The Petroleum Geologist and the Insurance Policy

by Susan E. Hough and Morgan Page

ABSTRACT

In a recent study, Hough and Page (2015) presented several lines of evidence suggesting that most of the significant earthquakes in Oklahoma during the twentieth century, including the M_w 5.7 El Reno earthquake of 9 April 1952, were likely induced by wastewater injection and possibly secondary oil recovery operations. We undertook an archival search for accounts of this event, which unearthed a newspaper article published immediately following the El Reno earthquake regarding a prominent petroleum geologist in the area who took out a rare earthquake insurance policy less than 60 days before the earthquake struck. In this study we present a historical context for this intriguing coincidence. We present a retrospective of oil industry practices in the early- to mid-twentieth century, gleaned from court records and other industry reports, that potentially bear on the interplay between oil exploration activities and earthquakes, focusing on the Oklahoma City region. We describe events of the day that could plausibly have alerted a geologist to the possibility of induced earthquakes, although there is no indication that the potential for induced earthquakes was widely recognized within the industry at that time.

THE EARTHQUAKE AND THE INSURANCE POLICY

Hough and Page (2015) presented evidence that there was a causal relationship between the 9 April 1952 El Reno earthquake, which they estimated to be M_w 5.7, and wastewater injection at two nearby injection wells that were permitted in 1945 and remained permitted until 8 May 1952 (Fig. 1). Nicholson and Wesson (1992) also identified this event as possibly induced, based on the proximity to production wells, although they were apparently unaware of the nearby wastewater injection wells. Conventionally known as the El Reno earthquake, the relocated epicenter of Gordon (1988) places the event west of central Oklahoma City (Fig. 1). No foreshocks to the El Reno earthquake have been identified, and newspaper reports do not mention accounts of shaking felt prior to the mainshock. Although the catalog is likely incomplete below M_w 3.0, newspaper accounts following notable earthquakes commonly mention earlier felt shaking, if any was noticed.

As we will discuss in more detail in the following section, oil exploration in the Oklahoma City area was nothing new by 1950. Early photographs show oil derricks scattered throughout the city, including some adjacent to the State Capitol building. The local economy benefited substantially, with oil wealth fueling the development of high-rise buildings and opulent homes (Oklahoma Historical Preservation Survey [OHPS], 1991). Sometime in February or March 1952, W. H. Atkinson, a consulting petroleum geologist, took out an earthquake insurance policy for his home in Oklahoma City. When the El Reno earthquake—the largest recorded earthquake in history in the state—struck on 9 April 1952, the *Daily Oklahoman* newspaper carried a small story with the headline "Geologist is Ready for Quake with Rare Insurance Policy" (Fig. 2). Atkinson is quoted in the article as saying that he took out the policy because, "we're sitting on a fault here and I just thought it was about time. You could call it my 'women's intuition'" (*Daily Oklahoman*, 1952). Local insurance agent E. B. Ledbetter was quoted in the same article, remarking that earthquake insurance policies were extremely rare in the state, noting "I doubt if there are a dozen of them in Oklahoma City. I've sold only two and one of them was several years ago." (The article does not note whether or not Atkinson's home sustained any damage during the earthquake; one assumes it did not, because the article does not mention any damage or payout from the policy.) Atkinson explained to the reporter that a 2000-foot fault (scarp) ran through the east side of Oklahoma City and that "any earth movement could possibly affect that area." He noted that the fault begins south of the city and runs through the Fairgrounds and north. Atkinson's description corresponds to the Nemaha fault (Luza and Lawson, 1982; Dolton and Finn, 1989; Fig. 1), which was not directly associated with the El Reno earthquake. As discussed by McNamara (2015), most recent (inferred induced) earthquake sequences in the area occurred on reactivated conjugate strike-slip structures in proximity to the Nemaha structure, which we now know is not oriented properly to be active in the current stress field

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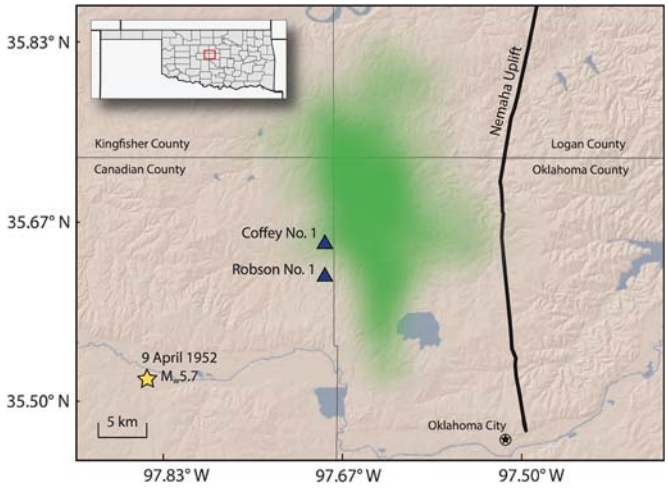
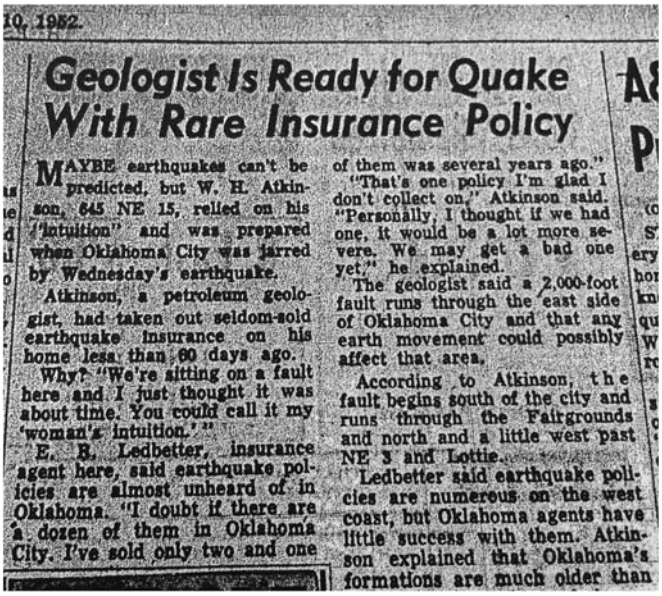


▲ **Figure 1.** Locations of West Edmond oil field (after Gaswirth and Higley, 2012), with county lines, location of 1952 El Reno earthquake (star) (Gordon, 1988), and location of Coffey and Robson wells (triangles). Green shading indicates smoothed oil well locations; color intensity provides qualitative indication of concentration of wells, and the main versus the peripheral extent of the field.



10, 1952.

Geologist Is Ready for Quake With Rare Insurance Policy

MAYBE earthquakes can't be predicted, but W. H. Atkinson, 645 NE 15, relied on his "intuition" and was prepared when Oklahoma City was jarred by Wednesday's earthquake.

Atkinson, a petroleum geologist, had taken out seldom-sold earthquake insurance on his home less than 60 days ago.

Why? "We're sitting on a fault here and I just thought it was about time. You could call it my 'woman's intuition.'"

E. B. Ledbetter, insurance agent here, said earthquake policies are almost unheard of in Oklahoma. "I doubt if there are a dozen of them in Oklahoma City. I've sold only two and one of them was several years ago."

"That's one policy I'm glad I don't collect on," Atkinson said. "Personally, I thought if we had one, it would be a lot more severe. We may get a bad one yet," he explained.

The geologist said a 2,000-foot fault runs through the east side of Oklahoma City and that any earth movement could possibly affect that area.

According to Atkinson, the fault begins south of the city and runs through the Fairgrounds and north and a little west past NE 3 and Lottie.

Ledbetter said earthquake policies are numerous on the west coast, but Oklahoma agents have little success with them. Atkinson explained that Oklahoma's formations are much older than

▲ **Figure 2.** Article from *Daily Oklahoman*, 10 April 1952.

(e.g., Keranen *et al.*, 2014). By his own account, Atkinson was aware of the existence of the fault, which remains one of the few faults in the central and eastern United States with clear geomorphic surface expression, and he would have reasonably assumed it to be potentially active.

One is then left with the question, Were there other factors beyond his awareness of the Nemaha fault and "women's intuition" that might have led Atkinson, who had lived in Oklahoma since his teenage years (Kate, 1973), to take out a seldom-purchased insurance policy in February or March of 1952? It is, of course, impossible to answer this question with certainty. Because Atkinson died in 1972 (Kate, 1973), it is not possible to put the question to him directly, so we are left to consider available archival evidence. We use available archival sources to address the question: What information about earthquakes would have been known to Atkinson in particular and geoscientists in general as of the mid-twentieth century?

The fact that, by the account of insurance agent E. B. Ledbetter, earthquake insurance policies remained rare at the time suggests that there was not widespread concern for earthquakes, induced or otherwise, within the oil industry. We are further aware of no evidence suggesting that an association between earthquakes and oil production and/or wastewater production was generally recognized by Earth scientists by the time of the El Reno earthquake. The 1952 publication, *Pacific Coast Earthquakes*, by leading earthquake expert Perry Byerly (Byerly, 1952), provides a useful summary of the state of understanding of earthquakes at that time. Both the association between earthquakes and faults and elastic rebound theory were established in the years before and after the great 1906 San Francisco earthquake. As noted by Byerly, however, "in one sense the Elastic Rebound Theory evades the issue, for we immediately inquire: What are the internal forces which cause the strain to accumulate." He goes on to say, "Here we have a puzzler." He then summarizes theories that had been proposed: including subcrustal "currents" possibly associated with isostasy, "great convection currents within the Earth's mantle," and an old theory that earthquakes were caused by the long-term cooling of the planet. As summarized by Gupta (2002), an association between reservoir empoundment and earthquakes was first noted in 1945 (Carder, 1945). Results from this and other early studies were reported in media articles (e.g., *Morning Olympian*, 1947). In our search of newspapers published following the 1952 El Reno earthquake, or at other times prior to 1952, we found no speculation about an association between earthquakes and either oil/gas production or wastewater injection. A Google Scholar search moreover turned up no scientific articles published prior to 1952 about human-caused earthquakes, apart from a few about earthquakes linked to reservoirs.

As a prominent industry geologist, one expects that Atkinson was more generally aware of earthquakes than were others in industry. It does not appear that Atkinson's concern about earthquakes could have been motivated by observed earthquakes in the immediate area. Although it is possible that earthquakes were induced in Oklahoma during the initial oil boom in the 1920s (Nicholson and Wesson, 1992; Hough and Page, 2015), the catalog of felt earthquakes (Lawson and Luza, 1995) reveals no events anywhere in the state of Oklahoma between June 1942 and the 9 April 1952 El Reno earthquake. There was at least some instrumentation operated by industry: a newspaper article published after the El Reno earthquake noted that "There were no oil exploratory seismograph instruments in operation at the time of the quake" (*Dallas Morning News*, 10 April 1952). Data from industry instruments are unavailable; however, from the absence of cataloged events, one can infer that no earthquakes larger than M_w 3.0 occurred in the years immediately before 1952.

It is possible that a petroleum geologist might have taken note of earthquakes in other oil- and/or gas-producing regions during the mid-twentieth century. A series of shallow earthquakes occurred within the Wilmington oil field, California, in 1947, 1949, 1951, 1954, 1955, and 1961, causing significant damage to wells within the field. These earthquakes garnered nationwide media attention. At the time neither the media nor experts voiced suspicions that they might be induced, but Richter (1958) described the events as shallow "slump earthquakes," and noted the spatial correspondence to the oil field. (A study published years later did discuss the "unusual set of man-made 'earthquakes' ... in the Wilmington Oil Field"; Kovach, 1974). Significant ground subsidence was discussed in earlier studies (e.g., Grant, 1954). Two moderate earthquakes struck the Po Valley in Italy on 15–16 May 1951, in an area of active methane gas extraction (Caloi *et al.*, 1956). Although the association between gas extraction and the earthquakes remains debatable (Caciagli *et al.*, 2015), by the mid-1950s at least some Earth scientists were aware of the spatial and temporal correlation between the two, and Caloi *et al.* (1956) concluded that the 1951 Po Valley earthquakes may have been induced. Interestingly, although the earthquakes themselves did not appear to garner much media attention in the United States, an Associated Press article was widely reprinted on 5 November 1951, describing that an "unprecedented seismic movement" had occurred, whereby the entire Po Valley had risen 30 cm over the course of about two weeks (e.g., *Dallas Morning News*, 5 November 1951). Closer to Oklahoma, an earthquake large enough to be felt throughout much of the Texas panhandle occurred on 20 June 1951. Oil exploration had begun in the region in the early twentieth century (e.g., Texas State Historical Association [TSHA], see Data and Resources); enhanced oil recovery (EOR) operations began in the region in 1946, with mixed results (TSHA; see Data and Resources). It was recognized as early as 1943 that substantial subsidence had occurred in this area, as well as other regions, as a result of oil and gas extraction (Weaver, 1943). Frohlich and Davis (2002) conclude that it is uncertain whether the 1951 event was a tectonic or induced earthquake. This earthquake was also reported in local newspapers.

Although one cannot know with certainty that Atkinson was aware of the earthquakes in other areas with active oil and/or gas production, any number of news articles about the above events were published in local newspapers in the late 1940s and early 1950s. Although, again, there is no evidence for a general awareness of an association between earthquakes and oil and/or gas production, by the 1950s clearly at least some professional Earth scientists were beginning to notice earthquakes in regions of active production and starting to connect the dots (e.g., Caloi *et al.*, 1956). In the following section, we discuss oil industry activities in the West Edmond oil field, the major field near Oklahoma City, and Atkinson's involvement with the field.

THE OIL MAN AND THE OIL FIELD

The association between injection of oil industry wastewater and induced earthquakes is now well established (e.g., Keranen *et al.*, 2014; Walsh and Zoback, 2015; Weingarten *et al.*, 2015). There is increasing evidence that, while most wastewater wells do not trigger earthquakes, the biggest risk of induced earthquakes is associated with deep, high-injection-rate disposal wells (Weingarten *et al.*, 2015). The rate of earthquakes in the central and eastern United States has increased sharply since 2009 (e.g., Ellsworth, 2013). The advent of widely used hydraulic fracturing methods around 2009 led to a substantial increase in the total volume of wastewater generated and its subsequent injection in class II disposal wells (Walsh and Zoback, 2015). Injection of wastewater in deep wells is not, however, a new practice (e.g., Hough and Page, 2015). Available records show that wastewater disposal wells were permitted in the state of Oklahoma as early as the 1930s. In their recent study, Hough and Page (2015) showed that there is a strong statistical spatial and temporal correlation between wells permitted in the 1950s and the occurrences of M 3.5–5.7 earthquakes in Oklahoma during that decade, and there is weaker evidence for induced earthquakes in the state as early as the 1920s. Earlier studies had also identified a number of possible and probable induced earthquakes in the central United States, including earthquakes in southeastern Texas in the 1920s and in central Oklahoma between 1918 and 1979 (Nicholson and Wesson, 1992).

A retrospective of oil industry practices is given by Boyd (2002) and summarized very briefly by Hough and Page (2015). Some detailed information about practices is available in industry reports, literature, and, in some cases, court records. In this study, we draw on available reports and records to provide an additional retrospective of oil industry activities that potentially relate to the occurrence of induced earthquakes and further establish the historical context for Atkinson's story. We focus on the Oklahoma City area, specifically the West Edmond oil field.

Throughout the 1940s, oil exploration in Oklahoma generally led to the discovery of numerous small fields, with over 100 new discoveries or extensions of established fields (OHPS, 1991). The West Edmond oil field (Atkinson, 1944) was a notable exception to this trend, ultimately covering 40,000 acres with a total production over 100 million barrels as of 1967 (Keplinger, 1967). The field was discovered by Ace Gutkowsky using a controversial "doodlebug" device, akin to a divining rod (OHPS, 1991). At the time, Atkinson was a consulting geologist who had enjoyed considerable professional success during the late 1920s and early 1930s but fell on hard times during the Great Depression (Kate, 1973). Atkinson agreed to provide consulting for Gutowsky's well in exchange for expenses and an 80-acre lease (Kate, 1973). Although oil experts remained skeptical of the doodlebug method, an initial well was spudded in 1943; by the end of 1944, there were over 256 wells in a 14,000-acre field stretching across portions of Oklahoma, Logan, Canadian, and Kingfisher Counties (Atkinson, 1944; OHPS, 1991; Fig. 1). At the time, this represented the largest concentration of rotary oil rigs in the world. Around 1944, the majority of leaseholders in the area formed an organization known as the West Edmond Field Engineering Association for the purpose of obtaining, co-

ordinating, and reporting factual data pertaining to the field (Kenney, 1947). On 1 October 1947, the West Edmond Hunton Lime Unit was formed, merging independent operators' interests into a single so-called unit so that the field could be operated as a single lease (Kenney, 1947). Atkinson served on the Executive Committee of the West Edmond Hunton Lime Unit, which managed the operations of the West Edmond Field (Kenney, 1947; Kate, 1973).

Around the same time that the West Edmond field was discovered, EOR was increasingly employed as old wells became depleted (OHPS, 1991). The Sohio Petroleum Corporation applied for a total of 12 EOR well permits in Logan and Oklahoma Counties, with permit application dates of 30 July 1948, 31 March 1949, and 28 February 1950 (OCC; see Data and Resources). During 1950 and 1951, a total of 33 new wells and field expansions occurred in Oklahoma and Logan Counties (OHPS, 1991), including a well application in Oklahoma County from Wilcox Investment Co. on 21 December 1951 and an EOR application in Logan County from Cities Service Oil, Inc., on 8 March 1952. Wastewater volumes increased generally as a consequence of both increased EOR operations, which produce large volumes of coproduced wastewater, and the depletion of wells, which led to production of lower-cut oil.

In the early part of the twentieth century, various methods were employed to dispose of wastewater, including pumping into cavity wells, direct run-off, use of city sewers, evaporation ponds, and seepage into the ground (Cloud, 1937). In Texas, Oklahoma, and California, when new fields were discovered, it became common practice to form a separate company to handle wastewater disposal (Cloud, 1937). During the initial development of West Edmond oil field, wastewater was initially disposed of in the Canadian River (Cloud, 1937). Because of the very high concentration of salts, with levels rivaling those of the Great Salt Lake, wastewater disposal became an increasingly contentious issue. After a study of location conditions, a dam and open ponds were constructed near the Canadian River, several miles southwest of the field. The main pond covered 23 acres, with a capacity of 1.5 million barrels (Cloud, 1937). Although Canadian and Kingfisher Counties remained largely on the periphery of oil production associated with the West Edmond field (OHPS, 1991), wastewater disposal operations were located in Canadian County.

The disposal of wastewater in open ponds was itself problematic. As early as 1932 a lawsuit was brought against Peters Petroleum Corporation, seeking damages for cows harmed by ingesting water from a disposal pond. Although damages were initially awarded to the plaintiff in this case, in 1932 the Oklahoma Supreme Court overturned a lower court, ruling in Peters Petroleum Corp v. Alred that there is no requirement for a corporation to fence their premises in areas where the law requires that owners of domestic animals keep the animals restrained. Nonetheless, facing increasing environmental and regulatory pressures, the industry moved toward disposal of wastewater in deep injection wells. In 1945, two early disposal wells were drilled in Canadian County: The Robson No. 1 well and the Coffey No. 1 well (Fig. 1). (Note that the well names are not specified in the permit records, but are specified in another case heard by the Oklahoma Supreme Court, discussed below.) According to permit records, the Robson No. 1 well was drilled to a depth of 4500–5000 ft into the Hoover and Tonkawa sand formations. (We preserve reported non-SI units because they are essentially part of the archival record and provide a general indication of the precision to which relevant numbers were known and reported.) At the Coffey No. 1 well, drilling reached depths of 4500 and 8000 ft in the Tonkawa sands and Wilcox formations, respectively.

As of 1950–1951, when the aforementioned expansion of new production wells in the West Edmond field occurred, the Robson No. 1 and Coffey No. 1 wells were the only wastewater disposal wells permitted in Canadian County. Through 1952, no other wastewater wells had been permitted in neighboring Oklahoma, Logan, or Kingfisher County. Production data from the West Edmond field indicates that produced water peaked between 1945 and 1949, dipped briefly between mid-1949 and mid-1950, and increased again from mid-1951 to mid-1952 (Keplinger, 1967). Because the Robson and Coffey wells were the only nearby wells permitted during this time, they were therefore likely to have had increased rates of disposal during these periods of increased production.

Detailed injection volume and rate data are unavailable for the Robson and Coffey wells, but some details regarding wastewater injection at the two disposal wells can be gleaned from the case West Edmond Hunton Lime Unit v. Lillard, decided by the Oklahoma Supreme Court on 16 February 1954. In this case, the plaintiff sought damages from the West Edmond Hunton Lime Unit. According to the facts of the case, the plaintiff acquired a lease adjacent to the Robson and Coffey wells. After purchasing the lease, the plaintiff learned that the defendant "had been, and was then injecting under great pressure enormous quantities of salt water into the subsurface structures and into the Hoover and Tonkawa sands in the Robson No. 1 well...at a depth of approximately 4,500 feet to 5,000 feet, and had been so injecting salt water into the Tonkawa and Wilcox sands of the...Fox Coffey No. 1 well." Case records indicate that the defendant admitted injecting "many thousand barrels of salt water under 600 or 700 lbs of pressure per square inch daily" on the offset lease just a few hundred feet from the plaintiff's wells. The plaintiff was unable to produce oil and gas from his lease because wastewater allegedly penetrated into and across the subsurface of his lease, destroying the productivity of nearby production wells, which were reportedly drilled to a depth of approximately 6850 ft. The plaintiff further alleged that he was unable to remove the casing from one of his wells because salt water flowed out of the well onto the surface of the surrounding land, forcing the plaintiff to shut off the flow. In this case the Oklahoma Supreme Court upheld the decision of a lower court jury to find in favor of the plaintiff and awarded damages.

Legal proceedings involving the Robson and Coffey wells were underway in 1950, with an earlier case, West Edmond Salt Water Disposal Association v. Rosecrans, entitling the plaintiff to recover damage as an adjoining property owner. (The court

cases focused on alleged damage from injection to nearby producing wells; there is no mention of earthquakes.) Court records establish that large volumes of wastewater were being injected to 4500–5000 ft depth by 1949. In a recent study, Weingarten *et al.* (2015) show that high-rate injection wells, with rates > 300, 000 barrels per month, are much more likely to be associated with induced earthquakes than lower-rate wells. The precise meaning of "many thousands of barrels" is not clear. If the injection rates were on the order of 10,000 barrels per day, the Robson and Coffey wells would qualify as high rate by today's standards. If rates were on the order of 5000 per day, the injection rates would still have been relatively high rate by today's standards. Pressures of 600–700 psi also exceed the average monthly wellhead injection pressure in recent years in Oklahoma (< 500 psi; Weingarten *et al.*, 2015), although Weingarten *et al.* (2015) find no strong correlation between earthquake occurrence and injection pressure.

In summary, court records document moderate-to-high rates of wastewater injection at the Robson and Coffey wells in Canadian County through at least 1949. The records do not provide an indication of injection rates after 1949. However, extant records establish that wastewater production began increasing in mid-1950 (Keplinger, 1967) and that no new disposal wells were permitted in Canadian County or neighboring counties between 1945 and 1952. It is thus reasonable inference that wastewater injection continued at the Robson and Coffey wells after 1949. As discussed above, records also show that a number of EOR wells were permitted in Logan and Oklahoma Counties between 1949 and March 1952. Permit records indicate that permits for the Robson and Coffey injection wells remained active until 8 May 1952, when both wells were reported plugged. Interestingly, both wells were reported plugged a month nearly to the day following the 9 April 1952 El Reno earthquake.

Because of his position on the executive Committee of the West Edmond Hunton Lime Unit, Atkinson certainly would have been aware of both the recent increase in EOR operations in the West Edmond field and the issues associated with wastewater disposal in Canadian County by early 1952. Although court records only document wastewater injection at the Robson and Coffey wells through 1949, the permits for wastewater disposal remained active until they were plugged in May 1952.

DISCUSSION AND CONCLUSIONS

The association between oil production activities and induced earthquakes has been established in recent years using extensive data with which one can characterize both the earthquakes and the detailed oil exploration activities (e.g., Keranen *et al.* 2014; Walsh and Zoback 2015; Weingartner *et al.*, 2015). Hough and Page (2015) presented several lines of evidence suggesting that most significant ($M_w \geq 3.5$) earthquakes in the state of Oklahoma in the twentieth century were likely induced. Although there are no detailed records documenting the overall volume or rate of wastewater injection, their conclusion is based on a strong spatiotemporal correlation between twentieth century earthquakes and permitted wastewater wells, as well as the ground-motion intensities felt in the 1952 El Reno earthquake. In this report, we summarize additional information that documents oil industry activities at the time, including additional detailed information about the history of wastewater injection at the wells in question (Hough, 2014). This retrospective provides the context for the newspaper article published in the immediate aftermath of the 1952 El Reno, Oklahoma, earthquake, about a consulting petroleum geologist who had, out of "women's intuition," taken out a seldom-purchased earthquake insurance policy less than 60 days before the earthquake struck. By the account of an insurance agent quoted in this same article, earthquake insurance was rarely purchased in Oklahoma as of 1952, suggesting that an association between oil industry activities and earthquakes was not widely recognized at the time among industry experts (few of whom were geologists). Based on a consideration of the geologist's position and experience, however, as well as recent events at the time (including earthquakes in regions of active oil or gas production), there is evidence to suggest that factors other than "women's intuition" might have motivated him to purchase the insurance policy.

DATA AND RESOURCES

Google Scholar is freely available at http://scholar.google.com (last accessed October 2015). Permit records for wastewater wells in Oklahoma are available online at http://www.occeweb.com/og/ogowu.html (last accessed November 2015). Records of the Peters Petroleum Corp. v. Alred case and the West Edmond Lime Unit v. Lilliard cases, both heard by the Oklahoma Supreme Court, are respectively available from http://law.justia.com/cases/oklahoma/supreme-court/1932/30575.html (last accessed November 2015) and http://law.justia.com/cases/oklahoma/supreme-court/1954/21335.html (last accessed November 2015). The Texas State Historical Association (TSHA) website (https://tshaonline.org/handbook/online/articles/dop01, last accessed November 2015) was used to locate information on early twentieth-century oil exploration.

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