OPINION

The Biggest Little Contributions

At about 10 p.m. on the first day of October 1915, some 200 km west of Reno, Nevada, the U.S.A.'s Biggest Little City, and 100 km or so north of our nation's Loneliest Highway, the sky was cold and moonless. And in this particular location of the arid and sparsely settled Basin and Range, as is generally the case, absolutely nothing happened. The next day was different though. It was then, only nine years after the great 1906 California earthquake, that Nevada's contributions to earthquake science began. After a couple of quite strong earthquakes in the late afternoon, things had apparently quieted down sufficiently for the residents of the little mining community of Kennedy, adjacent to a little valley called Pleasant, to consider safely retiring for the night. It was not to be. At about 10:50 p.m., a yet more violent shaking occurred. Those present who had also been through the San Francisco earthquake of 1906 were of the general opinion that "the Kennedy shake was more violent than that one" (Berry, 1916, 52). It was a big one. Now, 101 years later, the Pleasant Valley earthquake has given Nevada's Seismological Laboratory at the University of Nevada, Reno, reason to host the 2016 Annual Meeting of the Seismological Society of America in Reno, Nevada.

The Pleasant Valley earthquake is generally assigned a magnitude of 7.2. It is not the only large earthquake to have occurred in Nevada. The 1932 Cedar Mountain and the 1954 Dixie Valley–Fairview Peak and Fallon–Stillwater earthquake sequences registered similar magnitudes (see Fig. 1). As a Biggest Little City resident, in a state commanding less than 1% of the nation's population, I am led to suggest that these historical earthquakes, and the investigators who had the privilege of first studying them, have played an outsized role in illustrating and defining problems in earthquake science that we grapple with to this day.

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It's appropriate. The first scientific account of the 1915 Pleasant Valley earthquake was put forth by a professor from the University of Nevada, Reno, in the *Bulletin of the Seismological Society of America*. Claude L. Jones spent a brief two days in the field in the week subsequent to the earthquake (Jones, 1915). He made some quite fundamental observations during that short time, all generally supported since and, of course, influenced by the earlier studies of Grove Karl Gilbert, Israel Russell, and George D. Louderback (Gilbert, 1884; Russell, 1885; Louderback, 1904). Among those, Jones associated the earthquake with Basin Range structure; recognized that the movement that caused the earthquake was along a normal fault; that the fault trace extended more than 20 miles (his units then); that morphology preserved both in bedrock and alluvium showed that earthquakes had previously occurred on the fault; and that repeated offsets along the fault are largely responsible for the relative, though perhaps not absolute, elevation of the Sonoma Range above Pleasant Valley. From this, he induced "that movement has not entirely ceased along the faults that bound the range on one or both sides" and, in so doing, articulated the foundation of today's seismic-hazard analysis: that earthquakes occur repeatedly on pre-existing faults. All this alone is quite impressive, though it is perhaps more impressive that Professor Jones' description of the October 1915 earthquake was also published in the 1915 volume of *BSSA*! Makes one think the peer-review process of today is maybe at times a bit cumbersome, doesn't it?

Time and time again old earthquakes are revisited as new perspectives and tools of analysis come forth. The history of the 1915 Pleasant Valley earthquake is no exception. Eighteen years later, Ben Page, a young Stanford professor born only a few years before the earthquake, took a look at the site (Page, 1935). He adds to the story that the location and geometry of faulting was controlled by pre-existing basin-and-range structure and that this "could have easily been recognized as such prior to 1915," in effect again defining the tenets of modern seismic-hazard analysis whereby mapped faults are used to define and approximate the location and length of future earthquake ruptures. Then some 40 years later, in 1984, at the tender age of 67 years, Bob Wallace provided us with his definitive tome describing the earthquake to reaffirm Page's recognition of structural control (Wallace, 1984). Wallace's study, to my knowledge, was the first to systematically collect geological estimates of the coseismic slip along the length of a basin-and-range normal fault and then calculate the seismic moment of that earthquake. The use of seismograms to estimate the seismic moment of the event was to wait another four years until Diane Doser, the current editor of the *Bulletin of the Seismological Society of America*, applied then-new methodologies to analyze old seismograms of the earthquake (Doser, 1988).

There is more. Vincent P. Gianella and Eugene Callaghan were economic geologists by practice, one with the University of Nevada, Reno, and the other with the U.S. Geological Survey. They shifted gears with the occurrence of another large earthquake in December 1932. I do not envision the shift was

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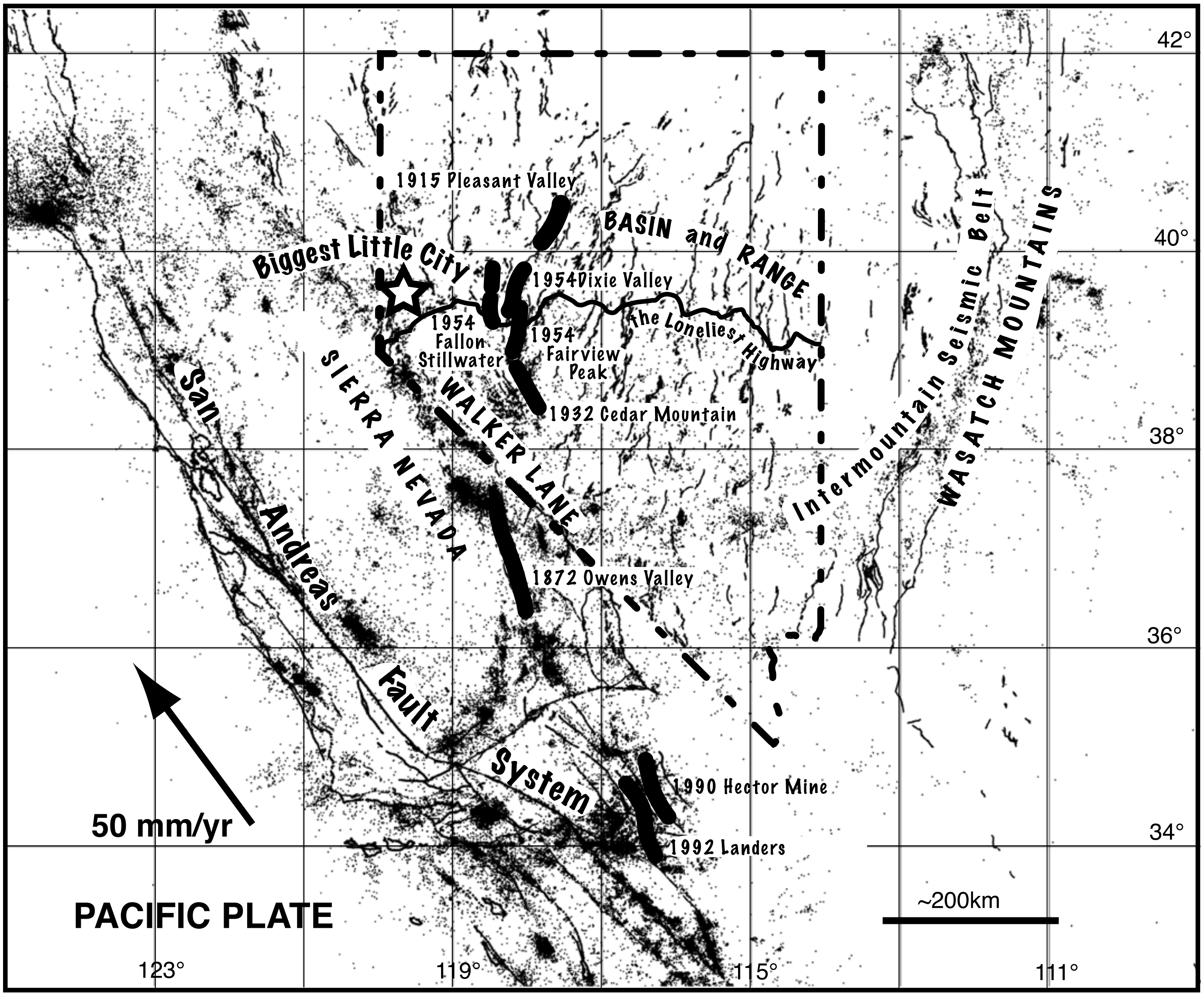

▲ **Figure 1.** The historical earthquakes of Nevada (dashed outline) and the investigators who had the privilege of first studying them have played an outsized role in illustrating and defining the problems in earthquake science that we grapple with to this day. Seismicity, faults, and historical earthquakes that have produced surface ruptures (bold lines) east of the Sierra Nevada give context to the location of this year's Seismological Society of America Annual Meeting in what is the Biggest Little City of Reno, Nevada, located along U.S. Route 50, which was dubbed "The Loneliest Highway in America" by *Life* magazine in 1986.

easy. The earthquake occurred in a sparsely populated region of Nevada, devoid of many roads (none paved at that), and it was a cold snow-covered field area at the time (Gianella and Callaghan, 1934). The earthquake occurred in a narrow northwest-trending range-bounded valley adjacent to Cedar Mountain. Their mapping revealed something quite different from what had become expected for basin-and-range shocks. Rather than being focused along a range front, surface faulting was discontinuous, distributed, and formed a rough left-stepping en echelon pattern in a zone "38 miles long and 4 to 9 miles wide" in the valley between bounding mountain ranges. The longest of the fault strands was 2–3 miles in length at best, and these too were formed of yet smaller en echelon-arranged strands. The en echelon pattern, offsets of morphologic markers recorded along a subset of the traces, and the observation that traces continued through both bedrock and alluvium, led the authors to conclude that the earthquake showed right-lateral motion, much like what had been reported in California's earthquake of 1872 along the eastern boundary of the Sierra Nevada (Hobbs, 1910) and the San Andreas fault in California (Gilbert, 1907). With that, they essentially birthed the idea of the Walker Lane, wherein "the underlying causes of movement in at least the western part of the Basin and Range may be related to those in California, and that horizontal movements must be considered in future studies of the Basin and Range structure" (Gianella and Callaghan, 1934). We now take these ideas for granted. Not bad for a couple of economic geologists. I guess science is a bit like sports. In the old days, participants played all the positions, not so specialized as today.

The magnitude of the 1932 Cedar Mountain event is today assigned a value of 7.2. Gianella and Callaghan's mapping defined another issue of seismology that remains with us in our attempts to use active fault traces to define the expected location and size of future earthquakes. It is quite certain that the morphologic expression was insufficient, either before or after the 1932 event, to predict that this particular valley could host a magnitude 7.2 earthquake. Thus, although the geomorphic signature of active faults provides an important tool in defining the expected location and approximating the size of future earthquakes, it remains problematic to do so for those earthquakes occurring in the background on faults absent of such a signature.

The couple of quiet decades that followed the 1932 Cedar Mountain earthquake ended in 1954. Central Nevada was shaken by a sequence of four earthquakes, all magnitude > 6.8, all producing ruptures of the Earth's surface, and all in the span of six months. Concurrent with the commercial push to develop nuclear reactors for energy in California, and with an eye toward understanding the potential impact of earthquakes in siting such critical facilities, Don Tocher, a doctoral student in geophysics (and subsequently president of the *Seismological Society of America* in 1974), headed east from California to construct maps of the first two of these, the 6 July and 23 August Fallon–Stillwater earthquakes (Tocher, 1956).

Maps of the subsequent Fairview Peak and Dixie Valley earthquake ruptures of December that same year were likewise produced by Professor D. B. "Burt" Slemmons of the University of Nevada, Reno (Slemmons, 1957). At the time, Burt was more involved with the study of Sierran granites. The earthquake changed his and our lives. The Dixie Valley and Fairview Peak earthquakes were the biggest of the four and of course drew a good bit of attention. Numerous parties came over from California to take a look, among them names well known to members of the *Seismological Society of America*, including two past presidents of our Society, Perry Byerly and Karl Steinbrugge. To hear Burt tell it, there he was, out there surrounded for some time by all of these excited and interested folks, then they all just got up and left, and the next day he found himself standing out there in the desert all alone with the realization that they left him with all the work to do! Good thing for us. Sierran granites became his thing of the past; he subsequently schooled an untold number of students in the geology of earthquakes, and the expertise he gained in the study of his faults led him to a long career in guiding the nuclear industry in their assessments of the potential impact of earthquake faults on their facilities. No less important, and perhaps more so for the long-term impact, Burt employed his newfound awareness and expertise in convincing the Nevada Board of Regents to establish both the Nevada Seismological Laboratory Center and the Center for Neotectonics as separate research divisions within the University of Nevada, Reno.

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With the aid of low-sun-angle photography, the 1954 ruptures and associated displacements have been revisited, remapped, and remeasured in yet greater detail (Caskey *et al.*, 1996). The resulting descriptions of the fault lengths, geometries, and coseismic offsets remain as fundamental data points in our seismic-hazard community's efforts to empirically predict the size of future earthquakes and the role of fault geometry on rupture propagation (Wesnousky, 2008). In like manner, the recent development of Global Positioning System arrays across the region has shown these earthquakes as examples of postseismic viscoelastic response (Hammond and Thatcher, 2007), apparently confirming Slemmon's observation at one site that the Dixie Valley fault scarp increased in height by about 3 ft during the several days after the earthquake. And so the earthquake keeps giving.

Taken together, the earthquakes considered here are part of the Nevada Seismic Belt (Fig. 1). Clustered in space and time, the sequence remains one of the more-cited examples in the argument that physical changes resulting in one earthquake may shorten the time until an earthquake occurs on nearby faults. Such triggering is often attributed to elastic stress changes, though this certainly is not the complete answer (Scholz, 2010). Elastic stress changes are instantaneous, whereas the time delay between earthquakes is not. The time between subsequent earthquakes is from minutes to years. Likewise, the distance between subsequent events reaches to 100 km or more, generally well beyond the distance at which elastic stress changes might be significant.

So there is more to learn. It has been 60 years since the last large earthquake in Nevada. It should not be a surprise when another one occurs soon, maybe even during the 2016 annual meeting. If it does, let's hope it comes like those before it, without loss of a single life, and that we can use it to further unveil secrets of the earthquake process.

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