

WEATHER UNDERGROUND

The arrival of man-made earthquakes.

BY RIVKA GALCHEN

In the fall of 2011, students in Katie Keranen's seismology course at the University of Oklahoma buried portable seismograph stations around the campus, in anticipation of a football game between the Sooners and the Texas A. & M.

Aggies. The plan was to see if the students could, by reading the instruments, detect the rumble of eighty-two thousand fans cheering for a touchdown. "To see if they can figure out if a signal is a passing train or a cheering crowd—that's much more interesting for them than discussing data in theory," Keranen, an assistant professor of geophysics, told me.

But at 2:12 A.M. on November 5th, the day of the game, people in seventeen states felt an earthquake of 4.8 magnitude, centered near Prague, Oklahoma, a town of roughly twenty-five hundred, which is about an hour's drive from Norman, where O.U. is situated. The students quickly packed up the seismographs and headed to Prague, hoping to measure the aftershocks. "Obviously, this was more worthwhile than a game," Keranen said.

Outside homes around Prague and nearby Meeker, Keranen and her students, along with Austin Holland, the head seismologist of the Oklahoma Geological Survey, buried their equipment. Portable seismographs look like mini-kegs, or time capsules, and they need to be placed underground and on a level. The researchers wanted to install them quickly, since the ground was still shaking.

Shortly before 11 P.M., people in Prague heard what sounded like a jet plane crashing. It was another earthquake, this time a 5.6, followed, two days later, by a 4.7. (The earthquake scale is logarithmic, so a 5.0 earthquake shakes the ground ten times more than a 4.0, and a hundred times more than a 3.0.) No one was killed, but at least sixteen houses were destroyed and a spire on the historic Benedictine Hall at St. Gregory's University, in nearby Shawnee, collapsed. Very few people had earthquake insurance; the five million dollars needed for the repairs at St. Gregory's was raised through crowdfunding.

The earthquakes were big news, but the victory of the Sooners—the name comes from the term for those who broke the rules of the 1889 land run and staked claims in advance—was followed more closely. Few noticed that Keranen and her team had gathered likely the best data we have on a new phenomenon in Oklahoma: man-made earthquakes.

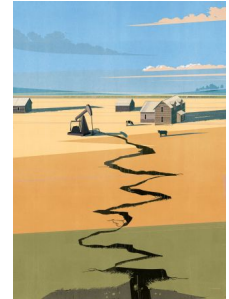
At the time, earthquakes were a relatively rare event for Oklahomans. Now they're reported on daily, like the weather, and generally by the weatherman. Driving outside Oklahoma City one evening last November, I ended up stopped in traffic next to an electronic billboard that displayed, in rotation, an advertisement for one per cent cash back at the Thunderbird Casino, an advertisement for a Cash N Gold pawnshop, a three-day weather forecast, and an announcement of a 3.0 earthquake, in Noble County. Driving by the next evening, I saw that the display was the same, except that the earthquake was a 3.4, near Pawnee.

Until 2008, Oklahoma experienced an average of one to two earthquakes of 3.0 magnitude or greater each year. (Magnitude-3.0 earthquakes tend to be felt, while smaller earthquakes may be noticed only by scientific equipment or by people close to the epicenter.) In 2009, there were twenty. The next year, there were forty-two. In 2014, there were five hundred and eighty-five, nearly triple the rate of California. Including smaller earthquakes in the count, there were more than five thousand. This year, there has been an average of two earthquakes a day of magnitude 3.0 or greater.

William Ellsworth, a research geologist at the United States Geological Survey, told me, "We can say with virtual

The increased seismicity is likely due to changes in the way oil and gas are produced.

ILLUSTRATION BY SHOUT



certainty that the increased seismicity in Oklahoma has to do with recent changes in the way that oil and gas are being produced.” Many of the larger earthquakes are caused by disposal wells, where the billions of barrels of brackish water brought up by drilling for oil and gas are pumped back into the ground. (Hydraulic fracturing, or fracking—in which chemically treated water is injected into the earth to fracture rocks in order to access oil and gas reserves—causes smaller earthquakes, almost always less than 3.0.) Disposal wells trigger earthquakes when they are dug too deep, near or into basement rock, or when the wells impinge on a fault line. Ellsworth said, “Scientifically, it’s really quite clear.”

The first case of earthquakes caused by fluid injection came in the nineteen-sixties. Engineers at the Rocky Mountain Arsenal, a chemical-weapons manufacturing center near Commerce City, Colorado, disposed of waste fluids by injecting them down a twelve-thousand-foot well. More than a thousand earthquakes resulted, several of magnitudes close to 5.0. “Unintentionally, it was a great experiment,” Justin Rubinstein, who researches induced seismicity for the U.S.G.S., told me.

In recent years, other states with oil and gas exploration have also seen an unusual number of earthquakes. State authorities quickly suspected that the earthquakes were linked to disposal wells. In Youngstown, Ohio, in 2011, after dozens of smaller quakes culminated in a 4.0, a nearby disposal well was shut down, and the earthquakes stopped. Around the same time, in Arkansas, a series of earthquakes associated with four disposal wells in the Fayetteville Shale led to a ban on disposal wells near related faults. Earthquakes were also noted in Colorado, Kansas, and Texas. There, too, relevant disposal wells were shut down or the volume of fluid injected was reduced and the earthquakes abated.

But in Oklahoma, which has had more and stronger earthquakes than the other states, it was late 2013 before an owner of a disposal well was asked by the Oklahoma Corporation Commission, which regulates oil and gas exploration, to temporarily reduce its operations—and that was because the well operator himself contacted the O.C.C. and the O.G.S., asking them to look into whether his well was causing problems. So far, there have been only eleven instances in which an owner has, by order, stopped injecting fluids or repositioned a well that was drilled into basement rock.

Driving through Oklahoma’s countryside, you see starlings and cows and nodding donkeys—also known as pumpjacks—and hundreds of disposal wells, of which there are around thirty-two hundred in the state. Disposal wells are generally simple structures: there may be trucks full of water parked nearby, and a typical wellhead is little more than a tank connected to a pump, with some knobs and a few meters visible. “You would be underwhelmed by the technology,” a well-operations engineer told me.

An area of oil and gas exploration is said to be “played out” when it no longer yields sufficient profits, and much of Oklahoma was considered to have been played out in the nineteen-nineties. One problem was the immense quantity of wastewater that was being brought up along with the diminishing yield of oil. “In the past, these wells that brought up so much water were abandoned,” Holland, of the O.G.S., told me. “They didn’t make economic sense. But then a new strategy came along, which was, basically, Let’s just pull up a lot of water.” Dewatering technologies and the rising price of oil made Oklahoma a rich business proposition again.

Although disposal wells have been used for decades, the new dewatering process has led to a dramatic increase in how much water is being disposed of. (In the state, the water used in the initial stage of fracking accounts for less than ten per cent of the water pumped down disposal wells.) In Oklahoma today, an average of about ten barrels of water comes up for every barrel of oil. Holland said, “We’re talking about billions of barrels, and it has to go somewhere.” Todd Halihan, a professor of geology at Oklahoma State University, in Stillwater, told me, “We’re injecting the equivalent of two Lake Hefners”—Oklahoma City’s four-square-mile reservoir—“into the ground each year, and we don’t really understand where that water is going.”

Austin Holland, who is forty, joined the Oklahoma Geological Survey in 2010, shortly after the occurrence of what is called the “Jones swarm”—seventy-five earthquakes felt in one county, around the town of Jones, in little more than a year. He said, “When I first came here, there were swarms, and I thought we were beginning to understand them, but I would say now—with the increasing rates of seismicity—I’d say all bets are off.”

I met Holland last November, at a conference on induced seismicity organized by the O.G.S. and the U.S.G.S. and held in Midwest City, which is between Norman and Oklahoma City, the academic and industry centers of Oklahoma, respectively. Holland grew up in a number of Western states; his mother worked as an accountant and

his father as a librarian and a Methodist minister.

On the first day of the conference, a few dozen people were gathered in a small room at the Sheraton: mostly scientists, but also oil and gas representatives, insurance representatives, and civil engineers. A bus tour of a local disposal well was cancelled, owing to icy roads. “I’ll give you the dog and pony show that I was going to give on the bus, and then I’ll answer questions and we’ll have a few beers,” Holland said.

The official position of the O.G.S. is that the Prague earthquakes were likely a natural event and that there is insufficient evidence to say that most earthquakes in Oklahoma are the result of disposal wells. That position, however, has no published research to support it, and there are at least twenty-three peer-reviewed, published papers that conclude otherwise.

When I spoke to Holland, I had the impression of a man who loved science and was politely trying to endure waking up each day, after insufficient sleep, to discover himself in the role of a politician. At the conference, someone asked Holland about several earthquakes of greater than 4.0 magnitude which had occurred a few days earlier, across Oklahoma’s northern border, in Kansas. Holland joked, “Well, the earthquakes aren’t stopping at the state line, but my problems do.” There was a follow-up question: Why had there previously been no quakes in Kansas—and now for a year and a half there have been so many?

As the question was asked, a couple of men wandered into the back of the room, where trays of beer and soda were set up. Holland called out, “Well, Justin, what do you think of that question?”

The U.S.G.S.’s Justin Rubinstein, one of the three organizers of the conference, said, “Um, well, if you map the fluid-injection records and the earthquake records—there you go.” There was a pause. “I didn’t even know this meeting was happening—I thought it was cancelled. I just came down here to get a drink.”

Holland said, “Well, you heard it from him, not me.” Soon afterward, he concluded, “I think I’m done sitting here in front of you all. Let’s relax and continue talking over beers.” Holland had been clear about the connections between disposal wells and earthquakes, and during the socializing a researcher from Princeton observed that Holland’s position seemed to have shifted from that represented in O.G.S. statements. “Let me think how I can answer that while there’s a reporter standing right there,” Holland said, lightly. “The O.G.S. is a nonacademic department of a state university that, like many state universities, doesn’t get that much funding from the state.” The O.G.S. is part of O.U.’s Mewbourne College of Earth and Energy, which also includes the ConocoPhillips School of Geology and Geophysics. About seventeen per cent of O.U.’s budget comes from the state. “I prepare twenty pages for those statements and what comes out is one page. Those are not necessarily my words.”

The first oil discovered in Oklahoma was found accidentally, in 1859, in a well drilled to find salt, near present-day Salina; the oil was sold as fuel for lamps. As related in “Oklahoma Oil: Past, Present, and Future,” by Dan Boyd, the next find came in 1889, near Chelsea, where a well produced half a barrel of oil per day; it was used to treat cattle for ticks. Then, in 1897, a well drilled near Bartlesville became a major oil producer, and many others followed. Within ten years, Oklahoma was producing more oil than anywhere else in the world. Not coincidentally, in 1907, Oklahoma went from being a territory to being the forty-sixth state. The state constitution includes a legal definition of kerosene.

I was brought up in Norman, where my father was a professor of meteorology in the college of geosciences at O.U. Although I had a happy childhood in Oklahoma, I grew up thinking of the state as an unlucky one, not so much because of, say, the Dust Bowl, but because of what I saw around me. One neighbor went bankrupt; another, a Mormon family of thirteen, had to move out of their barely furnished Tudor-style home and into a small trailer; another neighbor had a series of brain surgeries to help with damage from an infancy with an alcoholic parent who shook her. We had moved to Oklahoma shortly after the millions of dollars made following the 1979 oil crisis had begun to evaporate. In elementary school, I knew what “foreclosure” meant. When many local banks closed down after the savings-and-loan scandal, I had a sweatshirt, popular at the time, that had within the outlines of the state the words “I Bank at F.D.I.C.”

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Because I was a kid, the landscape of economic and moral reversals around me seemed like hailstorms or flash floods, which, although both my parents worked in weather-related jobs, I thought of as messages from the capricious but still venerable guy above. When I first began reading about the earthquakes in Oklahoma, even as I



read that they might be linked to the oil and gas industry, the exact words that came to my mind were the handily ambiguous “That’s natural.”

Oklahoma is an oil state. Which is not to say that it is a wealthy state. Twenty-four per cent of Oklahoman children live in poverty. It is ranked forty-sixth in over-all health, a measurement that considers such factors as

access to medical care and the affordability of that care. In 2013, a boom oil year, it was among the states that spent the least per student, and ranked No. 1 in cutting funding to education.

Oil has brought money to the state, but mostly to a few individuals. The state budget in Oklahoma in 2014 was seven billion dollars; the net worth that year of Harold Hamm, the thirteenth child of a sharecropper from Enid, who heads the oil company Continental Resources, was twice that.

A statistic from the Oklahoma Energy Resources Board that is often cited by politicians is that one in every five jobs in Oklahoma is directly or indirectly related to the oil and gas industry. (“Directly” accounts for only five per cent of the jobs.) But by psychological accounting oil and gas can seem like the whole world. The names of the oil and gas barons—Boone Pickens, Lloyd Noble, Sarkeys J. Sarkeys—are the names of nearly everything: the concert hall, the diabetes center, the aquarium, the football stadium. These “wildcatters” often have compelling rags-to-riches stories, and their eccentricities make for a kind of local Kardashian show. When Harold Hamm and his wife, a former executive of his company, were divorcing, the local press reported on a handwritten, nine-hundred-and-seventy-five-million-dollar check he wrote her. A man I know was with his daughter, shopping for a prom dress, when they ran into David Chernicky, the beloved head of the energy company New Dominion—“What a sweetheart he is!” the O.G.S. secretary said to me, apropos of almost nothing—and Chernicky insisted on paying for the dress and the shoes; he wouldn’t take no for an answer.

New Dominion’s main field office is in Prague, and many residents are reluctant to speak about the damage caused by the earthquakes there. A local, who didn’t want to be named, told me, “I know it sounds crazy, but I know people whose homes were levelled, and they won’t say anything.”

For decades, Prague has celebrated the Kolache Festival each spring, commemorating the town’s Czech heritage. It’s now preceded by the New Dominion Dayz, a sponsored fair that raises money for scholarships for graduating high-school seniors.

In state government, oil money is both invisible and pervasive. In 2013, Mary Fallin, the governor, combined the positions of Secretary of Energy and Secretary of the Environment. Michael Teague, whom she appointed to the position, when asked by the local NPR reporter Joe Wertz whether he believed in climate change, responded that he believed that the climate changed every day. Of the earthquakes, Teague has said that we need to learn more. Fallin’s first substantive response came in 2014, when she encouraged Oklahomans to buy earthquake insurance. (However, many earthquake-insurance policies in the state exclude coverage for induced earthquakes.)

That year, Fallin convened the Coördinating Council on Seismicity Activity, with Teague as its head. The council has no power to enact rules. It met only twice last year, and the second meeting was held at the same time as the conference on induced seismicity, in Midwest City, thus precluding the attendance of most experts. The council met for a third time this February, but the meeting, like all the previous ones, was closed to the press.

In September, 2014, at the request of two state representatives, the Oklahoma legislature conducted an official interim study on induced seismicity. In subsequent hearings, more than five hours of testimony were presented to a committee of legislators. Holland, Dana Murphy, of the Oklahoma Corporation Commission, and Todd Halihan, the professor of geology at Oklahoma State University, all spoke about the link between disposal wells and earthquakes. Tim Baker, of the O.C.C., spoke about the link between drilling into basement rock and earthquakes.

After the hearings, Mark McBride, the committee chair, issued a press release. It denied “a correlation between the injection wells and seismic activity,” and quoted a legislator’s speculation that perhaps the quakes were caused by “the current drought.” None of the scientists who had been present were quoted. I called McBride, who at first had no memory of the study—nor did his secretary. Then McBride remembered it. I asked what he had learned from it, and he said, “Well, one question I had for them was about the drought. That maybe the drought is causing these

problems. And I seem to remember that sometimes there's a problem, if they drill down too far. But that's about it, really."

Between 2009 and 2014, no legislation related to earthquakes was even proposed by the state legislature. I asked Representative Jason Murphey, one of the legislators who had called for the interim study—after a town-hall meeting in his district was filled with seven hundred and fifty angry and scared residents—whether he felt that the legislature should respond to the quakes. He said, "I think the most important thing that the legislature can do is to insure that government regulation doesn't get in the way of technologies of wastewater being disposed of by other means." The main technology for aboveground treatment of wastewater is a device called the Koch membrane, developed by Koch Industries; it filters out most toxins, though it is considered quite expensive, and can handle only limited volume.

In the 2015 legislative session, the other state representative who had convened the interim study, Cory Williams, of Stillwater, has introduced two earthquake-related bills. One proposes tax breaks for aboveground water-treatment technologies; the other seeks to make earthquake insurance more fair to consumers. At least eight bills have been proposed that aim to make it difficult for communities to set their own rules for oil drilling.

Some people argue that the legislature and the governor are ill-equipped to address the issue of earthquakes, and that the Oklahoma Corporation Commission is far more powerful. The O.C.C. has three elected commissioners, with extensive campaign platforms, but not one cites earthquakes as an issue. The most recently elected commissioner, Todd Hiatt, listed on his campaign Web site nine issues as priorities, including the fight against "Obama phones"—subsidized cell phones for poor people.

Which is not to say that the O.C.C. does not hear from the public about earthquakes. "This is our No. 1 priority," Matt Skinner, a spokesman for the O.C.C., told me. "We are thinking about this every day, we are working on this every day, and we ourselves—some of us—live in earthquake-prone places. Our houses are shaking, too."

Yet the O.C.C. has never denied a permit for a disposal well on the ground of seismicity. Skinner said that this is because people ask the commission if a permit is likely to be granted before they apply for it. "I would estimate that we have told about ten folks in this way, informally, that their permit is unlikely to pass," he said. In total, there has been one fine related to seismicity, for five hundred dollars. "As of yet, we haven't needed fines to have compliance," the O.C.C. commissioner Dana Murphy told me. "The amount of collaboration and cooperation we have had around this issue has been tremendous, like nothing I've ever seen."

Last September, the O.C.C., in consultation with the O.G.S., developed a set of best practices, asking for data from disposal wells within a ten-kilometre radius of earthquakes of magnitude 4.0 or greater, but the data have not always been timely, and the owners of only a handful of wells have subsequently been asked to reduce or cease operations. The radius is, in any case, an arbitrary one; studies suggest that a larger radius would be more appropriate.

There remains no rule against drilling into basement rock. "It was never specifically allowed, and it was never specifically forbidden," Skinner explained. The O.C.C. has passed its first rules relating to seismicity within the past six months. One requires well operators to keep track of daily volumes and pressures; another requires an annual well inspection. A third rule proposed will simply require that the O.C.C. be notified when a well goes into use. "Keeping things as best practices rather than rules allows the staff to respond more quickly to the situation," Skinner said. "Rules take time, and are difficult to change."

Last summer, the O.C.C. asked New Dominion to provide evidence that four wells were not drilled into basement rock. The O.C.C. said that it was not satisfied with the evidence presented; it has requested further information, but it has yet to ask that the wells, which scientists have linked to twenty per cent of Oklahoma's seismic activity, reduce their volumes of disposal.



On the second day of the induced-seismicity conference, there was an industry panel scheduled, but, at the last minute, most of the participants cancelled, and the event was called off. Almost no one in the industry agreed to speak on the record about the earthquakes.

Yet some individuals acknowledge the problem. After Holland's talk, a well-operations engineer said to him, of the O.C.C.'s best-practices guidelines, which went into effect in the fall of 2014, "Look, I'm not speaking for my company, I'm just speaking as myself, but I'm surprised that the O.C.C. didn't ask for more." He continued, "We

have so much information.”

The engineer taught me a lot about enhanced oil-recovery techniques, disposal wells, 3-D seismic-imaging data, and core sampling. I asked him how he ended up in petroleum engineering, and he said that he was from Texas, where men either become football players or cowboys or they go into oil and gas. “If you’re short like me, and good at math and science, then you go into oil and gas,” he said. I asked him if I could use his name and he said, nicely, “Of course you can’t!”

A couple of days after the conference, I travelled to Stillwater, to O.S.U.’s Boone Pickens School of Geology, to meet with Todd Halihan, the geology professor. The town’s low redbrick buildings and cracked pavement give the impression of a hastily put-together Western town, but the O.S.U. campus, with its well-tended lawns and fountains, resembles an American Versailles. In the past year, Stillwater has had more than a thousand earthquakes. Halihan, one of the few experts in the state to speak openly about the earthquakes’ relation to oil and gas practices, has become the go-to guy for communicating to the public the science behind seismicity.

“I already have two jobs—I’m a full-time professor and I do consulting,” Halihan said. “I don’t really have time to do this, but I felt it’s part of my job, because, in a sense, I work for the state. For so long, it was as if the earthquakes weren’t happening.”

The lobby of the Lloyd Noble Research Center is decorated with rose-colored plaques commemorating donors; the largest plaques honor Devon Energy and the billionaire alumnus Boone Pickens. Halihan’s office is on the second floor, and a sign outside reads “Age and treachery always overcome youth and skills.” Like most scientists I talked to, Halihan does not believe that there should be a moratorium on disposal wells or fracking; he just thinks that there should be open discussion, and a rational plan to avoid triggering the earthquakes that are felt in Stillwater almost daily.

A milk bottle filled with what looked like gravel was on his desk. “That’s from the Arbuckle,” he said, a geological formation under Oklahoma. Like most geologists, Halihan has experience in the oil and gas industry. He feels that the business is, in its way, a naturally honest one: “They make deals on a handshake—you have to have a good reputation or no one will work with you.”

He went on, “We know more about the East African Rift than we know about the faults in the basement in Oklahoma.” In seismically quiet places, such as the Midwest, which are distant from the well-known fault lines between tectonic plates, most faults are, instead, cracks within a plate, which are only discovered after an earthquake is triggered. The O.G.S.’s Austin Holland has long had plans to put together two updated fault maps, one using the available published literature on Oklahoma’s faults and another relying on data that, it was hoped, the industry would volunteer; but, to date, no updated maps have been released to the public.

Halihan said, “As scientists, we *knew* the Dust Bowl was going to happen; it wasn’t a surprise. It could have been prevented, but scientists failed to effectively communicate what they knew to the people. I don’t want that to happen again.”

According to the Gutenberg-Richter Relation, a series of small earthquakes suggests that a larger one may take place in the same area. Ten 2.0s suggest that there may be a 3.0. Ten 3.0s suggest that there may be a 4.0. Recently, a 4.2 and a 4.0 and about a dozen smaller quakes shook Cushing, Oklahoma, a town of several thousand people that is known as the Pipeline Crossroads of the World; fifty-four million barrels of oil are stored there underground. A well near Cushing had been drilled into the bedrock. “Is that a bad place for an earthquake to occur?” Halihan said. “You bet it is.”

“I can’t believe he brought her.”

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In Stillwater, Angela Spotts took me on a drive along dirt roads outside the city, amid a landscape of scrub brush with little blue-headed roadrunners skipping past the black pipes that bring water to oil and gas exploration sites; the formation underground is called the Mississippi Lime Play. “See, that’s American Energy-Woodford, they’ve been painting their wells with those red and blue stripes to look so cheerful,” Spotts said. A

year ago, with five others, she founded Stop Fracking Payne County. She is concerned about the earthquakes and also about other health and environmental problems associated with fracking. “I only own a few acres, and I don’t

own my mineral rights,” she said. “I am learning that they can just come on your land and put a well right there.”

Spotts is one of a number of Oklahomans acting as gadflies to the state. “We go all the way to testify to the legislature, and then they still tell us it isn’t happening,” she said. She knows all the major studies that link disposal wells to seismicity, and she can name the authors. “I would say I spend about two-thirds of my day just learning about this—it has taken over my life,” she said. The activists’ fluent knowledge and ready evidence can, perversely, make them sound crazy—so much data!—if one forgets that they are being continually, from all corners, gaslit. “At least with tobacco, you could choose not to smoke it, but here in Oklahoma—I mean, how could I choose not to live here?” Spotts said.

Like Spotts, Robert Jackman, a petroleum geologist, regularly contacts members of the U.S.G.S., the O.G.S., and the Oklahoma media to update them on the accumulating peer-reviewed work that links disposal wells to seismicity. The oft-heard refrain that more studies are needed is a sore point for Jackman. “We know a cold is spread with sneezing and coughing, so we cover our nose and mouth, we wash our hands, we take precautions,” he said. “We don’t need to know exactly what the strain of virus is or all the technicalities of how the throat becomes inflamed in order to know to use a handkerchief.”

Earl Hatley, a Cherokee, has been working for decades on environmental issues, particularly water pollution. He has master’s degrees in both environmental and political science, and he was instrumental in raising awareness about the Tar Creek area—an expanse of abandoned lead and zinc mines that was named a Superfund site in 1983.

Hatley has been speaking with the O.C.C. about the earthquakes in the Stillwater area since November, 2013. He told me, “We had two hundred and twenty-two earthquakes reported as felt that year, and I said something should be done, and the O.C.C. basically said to me, ‘Go away, what’s your problem, that’s no big deal, and there’s no way you can link earthquakes to disposal wells, you’re just crazy.’ They said this even though in 2011 the U.S.G.S. was already reporting they were caused by disposal wells. The U.S.G.S. doesn’t just say things; they’re nearly as reliable as NASA.”

Devon Energy, one of the largest oil companies in the area, has threatened Hatley with legal action if he doesn’t allow it to perform a 3-D survey* (#editorsnote) on his land. “I don’t own the mineral rights,” he explained. “There was one family who owned the rights to the whole township, and I could never get them to sell to me.” In the nineteen-eighties, representatives of an oil company tried to come onto his property to do a seismic survey, which would have told them how likely they were to find oil. “But the rule back then was that I could keep them off my property,” Hatley said. More recently, people from Devon Energy approached him. “I told them no. I was sure I had the rule on my side. But I went to look up the rule and I discovered that the rule had changed. Now they *were* allowed to come on my property without a seismic survey. I went down to Payne County to see when that rule change had happened. It happened fairly recently.” (Devon Energy says that it has no further plans to drill in Payne County.)

Dea Mandevill, the city manager for Medford, a small town not far from Cushing, has been trying to draw attention to the hazard that the daily earthquakes pose to her town’s aquifer and to the oil pipelines that run underground. “The industry has been really good for us,” she said. “There’s a use tax for any equipment brought in from another state, and also the leases for drilling. Not now, but in past years it’s tripled our revenues. From the revenue to the county, we’ve bought a new pumper truck for our fire department, two new brush rigs, two ambulances.” She continued, “We want to be a good partner for the oil companies—it’s exciting for us that they’re here. But if they can move the disposal well even just three miles, what a difference that would make.”

Two weeks ago, a town-hall meeting was held in Medford. Austin Holland handed out earthquake-preparedness pamphlets, and representatives of the O.C.C. spoke about their intention to develop better maps and to ask for data from a larger number of wells. But there remains no directive to reduce the volume of fluid disposed of in wells in the Medford area, as was done fifteen miles north, in Kansas.

The day of the meeting, the O.C.C. announced that it had requested that ninety-two companies provide proof that they had not drilled too close to basement rock. It’s an important step, yet the O.C.C. has at other times claimed that it already has this information, from routine inspections, though it has not acted on it, owing to being understaffed. The same day, the governor’s office announced its biggest response to the earthquakes to date: allotting an additional fifty thousand dollars to the O.C.C.

Some argue that it is a deeply ingrained ethos of Oklahomans to consider freedom from regulation the most

important kind of freedom. A century ago, though, Oklahoma had one of the strongest populist and socialist parties in the nation, and in areas other than oil and gas the state has tight regulations. Recently, solar panels became subject to an additional tax. The rationale is that when the panels contribute unused energy to the grid they are using the infrastructure. The fact that money buys policy is well documented, and much of the money in Oklahoma is oil money. The wishes and inclinations of the majority of Oklahomans, by contrast, are difficult to discern.

From the data gathered by her graduate students, Katie Keranen published three papers, one in *Geology* and two in *Science*. They showed how four disposal wells were likely responsible for twenty per cent of the earthquakes in Oklahoma, and models made by a Ph.D. student, Matthew Weingarten, demonstrated that earthquakes could be triggered as far as thirty-five miles from the wells. When Keranen's first paper came out, she was still at the University of Oklahoma, where the geology department and the O.G.S. share a building. (Keranen has since left her position at O.U., and is now at Cornell.) But the O.G.S. made, and continues to make, no mention of Keranen's research on its Web site, which does include links to relevant outside work. When Keranen linked the Jones swarm to disposal wells, the O.G.S. linked it to water levels at nearby Lake Arcadia, producing a study that did not appear in a peer-reviewed journal. A U.S.G.S. researcher wrote to Holland, concerned that trying to link the earthquakes to lake levels could be "distracting from the larger issue of earthquake safety in Oklahoma." Holland replied that he was "quite skeptical of the potential link" but that the O.C.C. had asked him to study it.

The O.G.S. received an early copy of Keranen's Prague work. The day before it was published, the survey's director at the time, Randy Keller, posted a position statement saying that the O.G.S. believed that the Prague quakes most probably resulted from natural causes. The statement, which also had Austin Holland's name attached to it, made no mention of any relevant peer-reviewed scientific research and was itself not published in a peer-reviewed journal. (Holland said that he was "not comfortable with the way it was worded.") To date, no journal-published, peer-reviewed work on the specific role of disposal wells in Oklahoma's earthquakes has come out of the O.G.S. Keller, who has since retired, told me, "We just go about our business, day to day, locating earthquakes and scratching our heads and installing new seismic stations and wondering what the heck is going on. It's just such a complex, fuzzy picture."

E-mail archives of the O.G.S. reveal that Keller's objectivity on the issue of induced seismicity was widely doubted at the university, with one researcher writing that the agency "couldn't track a bunny through fresh snow!" Holland said to me, "My focus now is on getting a clean database together, so that any researcher—researchers outside of the state or country, researchers anywhere—can make use of that data."

In October, 2013, the U.S.G.S. and the O.G.S. issued a joint press release warning that the chance of an earthquake of magnitude 5.5 or higher had "significantly increased." The release quoted a statement that Oklahoma has "always been earthquake country," but no reference to Oklahoma as "earthquake country"—a consistent talking point of the O.C.C. and the O.G.S.—can be found in any database predating the recent earthquakes.

Shortly after the press release, Holland e-mailed a colleague at the O.G.S., saying, "I have been asked to have 'coffee' with president Boren and Harold Hamm." The colleague replied, "Gosh, I guess that's better than having Kool-Aid with them." David Boren, a former U.S. senator, has been the president of O.U. for twenty years, and sits on the board of Hamm's oil company, Continental Resources. Hamm has donated more than thirty million dollars to O.U.

In another note after the joint statement, Holland wrote to Keller and the university's dean, Larry Grillot, about a meeting he had had with Patrice Douglas, a commissioner of the O.C.C.: "Jack Stark, the senior vice-president of exploration with Continental Resources, was there. The basic gist of the meeting is that Continental does not feel that induced seismicity is an issue, and they are nervous about any dialogue about the subject."

“**O**f course, sometimes I wish I was back in an area of scientific research that only a few experts cared about," Austin Holland told me. O.G.S. is understaffed, and from 2010 to 2014 Holland was able to publish only two peer-reviewed papers, neither dealing specifically with disposal wells. This year, though, he has already co-written two papers. In late January, he was one of eight authors of a paper that catalogued the thirty-six hundred and thirty-nine earthquakes of magnitude 3.0 or greater in Oklahoma between late 2009 and 2014; the paper sidestepped the question of any relation between energy exploration and earthquakes but noted that significantly larger earthquakes can be expected to occur along

the fault lines that recent earthquakes have traced. In February, he was one of twelve authors of a paper, published in the policy forum of *Science*, that discussed the now obvious point that induced earthquakes are not, like natural earthquakes, a matter of chance.

Chance is important to the oil and gas industry, which retains something of the luck-culture mythos of its earliest days. Companies are usually called “players,” and they “win” or “are awarded” contracts; the areas they explore are “plays.” Once, there was a fair amount of chance involved in striking oil. Stories of poor people coming across “gushers” on their property, or of discovering unknown inheritances of mineral rights, are emotionally important, and widely shared, in Oklahoma. And the tradition of Okie endurance—of uncomplainingly handling dust storms, tornadoes, poor soil, economic depressions—heightens the sense that Lady Fortune spins you up, spins you down. Maybe it’s not surprising that Oklahoma’s earthquakes have been in large part treated as simply one more hardship to withstand, a matter of bad luck following good.

But today the oil and gas industry understands that exploration is not a matter of a lucky hand. Science is as powerful epistemologically as it is weak politically. “I don’t rely on luck,” David Chernicky told the *Oklahoma City Journal Record*, in 2010, about a dewatering process he helped develop. “I rely on science because I’ve never been lucky in my life.” He continued, “I never won a raffle. The only thing I got was out of a Cracker Jack box, but then everybody gets something out of that box.” ♦

* (#correctionasterisk)An earlier version of this article misstated the basis of Devon Energy’s threat to take legal action.

Rivka Galchen is the author of the short-story collection “American Innovations” and the book-length essay “Little Labors,” which is due out later this year.
