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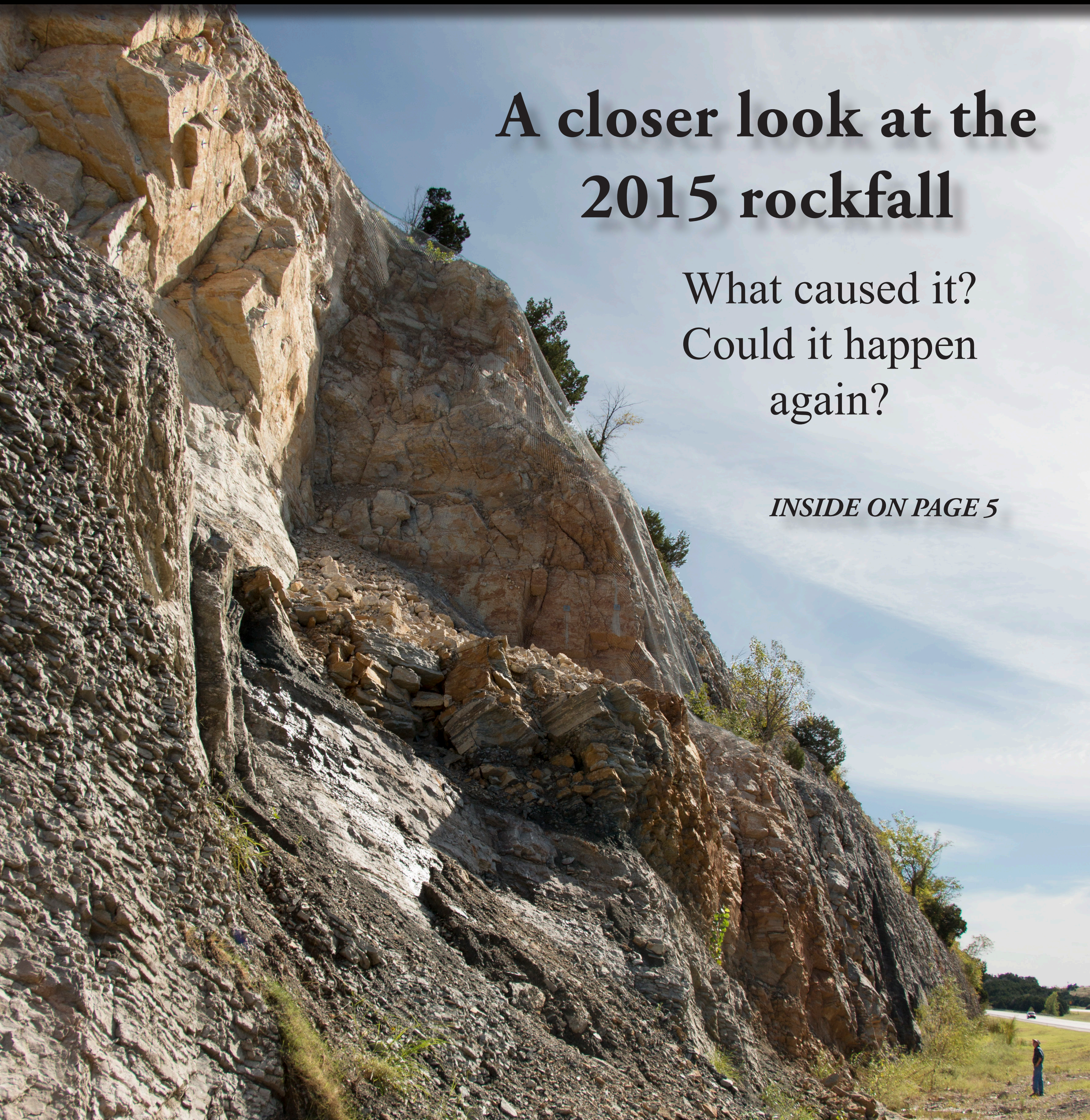

A closer look at the 2015 rockfall

What caused it?
Could it happen again?

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OKLAHOMA GEOLOGICAL SURVEY

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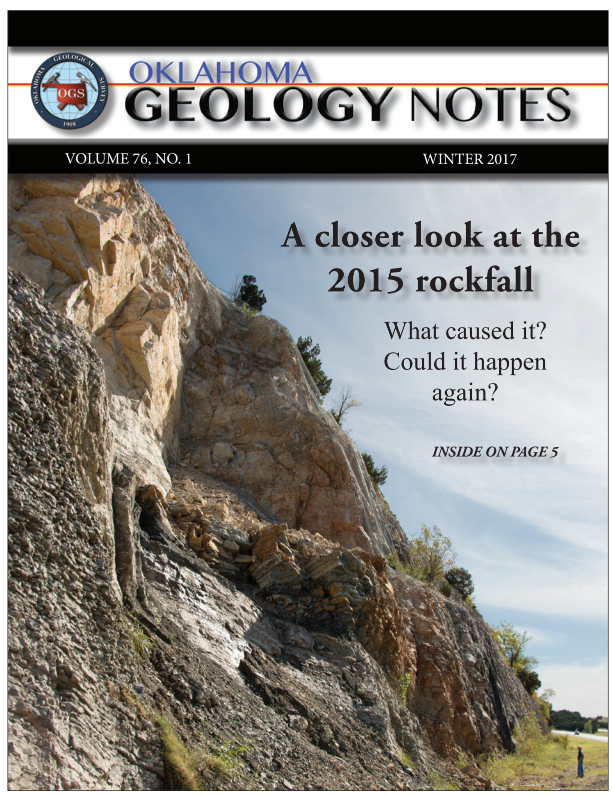
The Oklahoma Geological Survey is a state agency for research and public service, mandated in the State Constitution to study Oklahoma's land, water, mineral and energy resources and to promote wise use and sound environmental practices.

IN THIS ISSUE

OGS Associate Director David Brown looks at the 2015 rockfall on I-35. He addresses all of the elements that led to the rockfall and whether another one is in our future.



Cover: Outcrop at the site of the 2015 rockfall. Photo was taken in October 2016. (Photo by Ted Satterfield).

From The Director

More Details on a Rockfall, Welcomes, Goodbyes, Anniversaries, and a Highlight

Jeremy Boak
OGS Director

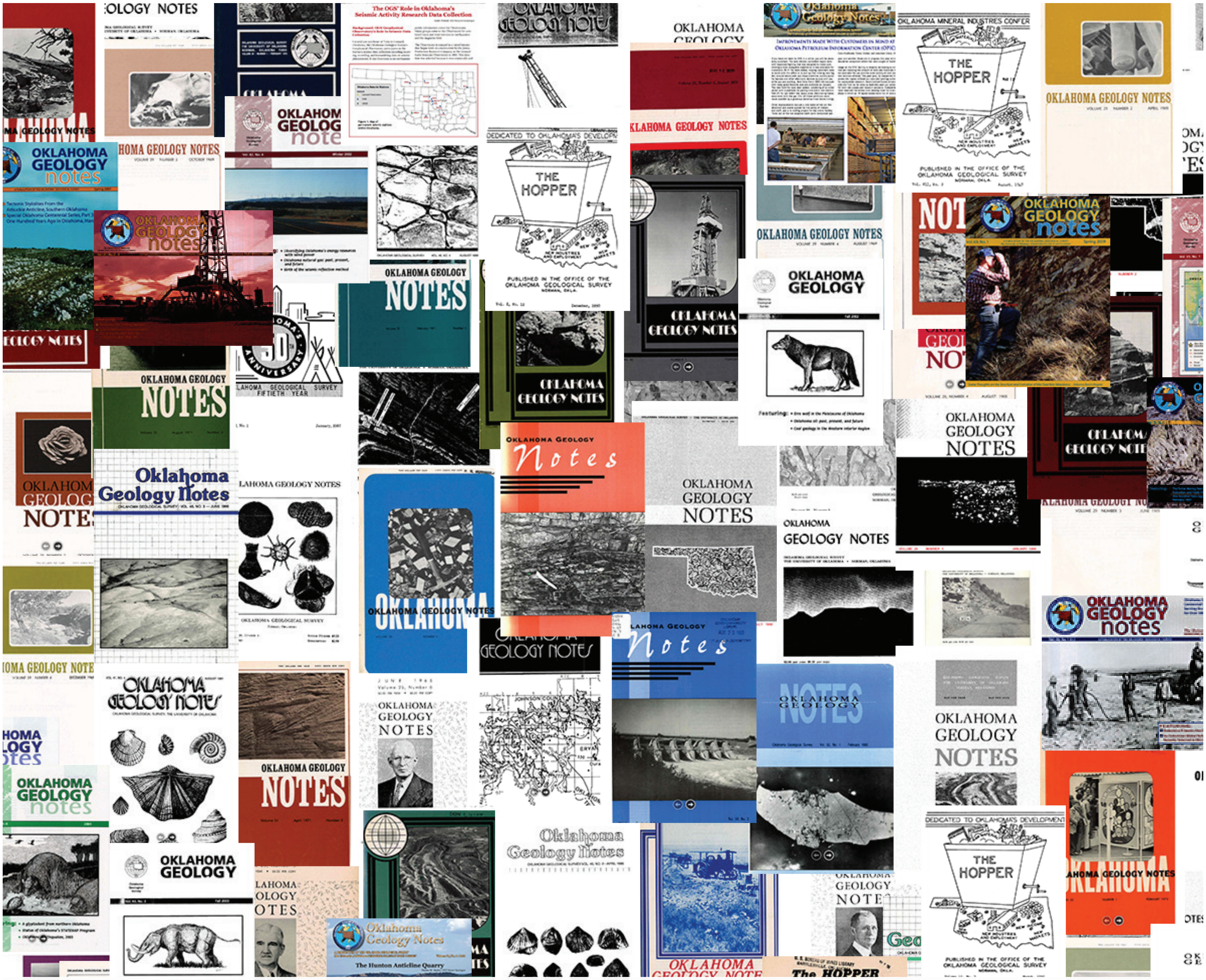
This new issue of the Oklahoma Geology Notes highlights a rockfall on Interstate 35 that was briefly described in the last issue. David Brown, OGS Associate Director, provides a detailed description of the rockfall and the efforts to remove the debris, as well as additional loose rock that was considered too vulnerable to leave in place. The rockfall occurred in June, and stabilization of the rock face continued throughout the summer. Such hazards are not as common as in mountainous states like Colorado and California, but Oklahoma has enough places with steep slopes and faces that rockslide and landslide hazards cannot be ignored.

The Oklahoma Geological Survey has added some new people, and bid goodbye to others in the last few months. Research Associate Ella Walker came on board to work with Kyle Murray in the Water, Environmental and Engineering Team. Jacob Walter joined the OGS in November, replacing Austin Holland as the State Seismologist and Geophysics Team leader. In addition, David Brown was promoted to Associate Director.

At the end of the year, four people retired under the Special Voluntary Retirement Incentive offered by the University. Petroleum geologist Richard Andrews, general geologist and jack-of-all-geologic-trades Neil Suneson, workshop and field trip coordinator extraordinaire Michelle Summers, and publication sales expert Sue Palmer took with them 115 years of experience at OGS. We celebrated their retirement along with those of other recent retirees Gene Kullman, former OPIC Manager, and Tommy Sanders, our OPIC handyman, at a party in November. In early February, Noorulan Ghouse, a seismic analyst on our Geophysical Team also departed for an exciting new job in Florida. We will be filling some of these positions, but cannot hope to immediately replace the sterling individuals who left us.

OGS is also celebrating major service milestones for Brian Cardott (35 years), Richard Murray (25 years), Joyce Stiehler (20 years), Stan Krukowski (15 years), and Richard Tarver (10 years).

Another milestone completed in the last quarter was submittal of the final report of the major project on seismicity funded by the Research Partnership to Secure Energy for America (RPSEA). This report is posted on our website at http://ogs.ou.edu/docs/reports/RPSEA_Project_12122-91_Final_Report.pdf. It describes the rise and fall of seismic activity in Oklahoma over the last eight years, and details work on the seismic network, analysis of the earthquake catalog, and gravity measurements. It also discusses integrated models of the bedrock of Oklahoma increased seismicity Area of Interest, using data on the gravity and magnetic fields, seismic velocity, and other geophysical and geologic information. In addition, it presents the results of two modeling efforts of the geomechanical and hydrologic behavior of rock volumes under the stress field and injection history of central Oklahoma.



Geology Notes are Back

The Oklahoma Geology Notes, originally called "The Hopper", has been a fixture at the OGS since the early 1940s. It is now back with a new look. For information about how to contribute to the Oklahoma Geology Notes, contact Ted Satterfield at tgsatterfield@ou.edu

A closer look at the 2015 rockfall

What caused it? Could it happen again?

By David Brown

INTRODUCTION

In the pre-dawn hours of Thursday, June 18th, 2015, rock layers on an exposed roadcut in the Arbuckle Mountains of southern Oklahoma failed, sending tons of debris onto the roadway below. In an instant, rocks as small as baseballs up to blocks as large as small cars were deposited in the pathway of startled motorists. Darkness and rainy conditions made an unsafe situation all the more dangerous as travelers attempted to avoid the newly formed rock pile.

The incident occurred at mile marker 50 along a section of Interstate 35 (I-35) known as Honey Creek Pass, a heavily travelled north-south thoroughfare through the southern part of the state (Figure 1). According to the Oklahoma Department of Transportation (ODOT) Public Information Officer Cody Boyd, on any given summer day there are more than 30,000 people traveling this section of road (Personal Communication). Fortunately no one was seriously injured, but there were news reports from KOCO in Oklahoma City of damage to at least two semi-trucks (Chesky, 2015). ODOT officials quickly responded to the incident and were forced to re-route traffic to the southbound lanes as they closed a section of northbound I-35. Some traffic was directed to US-77 as a detour. What had hours before been an apparent safe and efficient means of transportation was now a dangerous and costly way to travel. These disruptions remained in place for six weeks until the rocks were cleared, and the location was again considered safe for travel.

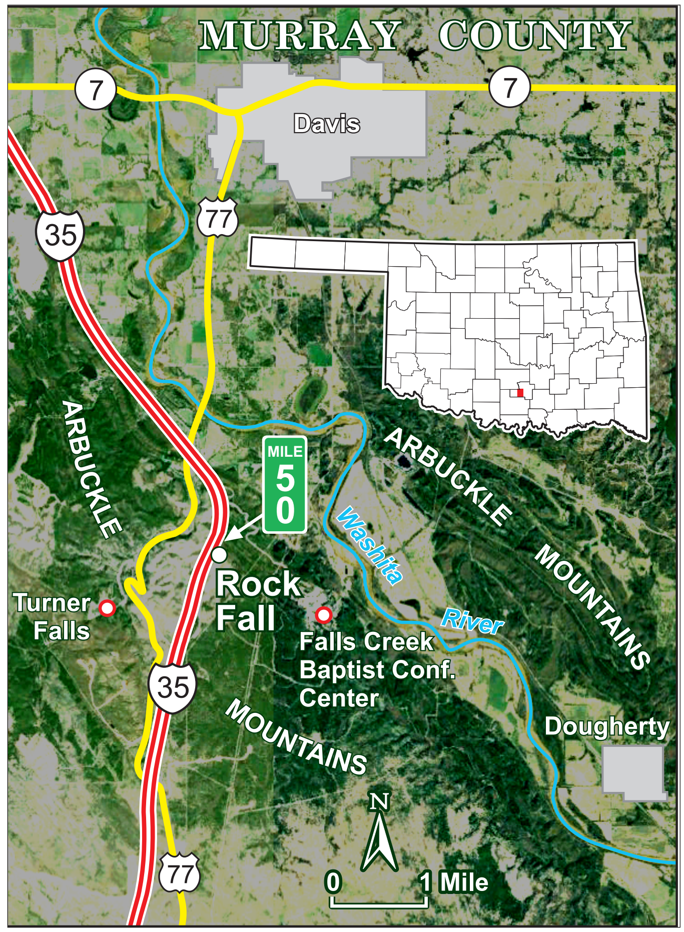


Figure 1. This map shows the location of the rockfall and the surrounding area.

DEFINITION

While this incident was a surprise to many, and something considered relatively uncommon in Oklahoma, it is a known phenomenon. In fact, geohazards such as this can occur in any hilly or mountainous terrain. For this article, the event is being technically classified as a "rockfall" (Figure 2), but some may use the term "landslide" to generally describe any mass movement of rock or soil. Whatever term is used, the geohazard and the harm it can cause can be serious. Whenever rocks or rock strata are positioned on a cliff, hill, or steep slope, a possibility always exists that they could tumble, slide, or fall (Highland and Bobrowsky, 2008). If such a possibility becomes reality, a very dangerous situation is created.

In their stationary positions on a slope, rocks possess potential energy as a function of their mass and height above a surface below. If an acting force or process frees the rocks from their resting positions, gravity will pull them down. As the rocks move, their velocity increases, converting their stationary potential energy into moving kinetic energy. The momentum or force that accelerating rocks can possess at the bottom of a slope can be significant. Property, vehicles, and especially humans are no match for even a small

Figure 2. There are various classifications of falling rock and/or soil, which are determined by the materials involved and the way they move from one location to another (Highland and Bobrowsky, 2008; Stock and others, 2013). Because the rocks in this case were thought to have broken free and fallen down the slope, the incident is being termed a rockfall. Note the northbound lanes of I-35 were closed for six weeks to allow for debris removal and safety enhancements.

rockfall (Figure 2).

GEOLOGY

While weathering was an important factor in the cause of this rockfall, the geology of the area played an equally important role. Sedimentary layers present at this site are part of a succession of Middle Ordovician strata known as the Simpson Group (Figure 3). The Bromide Formation is stratigraphically the youngest formation within the group and is well exposed in the roadcut at mile marker 50 (Figures 4 and 5). Fay (1989) described the Bromide at this location as being composed of two members: the Mountain Lake and the Pooleville. The northern portion of the roadcut is made up of the stratigraphically lower Mountain Lake Member. Fay (1989) described the Mountain Lake as a "Shale, bluish-gray, calcitic, platy, laminated, weakly indurated, fossiliferous alternating with tan to bluish-gray medium-bedded coarsely crystalline echinodermal limestone, with a brecciated pocket of tan fine-grained dense limestone 6-8 feet below top... ." Fay (1989) also

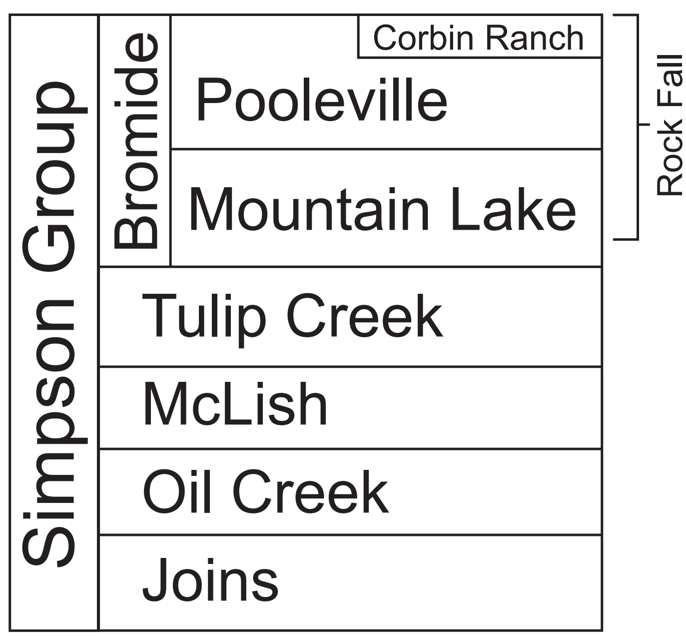


Figure 3. This is a simplified stratigraphic column for the Simpson Group showing members of the Bromide Formation that were involved in the rockfall.

Figure 4. (Top) This photo shows the full outcrop of the area where the rockfall occurred after the debris was cleaned up. The beds along the hill at mile marker 50 strike in a northwesterly direction and dip normally 25-30 degrees to the southwest.
Figure 5. (Above) The rockfall took place close to this spot at mile marker 50 along northbound I-35.
Figure 6. (Above right) This marker was placed on the outcrop by the OGS and the Ardmore Geological Society to mark the location of the Mountain Lake Member of the Simpson Group.
Figure 7. (Below right) This photo shows the variety of rock sizes at the site of the rockfall.

Figure 8. This photo shows the outcrop before the debris was cleaned up.

Table I. — Rainfall

Oklahoma Mesonet data indicated that 6.5-7 inches of rain fell in the area on June 17 and 18. At the time, officials reported the month of May 2015 as having the most rainfall ever recorded in Oklahoma's history.

Source: (Mesonet)

identified a slumped 11-ft thick sandstone layer within the lower section of the Mountain Lake at the far north end of the roadcut. A brass marker (Figure 6) placed on the site by the Ardmore Geological Society and the Oklahoma Geological Survey identifies this sandstone as being 53 ft above the base of the Bromide Formation.

Immediately overlying the Mountain Lake to the south is the Pooleville Member. Fay (1989) described a portion of this section of Pooleville as "Limestone, light-gray to tan, fine-grained, fossiliferous, medium- to thick-bedded, well indurated, with some argillaceous laminae in lower 13 ft; eroding into an escarpment." It's important to note that Fay (1989) also mentioned the lower eight ft of this roadcut as having formed a slide area, decades before the June 2015 incident.

Images from Google Street View show this particular site in early 2015. A small drainage feature can be seen to have already deposited rocks at the bottom of the slope in a typical alluvial fan pattern. This feature was greatly accentuated by historic rainfall later in the year (Table 1). It was only a matter of time before erosion caused naturally fractured rocks near the top of

Figure 9: A fan of rock debris lays scattered along the side of the road, with large rocks falling onto the road.

the hill to separate and fall to the road below.

Carlucci and others (2014) identified the same Bromide members as Fay (1989), but also included a thinning section of the Corbin Ranch Sub-Member in the upper portion of the Pooleville. Carlucci and others (2014) described the Corbin Ranch as “alternating units of fenestral lime mudstones … and rubbly shale and wackestone.”

While not involved in the rockfall, the Viola Group limestone is also present at this location. The Viola limestone immediately overlies the Pooleville near the crest of the hill and forms the southern half of the roadcut. Since the Viola rocks are generally more resistant to weathering than adjacent rocks in the area, they typically form ridges in the Arbuckle Mountains.

Samples observed at the rockfall site were found to be consistent with rocks mentioned by Fay (1989). Light-gray limestone weathering to tan composed the majority of the larger blocks in the debris pile – some pieces were seven-to-ten ft in length, six-ft wide, and five-ft tall (Figures 7, 8, and 9). These were interpreted to have come from the Pooleville Member near the top of the hill. The smaller rocks included gray limestone and pieces of gray wackestone and calcareous mudstone with some dark-gray to green argillaceous shale mixed in. Many of the thinner bedded fine-grained rocks, less than a foot in girth, were found lying below and between the larger limestone blocks in the pile (Figure 7). Most of the smaller limestone and fine-grained rocks were interpreted to have come from the Mountain Lake Member.

Depositional Environment of the Bromide

Carlucci and others (2014) described the Bromide Formation in this area as being deposited in a mostly shallow-marine setting along a ramp that gradually

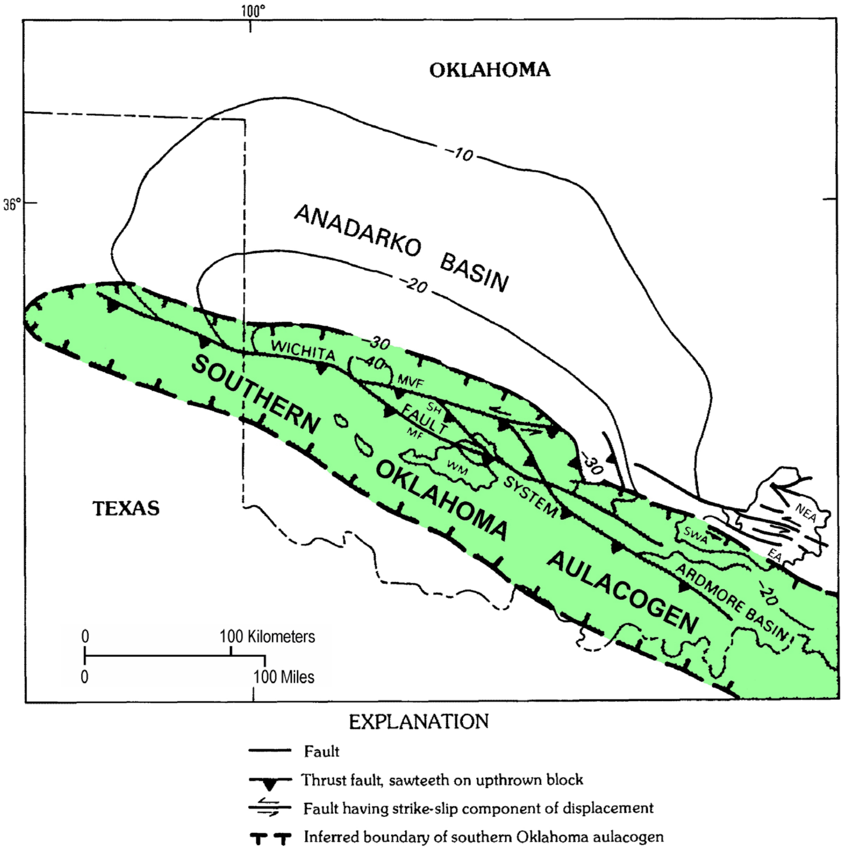


Figure 10. Map of the southern Oklahoma aulacogen. (Modified from Perry, 1989)

steepened towards the southern Oklahoma aulacogen (SOA). The SOA (Figure 10) was a major subsiding tectonic feature that affected deposition across what is now southern and western Oklahoma. As Bromide sediments were deposited on the shallow ramp from the north and east, they thickened towards the south and west as accommodation areas increased along the steepening ramp (Carlucci and others, 2014). Changes in water depth and accommodation areas controlled the type and amount of sediments deposited on the ramp, and thus, the rocks we see today.

WHAT HAPPENED?

A slope's gradient is important in determining whether a rockfall will occur. If the gradient is beyond a critical value, then any action that dislodges rock or debris will usually result in those materials being removed by gravity (Highland and Bobrowsky, 2008). In the case of this rockfall, it is hypothesized that rainwater drained through natural fractures in the Pooleville at the top of the hill, which then continued into the underlying thinner bedded layers of the Mountain Lake Member below. Natural fractures over 12-in. wide were observed at the site allowing for large volumes of water to pass through. While slope and water were major factors in the creation of this incident, it's likely they weren't the only culprits.

Figure 11. The west side of I-35 (directly opposite of the rockfall) shows trees growing out of natural fractures in the rock face.

Figure 12. Pre-rockfall images from Google Street View (2015) show ice forming within cracks in the outcrop just south of the site of the rockfall. This is a clear indication of water flow through the rocks

Figure 13. Water is seen flowing out of cracks in the outcrop at the location of the rockfall in October 2016.

Here are some other processes that could have played a role:

Root Wedging

Observations made at the site after the rockfall showed evidence of vegetation growing out of the rock face along the hill. It was noticed in particular that tree roots had penetrated some of the rock fractures; some were quite established into rocks. A pre-rockfall photo from Google Street View (2015) shows trees growing in a similar fashion on both sides of a small drainage feature. Root wedging is a process where fractures are expanded from roots as they grow into the available openings (Stock and others, 2013). Even small cracks can become infiltrated by roots as they seek out the water source such openings provide (Figure 11). This process can be a powerful force that loosen the rocks over time, and thus, makes them more susceptible to falling. It was noticed that many small trees were carried down the hill with the rocks in this rockfall, and it is suspected that root wedging played a role in destabilizing some of those rocks.

Figure 14. (Left) On the opposite side of I-35 across from the rockfall, blocky more consolidated layers can be seen protruding as ledges over finer-grained material below. The protruding blocks are poised to fall at any time. **Figure 15.** (Right) Also on the opposite side from the rockfall, vegetation can be seen growing along fractures of the thicker-bedded layers above the finer-grained material. Roots expand the fractures making the rocks more unstable.

Figure 16. Rocks at the top of the rockfall site hang precariously after the rockfall but before the big blast.

Ice Wedging

Ice wedging, sometimes called freeze-and-thaw weathering, is another action that could have worked to loosen fractured rocks. Stock and others (2013) point out that as water expands upon freezing, it can cause elevated stress within rock fractures (Figures 12 and 13). The resulting force is sometimes large enough to move partially detached rocks outward making them less stable on a slope (Highland and Bobrowsky, 2008; Stock and others, 2013). Earlier Google Street View (2015) photos near mile marker 50 show places where ice formed as water drained from fractures on the slope. It's very plausible that some of the rocks in this roadcut were broken apart, or at least had their fractures significantly enhanced, by this process.

It is impossible to know all of the causes of this rockfall, but it would be safe to suggest that weather conspired with geology, erosion, and gravity to reduce the stability of this man-made hillside. Over time, small fractured ledges developed near the top of the hill, which then protruded over an increasingly eroded and less stable section of rocks at the bottom. As erosion continued, the fractures increased in size. Eventually, the lower portion of the hill could no longer support the overhanging beds. Rocks at the top of the hill were poised to fall if presented with high volumes of water. The historic rainfall in early 2015, plus the remnants of Tropical Storm Bill, which had been downgraded to a tropical depression just before it passed over the area, provided the final push.

It should be noted that the hillside morphology associated with this rockfall can be seen in mirror image in the roadcut on the opposite side of the interstate (Figure 11). There, the same geology and slope

VIDEO OF THE BIG BLAST

ONLINE VIDEO

Watch the full video on the OGS website: www.ou.edu/ogs

conditions occur along the southbound lanes. Small drainage features and fractured upper blocks are present, and the finer-grained cliff face of the lower slope is slowly eroding into the hill (Figures 14 and 15). If no efforts are made to mitigate this situation, it is possible that a similar rockfall could occur on that side of I-35.

THE SOLUTION

ODOT officials sought the assistance of the Colorado Department of Transportation (CDOT) to help assess safety concerns and cleanup efforts. CDOT's experience with similar slides in the Rocky Mountains was beneficial in developing a plan to secure the slope and to reopen the roadway to normal traffic in a quick and safe manner. According to ODOT (2015d), over $1.4 million was spent contracting with geohazard engineers and construction firms to perform the cleanup work.

Early assessments determined that not all of the potentially dangerous rocks fell in the original incident. Some blocks were left hanging near the top of the hill (Figure 16), and for several days debris could be seen randomly falling down the slope. A decision was made to remove this loose material by force.

Figure 17. (Above) Bolts were placed in the rock face at the site of the rockfall to provide stability. **Figure 18.** (Below) A high tensile steel mesh was attached to the rock face to catch rocks that might come unattached.

THE BIG BLAST

ODOT (2015c, 2015d) reported that engineers drilled holes in key locations along the hill and then

Figure 19. The final resting place of the debris from the rockfall is the Dolese Quarry west of Davis, Oklahoma.

Table II. — Other Oklahoma landslides in 2015

According to ODOT (2015a, 2015b), following the historic rainfall of 2015 there were several weather-related landslide repairs made within the state. Here are a few of them, excluding the Arbuckle rockfall, that were performed at significant costs.

Haskell County
SH-82 near Lequire - $421,394

LeFlore County
SH-1 (Talimena Drive) one mile east of US-271/SH-1 junction - $560,050

Pushmataha County
US-271 near Clayton - $1.3 million

Source: (ODOT Media Relations Office)

selectively placed approximately 400 lbs of explosives for use in bringing down the unstable rocks. Near 7:00 pm on July 8th, all lanes of I-35 were closed north and south of the rockfall. Only the engineering crew, ODOT/OGS officials, and some media were allowed within one half mile of the blast site. An eerie silence fell across the surrounding hills as noise from interstate traffic was temporarily suspended for the first time in perhaps decades. Birds could be heard chirping and conversations were possible with only whispers. A countdown commenced and then the warning “Fire in the hole!” In the distance, a silent eruption of rock and dust pushed outward from the hillside followed shortly after by the trailing sound of a strong, yet muffled, base thump. A sound like rain was heard next as thousands of pieces of rock cascaded down the slope and fell from the sky amid a huge cloud of dust. Moments later the eerie silence returned.

A few smaller blasts were used over the next few weeks to remove rocks that continued to pose a danger. There was at least one additional complete road closure required on July 15th as powerful explosives were once again detonated. It was finally determined the charges had done their job.

The next step for securing the site was to prevent

Figure 20. Man and Nature have both contributed to the landform along the I-35 corridor in the Arbuckle Mountains. These pictures from ODOT archives show the construction of the I-35 corridor through the Arbuckle Mountains.

another slide from occurring. To do this, contractors manually scraped the remaining loose rocks from the slope, and then secured the fresh rock face with bolts 20- and 30-ft long (Figure 17). According to an ODOT press release, these were drilled into the rock layers and will remain there permanently. A high tensile steel mesh (Figure 18) was also attached to the rock face as a way of catching anything that might become unattached in the future. None of these measures can be considered 100 percent effective, but they should minimize the possibility of a similar incident occurring in the future.

THE FINAL JOURNEY

The debris from the rockfall was transported to the Dolese Quarry west of Davis, Oklahoma. Dump trucks worked around the clock for 2 weeks to relocate the mass to its new home. Quarry officials reported that 12,820 tons of rock was delivered to their facility, although over 14,000 tons was estimated to have fallen, according to ODOT (2015d). It remains unclear what future uses the rock might have because there are strength and freeze tests that must be passed before any rock can be certified for use in certain commercial projects. So, now the rocks sit in the back of a large hole in the ground six mi. from their original depositional home (Figure 19). It is a nondescript final stop along a journey of distance and time for sediments that were laid down in an Oklahoma sea over 450 million years ago.

CONCLUSION

While states such as California and Colorado come to mind when considering dangerous rockfalls, Oklahomans do have some risk of experiencing these types of geohazards. The Arbuckle Mountain region is not the only area that is susceptible. The Wichita, Ouachita, and Ozark Mountains have all experienced such incidents (Table 2). Rock type, structure, and slope gradient all play a role in the potential creation of these events. Climate is also a factor, as annual rainfall can significantly affect the erosional processes of certain soil and rock types. Even humans are part of the equation for determining whether a geohazard will occur. The rockfall discussed in this report actually began to form in the 1960's when ODOT engineers cut a pathway through the Arbuckle Mountains (Figure 20). The fresh roadcuts created for the new interstate exposed rock formations that had been hidden for millions of years, thus initiating the interaction between rocks, weathering, and gravity.

A year and a half after the June 2015 rockfall, the I-35 corridor through the Arbuckles Mountains is back to normal and traffic appears to be moving safely. An incident like this could occur at anytime, however, and it should serve as a warning for any location that has exposed rock or loose soil. Geohazards, such as rockfalls, should always be taken seriously. There is a real price to be paid for these events, and it would be wise to consider a proactive approach towards identifying where incidents might occur. A systematic assessment of locations along roadways and railways could reduce or even eliminate the costs associated with loss of commerce and recovery operations. Any investment in hazard analysis or mitigation could prove beneficial, but the most important savings, of course, would the saving of human life.

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About the Author

David Brown was named OGS Associate Director in December 2016. He brings with him 25 years of oil and gas industry experience, including expertise in GIS and database technology for use in analysis and research.

After receiving a B.S. degree in Geology from the University of Oklahoma, David began his career at Amoco Production Company where he performed basin analysis for their Africa and Middle East division. He later returned to OU to work for Geo Information Systems, a research unit of Sarkeys Energy Center.

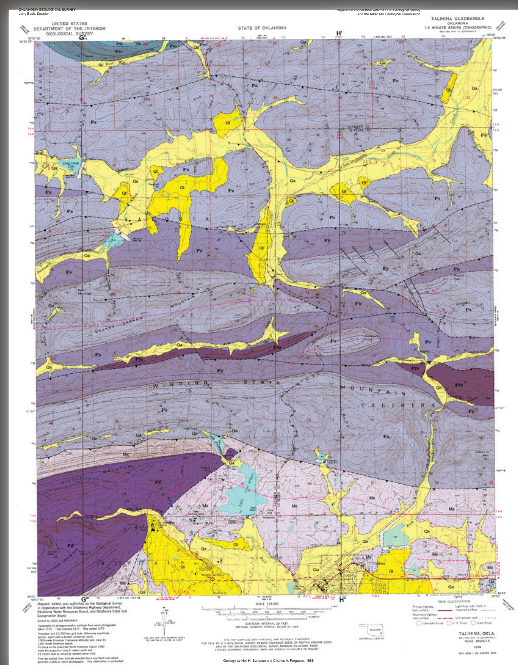
For over a decade, David helped Geo Information Systems advance the use of GIS in petroleum related efforts and worked on several projects with the Oklahoma Geological Survey, including the Mid-Continent Gas Atlas, the Fluvial-Dominated Deltaic (FDD) studies, and the Petroleum Technology Transfer Council (PTTC) program. In 2000, David joined Devon Energy where he implemented and managed the company's first GIS department. He spent nearly 14 years with Devon and was eventually named manager of GIS, Land Administration, and Data Management. In recent years, David has worked with the Oklahoma Energy Resources Board as a PetroTech instructor.

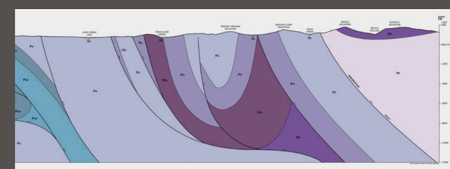
David became a licensed private pilot at the age of 17 and is an aviation and space enthusiast. He studies astronomy and quantum physics for fun, and enjoys snorkeling in the Florida Keys. David is married and has a wonderful daughter and son-in-law.

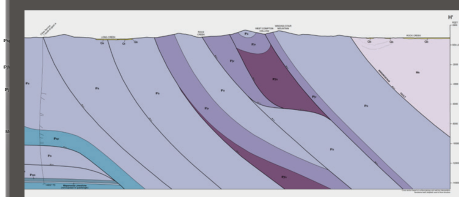
A CALL FOR VOLUNTEERS

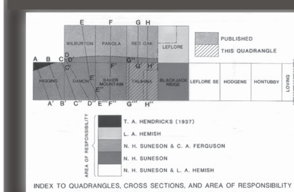
The Oklahoma Geological Survey's (OGS) STATEMAP program needs you, or a representative of your company or institution, to become a member of the Oklahoma Geological Mapping Advisory Committee (OGMAC).

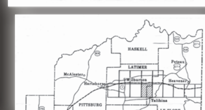
The STATEMAP program is a state geologic-mapping component of the National Cooperative Geologic Mapping Program of the United States Geological Survey (USGS), which provides federal matching funds to State Geological Surveys to achieve their mapping goals.

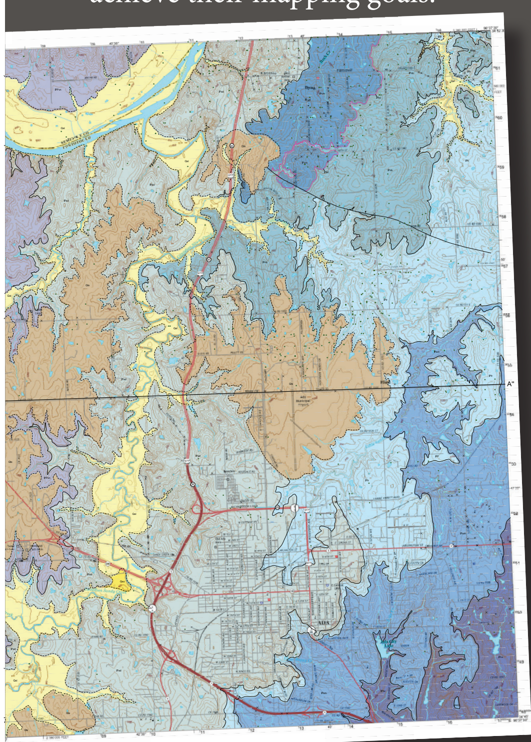


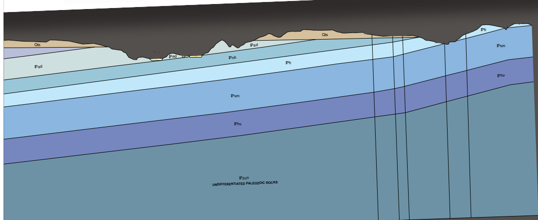












Part of the stipulation for the STATEMAP program by the USGS is the establishment of an Oklahoma Geological Mapping Advisory Committee (OGMAC), consisting of representatives from various university, state and local governments, tribal, private businesses, and even individual citizens. The purpose of the committee is to have broad, statewide interests that can be applied to directing the STATEMAP program. The committee would have the responsibility of establishing priorities for geologic mapping in Oklahoma that reflect multiple interests and goals.

As a committee member, the OGS would be soliciting your input and recommendations concerning regions, areas, or specific quadrangles that you, or a representative of your agency or company, feel have the highest priority for geologic mapping.

The committee would only meet once a year for two to four hours at some location in central Oklahoma.

If you wish to become a member of OGMAC or have additional questions, contact
Dr. Tom Stanley, tmstanley@ou.edu; 405-325-7281.

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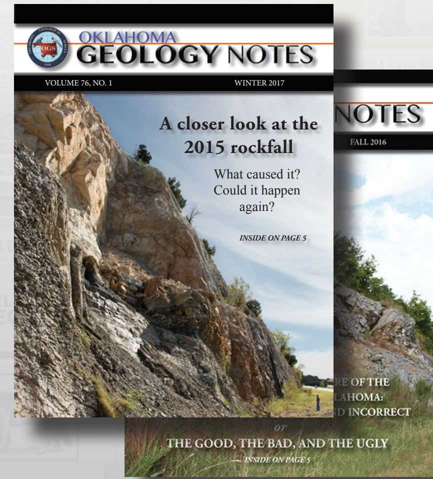

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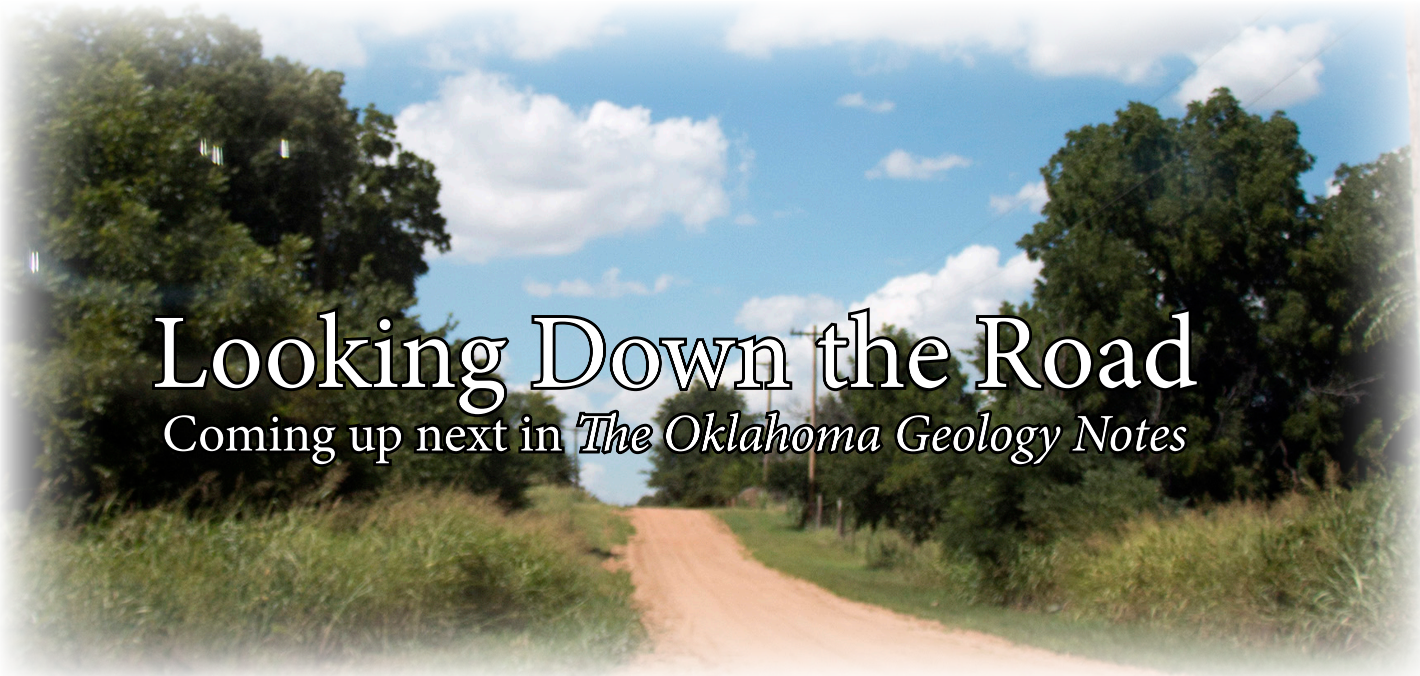

Looking Down the Road

Coming up next in *The Oklahoma Geology Notes*

Oklahoma's First Geologic Map

In the spring issue of the Oklahoma Geology Notes, OGS geologist Brittany Pritchett and OGS cartographer Jim Anderson tell the story of a remarkable discovery they made while searching for maps in a storage room. Hidden under miscellaneous maps and boxes, the two stumbled upon the first geologic map of Oklahoma, which was a handmade map created by the OGS's first director, Charles Gould. Brittany and Jim describe how they oversaw the conservation and preservation process that took over two years. After decades of hiding in obscurity, the map will soon be ready to display for all to see.