders and managers keyed into the threat. In **Figure 11** a response of a local fire station to three magnitude 3+ earthquakes in the morning was to bring the fire equipment out of the firehouse during the day until the earthquakes settled down. The escalating sequence created a natural anticipation of a larger earthquake.

Figure 11 Fire engines were pulled out of fire houses following a series of magnitude 3+ earthquakes within 12 hours. This occurred in June and the nice day made this an easy preparedness action. In a worst case scenario where the doors are stuck with equipment behind it, firefighters felt they could cut off a jammed or otherwise un-opening door in about three minutes.

Communication

The only communication issue was a “barrage” of calls to the 911 emergency communication system. Most calls were reporting the earthquake, asking for information, asking when the earthquakes would stop, or elderly people wanting to know what to do. An observation was also relayed that this was a night-time event, and there are many more calls when people are at home versus at work (maybe at work there is someone to talk to about it?). Only a single emergency was telephoned in to 911 and this was break in a canal causing water to flow near houses.

The 911 system is only to be used in an emergency. Making a non-emergency call to 911 during a disaster can literally cost the life of another individual if a telephone line was not available to set in motion a rescue. The interpretation of what is an emergency may vary somewhat from person to person and situation to situation, but one thing is clear, ***telephoning in to 911 that an earthquake has occurred is NOT an emergency call!*** **Neither is asking when the earthquakes are going to stop.** 911 operators are formally notified about earthquakes and no one knows the specifics of earthquake behavior, like when earthquakes will stop. This is a behavioral request we can specifically ask of people to help mitigate 911 saturation during earthquake emergencies.

Because most non-emergency calls to 911 come at night, people have to be particularly vigilant at nighttime not to make non-emergency calls to 911. Once you begin a call to 911, do not hang up and call again; in Washoe County your hang-up call will be addressed by a 911 operator calling you back, again tying up the system if it is a non-emergency.

An aspect to consider here is that this is a behavioral response of people, a need for other people in the scary and uncertain time of an earthquake. In a perfect world, there might be an earthquake hot line bank that could be quickly staffed or a series of live earthquake messages that could be put out on the radio that people would know were going to be said and if it helps them they could tune in for real time information. We can ask people not to call 911 and hopeful achieve some success at this, but it doesn't address a need people have to talk to someone, which is highlighted by the increase calls to 911 at nighttime. Addressing this need could be a side benefit of promoting more strongly that neighbors check on one another following an event. Throughout all historical earthquakes it is evident that it is hard for a person to go through the experience of a strong earthquake and hold it inside. People immediately begin to talk about what just happened to them and listen intently to what happened to others (they are trying to make some quick sense of it all). What we need to do is ask people to have this exchange of what happened with their neighbors instead of 911 operators.

Injuries

There was only one injury I am aware of from the April 25 earthquake, and that was an unspecified shoulder injury from a falling bookcase. The resident refused assistance and took care of themselves.

Building Damage

Overall buildings survived the magnitude 5 event well, which doesn't seem too surprising, but it was very shallow and likely within a mile (1.6 km) directly beneath structures. Houses and buildings in the near field performed well, although the rocking of homes back and forth cracked the paint and plaster along drywall seams, wall and ceiling corners, and diagonally up from doors and entry way openings (**Figures 12 - 15**); the repair of a house with these cracks in it can cost a couple of thousand dollars. In some cases, movement of the garage was enough to pop many rocks off of a decorative rock veneer, and in a few homes the outside stucco was cracked (**Figures 16 - 21**). On some homes with tile roofs, a few tiles were dislodged.

There was no systematic inspection of homes or safety tagging. Building inspectors from the city and county (different parts of the earthquake area are in different jurisdictions) received a total of about five calls to inspect earthquake damage. In none of these cases was there major structural damage caused by this earthquake. In two instances there were displaced garage walls (**Figures 22, 23, and 24**). In both of these cases, the garage wall was shifted about one inch (2.5 cm) to the side which sheared 16D nails that attached the sole plate of the wall to the mud sill (which was anchored to the foundation). The estimated cost to fix this to one of these houses (along with nail popping and seam damage) was between $5,000 to $10,000.

Figure 12 Cracking of plaster and paint in entryway of a home.

Figure 13 Cracking and chipped paint was broken away from the seam from rocking motion of a house.

Figure 14 Damage to plaster and paint along seams in a kitchen from rocking motion of house.

Figure 15 Common position of diagonal cracks near top corner of entryways or openings.

Figure 16 This house was rocked back and forth, cracking the stucco in the lower part, near the top of the three garage door openings. The slope created a small vertical irregularity in the structure and the garage door openings acted as a relatively soft first story.

Figure 17 Close up of cracked stucco from rocking motion of house in figure 16. Note the gas meter that apparently flexed along with the motion successfully.

Figure 18 Horizontal fracture in stucco exterior of a house.

Figure 19 Overview of house shown in figure 18. Crack is on the left side of the building between the first and second stories.

Figure 20 Decorative rock was popped off the garage, caused by the movement and distortion of the garage during shaking.

Figure 21 Detail of dislodged and damaged decorator rock.

Figure 22 Corner of garage wall is displaced off the mud sill and a few decorator bricks have been knocked off (photo by John Anderson)

Figure 23 Inside view of displaced wall shown in figure 22. Offset at the side of the garage door and at the corner of the wall of about an inch can be seen; note the daylight showing just above the mud sill (photo by John Anderson)

Figure 24 Corner of garage wall displaced to left off its mud sill. The gas meter handled movement successfully. (Photo by John Anderson)

There were some reports of homes that were wracked enough that some doors stuck in the door frames, but inspectors guessed (they had not seen most of these) that this might be localized damage versus damage to the entire house. There were a couple reported cases of foundation damage (settlement of fill?), but I did not verify any of these.

The column of one store appeared displaced slightly and was braced for reinforcement with four-by-fours (**Figures 25 and 26**).

Figure 25
Pillar displaced at top slightly is braced for aftershocks.

Figure 26
Top of pillar shown in figure 25 displaced from top about 2/10^{ths} an inch.

There are a large number of earth-fill pads and rockery walls in the earthquake area to support the foundations of homes in this hilly landscape. Some rockery walls I observed had individual or a few rocks that fell off the top, or out of (**Figure 27**), the wall, there were many instances of cracks in the fills behind rockery walls, but most rockery walls I observed appeared to perform well and had no cracks or loss of rocks.

Figure 23 Boulder that fell out of the middle of a rockery wall (boulder is laying on the ground in front of the wall, closet to the red curb).

The cracks were near or a few feet (~1m) into the fill and were commonly subparallel to the rock wall. In most cases I looked at, the rock wall itself seemed unaffected. But the crack needed an explanation. In addition to settlement of the wall filter material and fill, there may have some out-of-phase shaking of the rock wall versus the pad. The cracks indicate some sort of "preserved" tension. The parallel to subparallel nature of the cracks with the rockery wall indicates some relationship with the wall, or at least the edge of the fill that the wall is at.

In one case, the crack appeared due to settlement of the fill adjacent to the rockery wall, or the wall and fill settled together in places (**Figures 28, and 29**). This crack was over 320 ft (100 m) long, with vertical offsets as much as 7 inches (17 cm) across it, although most of the crack didn't show visible displacement. The crack was mostly continuous, but was discontinuous towards the ends. On one end, discontinuous cracks stepped back, but remained subparallel to the larger rock face, even though the slope curved back.

There was one case of a fill that was under construction and lacked a retaining wall; there were cracks in the top but these appeared to be mostly related to the slight failure of the slope below.

Figure 28 shaking and settlement fracture along the upper part of a large, three-tiered rockery wall. Total settlement was about 7 inches (17 cm) in places.

Figure 29 Approximate settlement of fill adjacent to the rockery wall in figure 28; scale is in centimeters. Here the scarplet is about 4 inches (10 cm) high.

Nonstructural Dislodgement and Damage

There was significant nonstructural dislodgement and damage in Mogul, Somersett, Verdi, south of the Truckee River from Mogul, and in westernmost Reno. Dishes and glassware fell from kitchen cabinets and china cabinets, dressers, book cases, and shelving were overturned, and pictures and mirrors fell from walls and were broken, and many that were left on the wall were tilted (**Figures 30 – 39**). Plastic covers over fluorescent lights in ceilings fell out and many broke. Some televisions fell over, and in one case a fireplace insert came out of the firebox breaking the connection with the stove pipe. In one strange case, a second-story toilet bowl shattered sending water out and down the stairs. At least one glass shower door was shattered. Random tiles were dislodged from several house roofs, and some of these were thrown to the ground.

In local grocery and other merchandise stores, a number of goods were thrown from the shelves, most of which were re-shelved. One wine store close to the event, however, lost hundreds of bottles of wine that were vertically displayed, at an estimated cost of $3,500.

Figure 30 Broken dishes and cups and drawers open in kitchen from the main shock. (photo by Terry Nielsen)

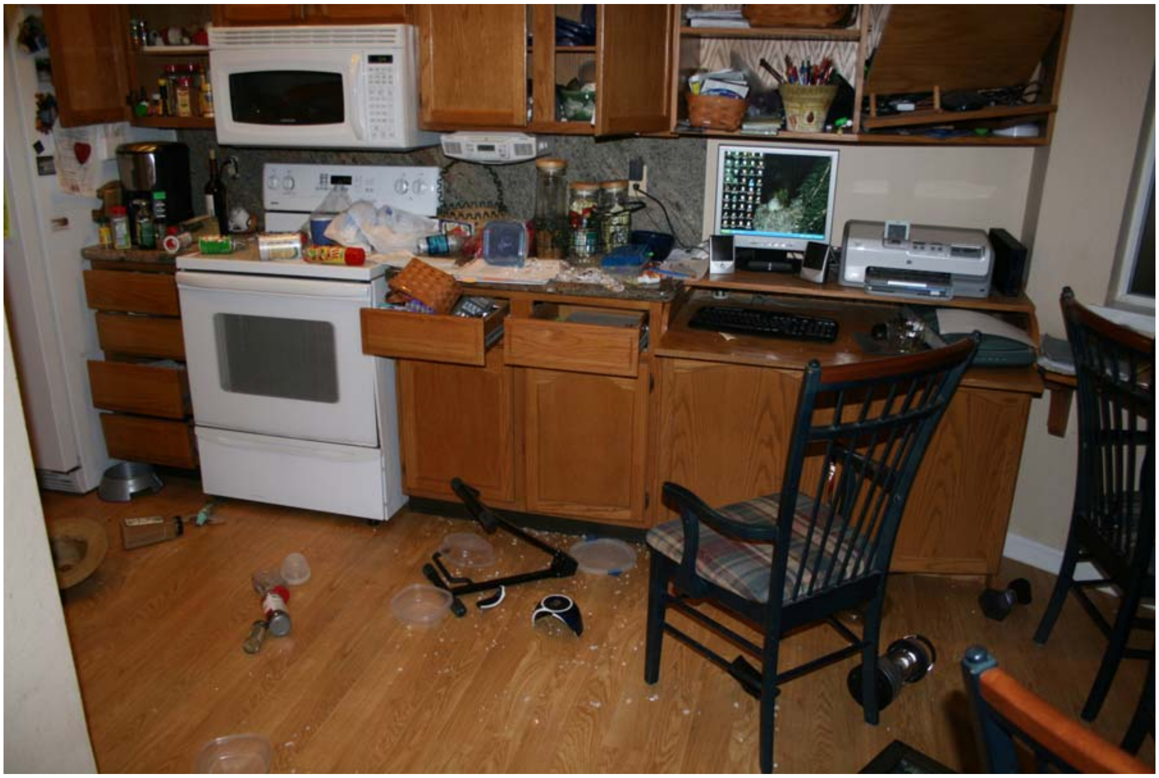

Figure 31 Kitchen with earthquake effects.

Figure 32 Fallen and broken mirror (photo by Terry Nielsen).

Figure 33 China cabinet that was attached to the wall, but the doors opened and some glasses fell out, breaking on the floor. Amazingly, the empty vase collection on top of the cabinet survived.

Figure 34 Broken glasses on the floor from the china cabinet shown in figure 33. During the earthquake the occupant ran through the house in slippers over glass on the floor to check on their kids.

Figure 35 Television flopped over from the earthquake. The low position of the television avoided major breakage and a significant safety threat.

Figure 36 Brick and wood shelving that collapsed from shaking. (photo by John Anderson)

Figure 37 Dislodgement of some items in a pantry. This is usually an acceptable misfortune of an earthquake. The cost is generally cleaning it up and loss of some broken items. More breakable and heavier items can be stored lower and the lighter items, like paper towels, can be stored higher to minimize losses. (photo by John Anderson)

Figure 38 Fallen picture with broken glass cover. (photo by John Anderson)

Figure 39 Telephone knocked over by shaking and with the receiver "off the hook". This affect likely caused a telephone line to be taken up for a period of time. In the post-earthquake inspection of a house, all telephones that are knocked off the hook should be placed back on, or unplugged to avoid further disruption from aftershocks if it is a secondary or generally unused telephone (photo by John Anderson).

There were two gas leaks and at least four water breaks in homes associated with the earthquake, all related to moving or falling water heaters; none of these created an emergency situation. The breaks were called in and local fire personnel came and turned off the gas or water for residents. In at least one case, plumbing was broken in the second story of a house while the owners were away causing extensive water damage, including sheet rock damage.

Most water heaters were strapped, or better yet, double strapped (yes you can put more than one) and stayed in place, although many had to be tightened back up (**Figure 40**), and at least a few pulled their fasteners out of, or nearly out of, the wall (although in these cases the water heaters still stayed upright). It is uncertain how many water heaters tipped over or pulled away from walls. Those that broke their connections requiring the turning off of their lines appear to have been a relatively small percentage of the total number of water heaters exposed to strong shaking. The earthquake effects on water heaters underscore four notions. First, it is important to have water heaters securely strapped, or double strapped, to the studs of a bearing wall in Nevada. Second, it is important for individuals to know how to turn off their gas or water to their house when a leakage occurs. Third, you need to check water-heater attachments following an earthquake and retighten them if necessary as they can be loosened by the event. And fourth, the exhaust pipe needs to be inspected for any misalignment that may have occurred during an earthquake, including strong aftershocks (**Figure 41**). A leaking exhaust pipe can cause carbon monoxide poisoning.

Figure 40 Water heater subjected to the moment magnitude 5 event. Double strapping of the heater helped it stay in place. The upper strap has been loosened during the shaking and needs to be slid up straight and re-tightened. The straps do quite a bit of work holding the water heater up during an earthquake and need to be inspected following an event for any adjustments.

Figure 41 Exhaust pipe of a gas water heater showing a slight misalignment from the earthquake. The exhaust pipe also needs to be inspected following earthquake shaking because an exhaust leak can lead to carbon monoxide gas poisoning.

House chimneys faired well during the earthquake, although there was at least one that spilled some bricks from its top (**Figure 42**). Most chimneys in Mogul and Somersett are not made of brick, however, but are wood exterior boxes with metal stove pipes going up them, so they are not as susceptible to shaking as brick chimneys (they are relatively light, flexible features).

Figure 42 Several bricks were thrown from this chimney near Mogul.

There was a significant amount of glass that littered the floor from this earthquake from broken picture frames, water and wine glasses that fell, vases, figurines and the like. The broken glass on the floor of this nighttime earthquake reinforces the importance of having a pair of sturdy soled shoes along side your bed. For many people this was the largest hazard they faced. Even if you only break a few glass items in each room, this is still quite a bit of glass to get through and the likelihood of a cut on your foot goes up without solid soled shoes. This includes children that might be wandering (running) through the house looking for their parents. They need to keep sturdy shoes near their bed and know to put them on after strong shaking.

Preliminary Modified Mercalli Intensity Map

A preliminary Modified Mercalli Intensity map (**Figure** 43) for the April 25 earthquake is based on observations and reported effects from this earthquake (Modified Mercalli Intensity is a measure of the effects on people and structures from an earthquake). All the lines are approximations. To help account for the uncertainties involved and the gradational nature of these boundaries, ranges of intensities are assigned to areas. There was some wall base damage and some minor damage to at least one chimney, so Modified Mercalli Intensity VII was being approached (intensities are given in Roman numerals). There were cracked walls and a few cracked windows in Mogul and Somersett indicating an intensity VI. Immediately outside of the damaged areas, people were awaken from their sleep or all people who were awake felt the earthquake indicating an intensity of V. The map indicates that the most severe effects were in the near field of the earthquake.

Intensity VI to VII effects occurred in Mogul, upper Mogul (immediately west of Mogul), and part of Somersett. In the neighborhoods between Somerett and roughly Rob Drive to the east there was a lot of nonstructural dislodgement, but wall cracking was isolated. In this area and in Verdi, nonstructural dislodgement and damage was more pronounced in second stories of homes and buildings. The USGS Community Internet Intensity Map indicates that intensity V was experienced throughout the greater Reno area.

Damage to Utilities

Only one utility appeared to have been damaged by the earthquake, a water canal used as a source for a local water treatment plant. An elevated and trussed section of the canal was struck by a rock fall and collapsed (**Figures 44, 45, and 46**). There are alternate water sources for the treatment facility, but the canal is needed for the increased summer water usage so a chain link blanket was lowered by helicopters to secure the slope from future earthquakes (**Figure 47**).

Elsewhere, numerous rocks were "caught" in the canal, some of these would have traveled into a neighborhood had they not been stopped by the canal (**Figures 48, 49, and 50**). The rocks will have to be cleared before the canal can be used again.

A major gas line and freeway cross the southern projection of the magnitude 5 earthquake and neither has any known damage (including two small underpasses that were close to the rupture). A local underpass's columns are wrapped in an apparent seismic-resistance measure and other bridges along the freeway have been studied and enhanced for earthquake resistance by the Nevada Department of Transportation over the last decade.

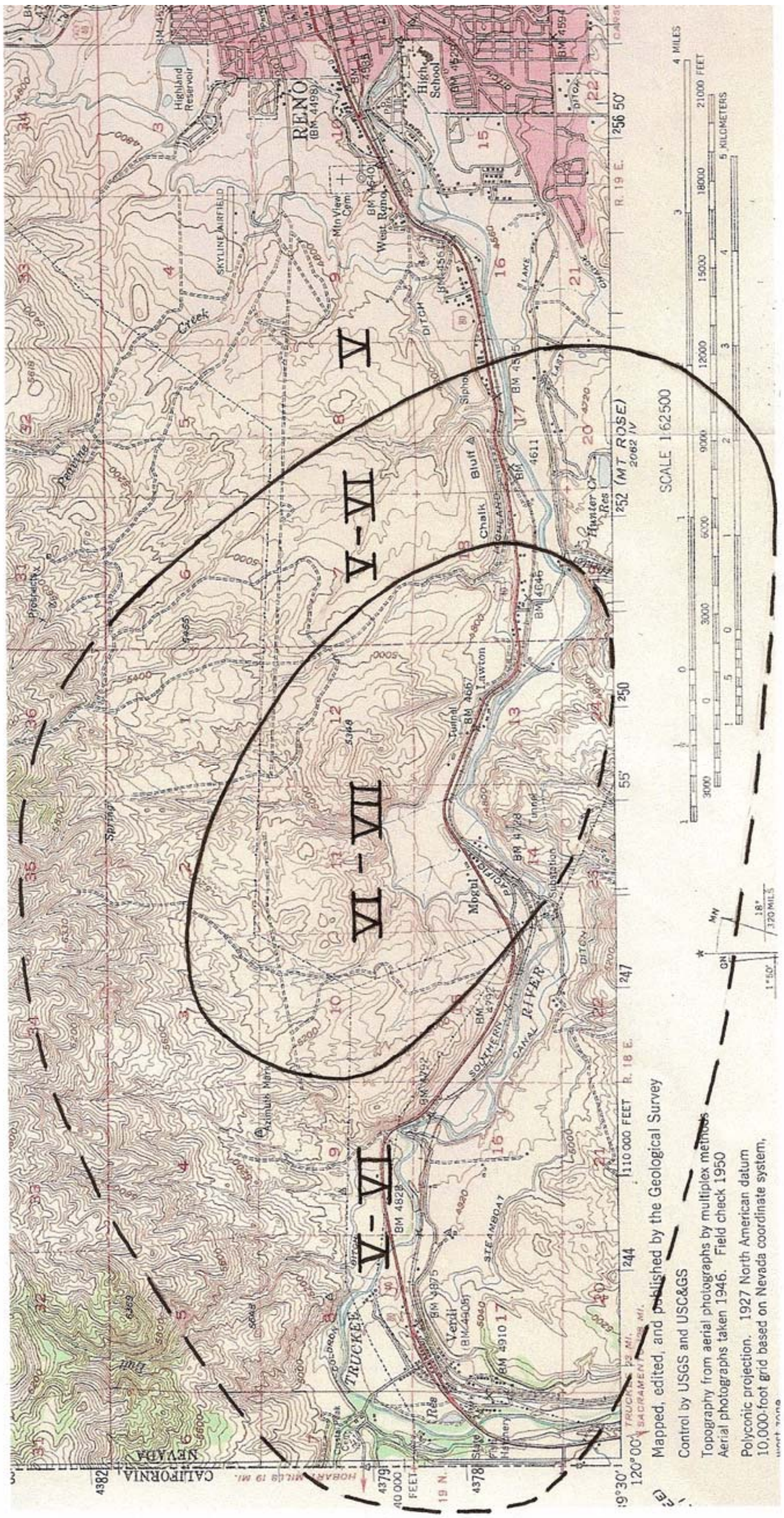

Figure 43 Modified Mercalli Intensity Map for the April 25th (PST) moment magnitude 5 earthquake. Intensity V is felt by all and people who are asleep were awakened by the shaking. Intensity VI is shaking that knocks items off shelves and creates some cracking in walls. Intensity VII is shaking severe enough to damage chimneys and walls; in a few cases damage was on the threshold of Intensity VII. The lines are dashed where they are less certain.

Figure 44 Rock fall damage to water flume.

Figure 45 Rock fall damage to water flume.

Figure 46 Part of the rock fall that damaged water flume.

Figure 47 Mitigation technique used to secure the rock-slope against future earthquakes. Two large helicopters dropped this chain-link netting over the outcrop.

Figure 48 (above) A large boulder was dislodged by the earthquake, rolled down the hill, and was fortunately caught by the water canal, as there are houses below.

Figure 49 Cleared dirt path made on the hillside from the boulder shown in figure 48.

Figure 50 Rock slide of boulders that were coming down the hill and were trapped by the water canal.

Pre-Event Mitigation

This was an extraordinary earthquake sequence in that it built gradually over time giving scientists and emergency managers time to get out safety and preparedness messages and information, and giving people a little time to get prepared before the earthquake. Escalating earthquake magnitudes in the sequence convinced people the threat was real (perhaps even imminent) and the time for action was now.

Mentally, the Mw 5 earthquake was something to endure that was distinctly larger than the rest, but by the time it came around, the locals had felt many earthquakes, so the brute surprise of the event wasn't there; it more needed to be ridden out differently. Many people were in bed when it began, and contrary to what we would like, many got up and moved around during the short event, checking on their kids and the like.

Prior to the main event, scientists held a press conference emphasizing earthquake preparedness, answered phone calls, and delivered safety booklets to the area. Over 1000 booklets titled "Living with Earthquakes in Nevada" were delivered to the area of the earthquake sequence prior to the Friday night event (this is a 36-page earthquake preparedness guide). The local County emergency management group has an excellent preparedness and mitigation web site (ReadyWashoe.com) and was encouraging people to visit this in press conferences and television spots. The local university sent out preparedness emails to students and faculty and prepared an earthquake preparedness flier which was distributed.

Many people took these messages to heart and mitigated nonstructural hazards prior to Friday night's earthquake (April 25^{th}). In one case an individual, who lives near the epicenter of the mainshock, strapped up his water heater (along with others) the day of the earthquake (likely motivated by the two M4 events on April 24). Consequently there were many items moved to safer locations or secured that were saved from damage, loss, and creating injuries or hazards (**Figures 51, 52, and 53**).

Figure 51 Mitigation works. Mitigated, more-valued journals stayed in shelves, whereas less-valued journals need to be re-shelved following the earthquake. This house was near the epicenter. (photo by John Anderson)

Figure 52 Simple mitigation for china cabinet used by many local residents. In this case, a simple rubber band that you might find around a newspaper saved dishes and glasses from falling to the floor and breaking during the Mw 5 earthquake. The cabinet was not anchored to the wall. (photo by Gesila Anderson)

Figure 53 Detail of the rubber band that defeated the magnitude 5 earthquake shown in figure 52. (photo by Gesila Anderson)

Earthquake Insurance

Earthquake insurance was being advertised in Nevada following the 2008 Wells, Nevada earthquake. Some people took advantage of this right away, and many were motivated by the April 15 increase in earthquake activity. Both individuals and companies were buying earthquake insurance. Insurance was sold up to the magnitude 4's on April 24, the day before the Mw 5 event. This event did not do enough damage to trigger any policies that I am aware of, but one company has subsequently cancelled all policies with 5% deductibles and transferred them to 10% deductible policies.

Something Nevadans should be aware of with earthquake sequences is that there is a relatively short time frame that is considered to be a discrete earthquake for claiming purposes by insurance companies. For example, if two damaging earthquakes occurred more than about 168 hours, or seven days, apart (this time varies by company), these would be considered separate events with separate deductibles to be reached (so if you have a $30,000 deductible and there is $25,000 damage in each event separated by enough time, you don't get any insurance money even though you had a total damage from the earthquake sequence that was $20,000 beyond your deductible). This is usually not an issue with a single large mainshock, but it can be a surprise and frustration for people exposed to damage from multiple earthquakes in a sequence that are separated by over a week.

Post-Event Mitigation

The occurrence of the Mogul-Somersett Earthquake Sequence and the February 2008 Wells, Nevada Earthquake have created a distinct window of opportunity for earthquake mitigation in Nevada. The next day following the magnitude 5 earthquake, an employee at a large warehouse store estimated that about 70% of all sales that day were related to earthquake mitigation. The State Seismologist prodded managers at one store to make sure mitigation materials were in stock and to set up a mitigation supply table up front to make it easy for people looking for supplies.

With such activity, the general preparedness suggestions are put to the test of applicability and situations arise where effective mitigation is not obvious. For example, some rooms will not have places to take cover (bathrooms and sometimes bedrooms) and thus the whole room becomes a "safety spot"; there should not be a threat of nonstructural harm in these rooms, anywhere. If strong shaking occurs when you are in bed, you will either not be able to get out of bed or if you do get up, you could be thrown to the floor (possibly getting an injury on the way down). Nonstructural items in these rooms need to be secured so they can't fall, you are not threatened, and you feel safe that you can ride out the earthquake where you are.

The 2008 Mogul-Somersett Earthquake Sequence and the 2008 Wells Earthquake aftershock sequence indicate that there are two levels of readiness for earthquakes. There is a standard preparation for earthquakes that can occur anytime and there is higher state of readiness that occurs when we are faced with the possibility of an imminent earthquake. All Nevadans can experience a strong earthquake anywhere in the State at any time. Thus, we must live with earthquakes, incorporating mitigation and preparedness as a part of our lives rather than a special activity. An earthquake can occur at anytime at the 2008 Wells Earthquake indicates. But two populations in Nevada have recently faced higher probabilities of an earthquake occurring near them and in the near future, distinctly different from the general earthquake threat for Nevada. These populations responded instinctively to this increased threat and acted accordingly. The reaction was a mix of temporary and permanent mitigation activities. Some of the seemingly extraordinary, yet perfectly logical steps taken include spending a couple of months with the pictures taken down (or anything above waist height that could break for that matter). Some people kept their cars outside as a state of readiness. For some, this level of readiness was only maintained for about a week following the event, after which they personally surmised the threat was over, and for some it was a couple of months.

Response of Visitors to the Earthquake

Hundreds of visitors to Reno hotels and casinos checked out early following the Mw 5 earthquake. Hotel workers were surprised that many of those checking out were from California and thought they should be "used to earthquakes." Actually the opposite notion may be true, that because Californians are familiar with earthquakes they are quick to anticipate aftershocks or a larger event.

Interestingly Reno visitors responded the same way to the 1948 Verdi, Nevada earthquake. The *Humboldt Star, Battle Mountain* December 30th edition tattled on Reno's uneasy visitors by noting there was an "exodus" of visitors from Reno that was described as "unusual" by bus lines, airlines, and railroads. The Star noted: "Hotels in general declined to admit how many visitors actually checked out. One however, finally admitted that "maybe a dozen or more people left immediately after the first quake and some others left later."" The paper reported that the checking station on Highway 40 (now Interstate 80) reported an "unusual number of west-bound cars with non-Nevada license plates" on the day of the earthquake (it was an early morning event).

Rumors and Rumor Control

As in other cases where people are fearful, rumors are a major part of the event. Careful monitoring of these and decisive action with clear messages can minimize the rumor and its effects. A volcanic eruption was a concern of many residents who had many other legitimate concerns as well. There are Miocene basalts that are visible and there is a local, small geothermal spring giving a visual reinforcement. This was effectively dealt with by a deliberate and reinforced message that there wasn't going to be an eruption for several reasons, but this nevertheless was a persistent low-level rumor and required some maintenance for a couple months.

The Nevada Seismological Laboratory adopted the vocal position that there are no earthquake predictions, and if you are reporting on one you are being irresponsible. This message was adopted early on and was never really challenged or developed. The strength and consistency of the message made it universally adopted as a fact by the media and earthquake predictions were not a distraction or an issue. Any serious earthquake predictions were to be forwarded to the National Earthquake Prediction Council for review.

The “Triangle-of-life” was injected in the community, but this was quickly countered in a single news cycle by citing reviews conducted by the Nevada Earthquake Safety Council and FEMA, access to internet truth sites, and describing the differences in response so people could make up their own mind. This philosophy was also injected into the aftermath of the 2008 Wells Earthquake and generally confuses people about how to react during an earthquake. The Nevada Earthquake Safety Council reviewed the triangle-of-life procedure and sides with FEMA and the Red Cross to stay with “Drop, Cover, and Hold” in Nevada. The triangle-of-life message is based fundamentally on scaring people that they are going to be crushed to death during an earthquake. It makes people think their houses are going to collapse on them, which is highly unlikely and it not really a useful concern or decision-making factor. Following the collapsed buildings with the recent devastating Chinese earthquake, people are again worried about collapse. They have abandoned the terminology of “triangle-of-life” but still talk about finding gaps to survive in rather than protecting themselves from the more dangerous nonstructural hazards.

The “Drop, Cover, and Hold” advise is based on observations from earthquakes that have occurred in the United States, not in other countries that might build their buildings differently and be faced with other issues. We are trying to reduce the number of people who are injured or killed and in the United States, this is usually from nonstructural damage. Although the United States is not free of dangerous buildings, it has been working hard to encourage and regulate for buildings with life-safety seismic resistance, and especially homes, which can have continuous occupation and are the easiest to design for earthquakes. People, waiting in open places that will supposedly become voids, are vulnerable to being struck by the obvious hazards (lamps, pictures, etc.), as well as ceiling tile metal holders that can cut, lights and light fixtures, computers, book cases, and the like. If we follow the “triangle-of-life” approach in Nevada we will have more injuries, a larger emergency response required (triage, doctors and nurses, hospitalizations, medical supplies), and more Nevadans will have their lives negatively impacted. “Drop, Cover, and Hold” would cause just the opposite, fewer injuries, less lives negatively impacted, and more able-bodied people to help with recovery.

Surface Fracture Survey

This was a relatively small earthquake that would normally not break the ground surface, but it was shallow, so I conducted a survey for any surface-ruptures. It will serve as a base-level survey as well.

I've completed road surveys in the far field, walking transects in the near field and in the hills north, west, and east of Mogul, and have crossed the projection of the Mw 5 earthquake several times. Much of the volcanic rock is covered with a clay rich colluvium that has shrink-swell cracks and, in many places, shaking cracks or enhanced shrinkage cracks. Surface cracking could be masked in these. In all these surveys no surface fractures from fault displacement were found.

There is some indication of ridge top fractures, probably from strong shaking in the hills east of Mogul. There were a couple areas of more continuous cracks that are not along the main earthquake trend, but are along faults; these were flagged and monitored, but appear to be shaking related and are limited to clayey materials. I inspected the area of rock fall that damaged the water flume in some detail because the earthquake projects near this; the rock fall appeared to be caused by shaking and not any kind of fault offset.

I have investigated a few of the cracks in the yards of Somersett and these appeared to be related to shaking or earth-fill settlement and were not tectonic.

Several faults mapped on Bell and Garside (1987) were inspected and none had definitive evidence of fracturing or movement. One weak equivocal case is the fault mapped between basalt and granite immediately north of Mogul. A recent road cut across this fault has been the source of some discussion. Along one fault trace, recent debris has fallen from the road cut some traces have at least shallow fractures along them. Whether this is movement or shaking related is hard to tell, but a lack of supporting evidence indicates it is due to shaking. There are other parts of the road cut that have cracks, but the area of scrutiny has more. However, there is no evidence on either side of this fault for any cracking of the ground surface or dirt road that might be related to the cracking in the road cut.

Subterranean Rumbles and Continuous Ground Tremor

Subterranean rumbles have been heard and commented on for earthquakes in this region, one of the most notable being the 1948 Verdi Earthquake (M6). The sound of a small earthquake can be described as distant canon fire. Rumbles are a sustained level of the “distant canon fire sound” and can also be likened to the sound of a distant train. They are described faint or loud, which could reflect the intensity of the phenomenon or might be related to different distances of the activity from the observer. During 1948 they were heard regionally for about a year prior to the event (Bell and others, 1977) and were associated with the two magnitude 4.3 foreshocks that occurred the day before the main event.

Most people living in Mogul and Somersett witnessed subterranean rumbles. On April 26th in the late afternoon I heard rumbles with neighbors in Mogul and on April 27th in the late afternoon, I heard some rumbles with neighbors in Somersett. In Mogul, the sounds I heard were at a very low level and sustained for minutes on end. They were punctuated by small earthquakes that didn't always come from the same directions as the sounds. A person familiar with sound engineering who lives in Somersett guessed the rumbles were occurring at roughly 15 Hz and that people were mostly hearing harmonics or overtones of these vibrations.

The rumbles in 2008 are commonly, but not always, accompanied by discrete earthquakes or ground tremor. Prior to the April 25th event and for a few days afterwards, rumbles occurred before and after events and for prolonged periods of time. Subterranean rumbles were reported as being particularly loud in Mogul around 11 p.m. to midnight on April 26th. For a while following about April 29th, rumbles preceded distinct microearthquakes and ceased following the event. More recently in May and June, rumbles seem to be only occasional events lasting 10 minutes to about an hour.

Earthquakes and People

The 2008 earthquake sequence occurred directly below two communities, Mogul and Somersett, where a few thousand people live. The shallow nature of the earthquakes (1-3 miles; 1-5 km) created an extraordinary situation where people have been subjected to literally hundreds of earthquakes, ground tremor, and subterranean rumbles that they have sensed. If you are familiar with the terms bangers and rollers for earthquakes, most of the earthquakes up to April 25 were bangers in the local area (because of their shallow nature and proximity). This repeated exposure to shaking and anticipation affected people's behavior and well being.

Understanding this situation, people's reactions to hundreds of earthquakes, gives insight into the best approaches for people to cope with earthquakes and possibly into precursory behavior before earthquakes, such as animals showing uneasiness immediately preceding a seismic event.

Earthquakes scare people; it is a natural reaction. Even scientists studying earthquakes can be scared by strong ground motion. This fear is generated by shaking (especially violent shaking), the fear of the unknown (will a bigger earthquake occur?), and a sustained background anxiety brought on partly by a subconscious trembling of the ground. This isn't a comprehensive list, just some observed effects. The earthquakes also caused severe sleep deprivation, diminishing people's capacity to cope with the relentless events. Subsequent waning of earthquake activity has relaxed, but not entirely alleviated, this anxiety (the earthquakes have not entirely stopped occurring).

In conducting an experiment to calibrate the time delay of an earthquake occurring and seeing it our computer shortly following a magnitude 4.2 event, I noticed three physical/psychological states I was experiencing while I sat on the ground, not far from where it occurred. There was ground motion that I had to slightly adjust my balance to, mostly related to discrete small earthquakes. To my distinct sensation, there was stillness (this is what triggered my attention). Stillness and absolute quiet were wonderfully stress relieving. It was sweet. It was good to be still. I really liked it, every time it happened. As I continued to observe, I noticed a third state of uneasiness. I felt tense, but didn't really notice ground motion. As I began to analyze this I realized the ground was vibrating just below perception, as I could occasionally sense the stronger parts. I believe my body and mind was sensing this ground movement at an subconscious level and it made me uneasy (maybe something like being constantly keyed up to adjust my balance). Thus, even though I could not consciously sense shaking I was experiencing, for significant periods of time I had sustained low-levels of anxiety or nervousness, that would dissipate with stillness.

When living amongst earthquakes, people become much more sensitive to ground tremor than others not subjected to this. This can be a significant sensory enhancement; as a guess, people become about an order of magnitude more sensitive to movement than others. They can sense real, very small earthquakes that others can't feel at all (one person felt they could sense earthquakes as small as magnitude 0.6. We likely filter this out in day-to-day life because normally it is due a vibration from equipment in a building and not a source of danger. With heightened awareness people stop and are alert even at a creak of the house or the abrupt closing of a door (there is some mental coupling with sounds and vibrations).

Experiencing earthquakes, however, heightens senses and thought processes, so the body is definitely keying up to anticipate danger. The most straightforward interpretation is that it helps give a little forewarning that an earthquake is about to occur. Whereas a person not exposed to earthquakes might not hear a faint rumble in the distance or at best would wonder what it is, people of shaking country will immediately recognize this as an approaching earthquake, giving a second or so of extra heads-up that one is coming. This swarm has been occurring so shallow that there isn't this kind of warning for most events, but at neighborhood meetings and visits with residents their behavior was such that they clearly anticipated some events faster than me.

The longer one is subjected to these shaking/vibration effects, the more this appears to create a sustained level of anxiety. In this extraordinary earthquake sequence, this has basically worn some people out. One of the main effects most people have experienced for over a month is sleep deprivation. Small earthquakes wake people up and it can be difficult to get back to sleep. There have been nights where small earthquakes have been accompanied with audible subterranean rumbles which also keep people awake.

People living over the earthquakes have coped with this experience in a wide variety of ways. There are many who have come to terms with earthquakes by understanding and characterizing them. Most people subjected to earthquakes become good at estimating their magnitude (as long as the earthquakes are located in roughly the same place). This helps people at least understand the phenomena better and give them a personal interpretation of the event, like judging there is a strong wind blowing versus a light breeze. People use duration first and strength of shaking second in their magnitude estimates. Shaking duration is also used as a general measure for earthquake severity, with three seconds being the difference between an earthquake that is just a nuisance and longer duration events that are more severe and may do damage.

Mitigation and preparedness are definitely a general coping mechanism people have used. They felt safer because things that could fall are taken down or the car is parked outside the garage, turned in a get-away position. This allows people to feel like they are as prepared as they can be, and even though it is scary, they are ready to ride out a strong earthquake, such as the recent Wells, Nevada event. Again with the analog of a storm, they are ready for the storm to hit. Some people slept in their trailers for a while feeling they eliminated the possibility of the house collapsing on them or to avoid being subjected to more nonstructural damage (people generally did this following the Mw 5 event). In the Somersett area, many residents are new (have only been in their homes for six months to a year) which may give an additional unfamiliarity to the situation, in comparison to some residents of Mogul which have lived there for years and are comfortable with their surroundings. As usual, humor and life perspectives also are also major coping mechanisms. And as for those rumbles, just turn up the music a little louder than they are.

There are some who are fairly unbothered, and don't really see a need to mitigate or do any whatsoever to get prepared for earthquakes. The couple of people I encountered with this approach expressed the situation as one of fate and what will be, will be.

The message gained from watching the people of Wells and Elko County of adopting a *pioneering spirit* to get through earthquakes seemed workable with most people of Mogul and Somersett. They accepted there were going to be hardships in life and we have to get through them and be stronger for it. Because we were talking about the future, the terminology *pioneering "courage"* was used in public forums and television interviews. For people making sense of it all, especially in the face of some pretty strong rumors, the terminology *pioneering wisdom* was also used; don't just believe and propagate some rumor coming from outside the community that doesn't entirely sound worthy and is "out-of-the-blue"; use your head, use your wisdom. Nevadans see the mountains out their front door and they know they are still a part of the west. The pioneers are those many admire for their ruggedness and fortitude, so it is a useful group to identify with for getting through disasters. There is also the parallel notion that the people of Wells survived their earthquake and aftershocks, and the people of Mogul and Somersett will survive theirs too.

Some people needed to get away for a couple days away from earthquakes where it was still for a break and some sleep. This helps people break the sustained levels of anxiety and relax a bit. It was an excellent strategy. For some this is easy because of a second home, cabin, or relatives or friends house to stay. For some they took an unplanned vacation or stayed in a regional hotel. And for some this was impossible due to financial limitations, work schedules, or lack of opportunity, and they just had to tough it out.

To some degree there were two groups of people in Reno during these events, those subjected to the earthquake sequence effects and most of the rest of Reno that have only felt some of the magnitude 3 and greater earthquakes, and just barely at that. In some mixed settings, such as work, people can't relate to those who have felt these events, and it has led to some misunderstandings or under-appreciation of the magnitude of the earthquake impact has had on some individuals. Many people simply don't realize what it has been like to live on top of these earthquakes or with constant shaking.

<u>April 25 Mogul-Somersett, Nevada Earthquake</u>

People handled the Friday Mw 5 earthquake fairly well, even though they were subjected to some pretty serious ground motion. People did not generally panic, but were definitely excited and nervous as they checked on each other and took stock of what just happened. The event definitely scared a number of people. Even though it was only a magnitude 5 event, it was shallow and was a very severe earthquake in the near field.

An exception to this relative control is an account from a large department superstore not far from the epicentral area. The initial M3.3 earthquake that occurred 11 seconds before the main event set signs in the store to swaying and caught the attention of many of the shoppers. When the second earthquake started, the shelves began to shake, contents began to fall off, and the roof seemed to be making a lot of noise as it flexed up and down so people ran towards the front entrance clogging it up as they tried to get out. People just dropped their merchandise and ran (there was already stuff all over the floor, as one person put it). Several people were reportedly screaming during and after the shaking. Checkers at the check-out stations were bewildered, but continued to check people out. At least a mild panic seems to have occurred in this store.

One resident I visited shortly following the event had fairly extensive nonstructural upheaval in their house (things weren't really broken so much as thrown around) and some damage. Their big concern wasn't themselves, however, it was some elderly friends on the other side of the subdivision; they wanted to know if their friends were alright. This was common. I ended up for other reasons near the elderly resident's home when people came to check on them. A few neighbors had the same idea and were approaching the home. A volunteer fireman with a truck and a Sheriff's Deputy who were cruising the neighborhood (visually looking for problems or to be of assistance) also pulled up and waited at the curb as neighbors knocked and checked on their friends, who were alright. This was a microcosm of how people reacted that night. After the event, people took stock of what happened in their homes, checked on each other to the degrees their familiarity with their neighbors and social constitution dictated, and then some when for short walks to see what else had happened, and perhaps as a small stress relaxation activity before facing an uncertain evening of aftershocks.

Over the weekend, many people held neighborhood meetings, gatherings, and barbeques to talk about what happened, share notes and stories, and think about being prepared as a neighborhood. Local meetings were also arranged by the community developer, one in which 350 people attended. Washoe County also arranged "Emergency Preparedness Community Forums" to talk about the earthquakes and encourage preparedness. These gathering and forums were important social events for affected residents and served as major coping mechanisms for the April 25 event.

For some people, the earthquakes were a bit of a game, fun to experience, up until the mainshock occurred. After that they dreaded the small earthquakes that make them tense with anticipation; after experiencing the magnitude 5 event, they now fear earthquakes. A few people simply do not wish to deal with earthquakes anymore and are moving out of Nevada as soon as they can sell their houses. In contrast, many people have taken some serious earthquake mitigation steps, and are feeling pretty good about it. They now feel more secure about their abilities to survive a large earthquake. This doesn't mean they are anxiety free, but mentally and from a preparedness point of view, these are probably some of the most seismically resistant Nevadans there are.

Ground Tremor and My Dog

For a couple days we had many felt events and several episodes of ground tremor at my house. Because there is commonly discussion of animal behavior with earthquakes, such as dogs acting up right before the 2008 Wells, Nevada Earthquake, I'll mention some of the responses of my dog, a very smart standard poodle. He had three basic responses to ground motion. To discrete events during this time period (when he became somewhat agitated about it all) he would commonly run and bark to the edge of the yard – then stand and sniff the air trying to identify the intrusion; he never could quite figure it out. With continuous tremor, he would pace around then give up after a while and lay down with his head lying on his front paws, and his eyes wide open, kind of looking around worried. When it was all too much, and after the magnitude 5 event, he came to the back door and cried; he was scared and wanted someone to hold him. My dog clearly was sensing very small levels of ground shaking and tremor.

Others closer to the earthquakes have noted their dogs were upset by the shaking and wanted to stay near their owners. Others mentioned that outside of some pacing, their dog didn't seem to care much. Our older dog slept through most of the smaller activity, but when the M5 occurred, he wanted to hide in the dog house, his safe den. Thus, there was a mix of animal behavior, but some dogs were definitely very sensitized to subtle ground tremor, and with their constant and more continuous contact with the ground, it might make sense that some dogs can sense earthquakes and precursory seismicity slightly before people can.

Afterword

After a long period of quiescence, earthquakes have returned to Nevada. Nevada has a long history of earthquakes, but they have never tended to slow down Nevadans, nor our Native American predecessors. Fortunately, with dozens of earthquakes throughout historical time, there is not one recorded death caused by one in Nevada.

Nevada ranks third in the United States with regard to major earthquakes, and many Nevada agencies have spent the last decade or so preparing for future earthquakes. Public buildings have been retrofit, highway overpasses have been strengthened for earthquakes, building codes with seismic resistance have been adopted and enforced, emergency response personnel, equipment, and facilities have been vastly enhanced for dealing with disasters – Nevada has been getting ready for earthquakes.

We still have some gaps in Nevada's preparedness, however, and one of them is individual preparedness. If people were more prepared for earthquakes there would be less of an emergency response needed, more people would survive, and recovery would be faster. Thus, individuals and families would be less impacted and would return to normalcy faster.

What we have seen with the opportunity to talk one-on-one with Nevada's citizens is that many of them have not taken the preparedness message to heart prior to recent earthquakes and were not really prepared enough for earthquakes. There were not hard soled shoes near beds, there were items that threatened their safety and their children's safety, there had not been a family discussion about earthquakes (really – how hard is this to do?), there was not specific disaster supply kit, there were glass items that could fall in walking and exiting paths, there were items that could fall and block exits, and many people appeared to not know how to turn off their gas lines to their house. This isn't good enough folks.

You just have to pay a little more attention when living in earthquake country; it doesn't mean mitigation is going to rule your life or that you have to live with some sort of constant fear, just be reasonably prepared. There are some things that should be routinely done in earthquake country, such as having water heaters strapped or pictures more securely attached to walls, and we as Nevadans need to take on the pioneering attitude of getting the job done, not leaving it for later. We want to reap the benefits of our preparedness, not do them out of the guilt we feel for our losses from an event.

Keep people safe (yourself, your family, your friends, your employees, and your customers) and protect what is really valuable to you (what do you really need to survive and thrive?). Once you are earthquake safe and reasonably prepared you can feel confident and relax. Earthquake safety will be more of a maintenance issue for you then, and something to be mindful of when changes are made. Even though Nevada has had a series of earthquakes in recent months there are usually several years between earthquakes when no shaking occurs. Earthquakes have to be respected because their consequences can be severe, but we do not have to live in constant fear; we can live safely with the occasional earthquakes that do occur.

Businesses also need to prepare more for earthquakes in Nevada. Do your employees know what to do during an earthquake? Is remaining at one's checking post and continuing to check while there is a near panic reaction of a crowd going on the best response? Should an employee consider "Drop, Covering, and Holding"? Should a manager come forward and take control – do they know that? Are exit ways clear of things that could potentially fall and block people from exiting? Businesses should have an emergency plan and an evacuation plan, clearly marked utility shutoff valves with instructions posted nearby, file cabinets and heavy bookshelves anchored, computers protected, heavy equipment and merchandise stored low, overhead lighting secured, chemicals in non-breakable containers or stored in secured places, water heaters strapped and with flexible gas lines, and have an emergency kit for employees.

There is a small window of opportunity for preparedness created by the 2008 Wells Earthquake and the 2008 Mogul-Somersett Earthquake Sequence in Nevada, but it is likely to be short. We can't just be satisfied with shallow preparedness, meant to pacify us until we are distracted with the rest of life and can justify no longer being bothered. Nevada's leaders should insist that Nevadans once and for all get reasonably prepared for earthquakes and other disasters (the preparation is similar for many disasters). We need to live safely in our environment and know how to do so. If we want to live with ornamentation in our homes and businesses, it needs to be secured so it doesn't fall from shaking. Nevadans don't have to spend huge amounts of money and our lives getting ready, we just have to attain a certain level of earthquake resistance and preparedness so when a strong earthquake does occur, we will survive it well. Then, like a big storm, we'll clean up the mess it leaves and get on with life.

Go to these web sites for earthquake safety and preparedness:

www.ReadyWashoe.com
www.nbmg.unr.edu
www.seismo.unr.edu

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