

Oklahoma Geology Notes

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A NEWSLETTER OF THE OKLAHOMA GEOLOGICAL SURVEY

The University of Oklahoma MEWBOURNE COLLEGE OF EARTH & ENERGY

From the Director ~ A Look at 2011...

G. Randy Keller, Oklahoma State Geologist

The OGS had a great year in 2011, and here, I have briefly highlighted some of the year's activities, developments, and accomplishments. It will take a big effort to have an even better 2012.

Personnel Changes

We added two excellent people to our staff.

Dr. Kyle Murray (*pictured below*) joined us as a Geohydrologist.

He has a PhD from the Colorado School of Mines and has extensive experience in academia, the U.S. Geological Survey (USGS), and consulting. He is particularly interested in the application of GIS to water resource studies.



Richard Tarver (*below*) joined us as a research technician at OPIC. He is an OU graduate who worked for us 10 years ago. He is experienced in web-based databases and has five years of experience in database construction and management.



Jennifer Veal and David Pennington

retired after many years of service. David is enjoying his retirement, and we are happy that Jennifer has returned on a part-time basis.

Improved Office Space in Sarkeys Energy Center

Those of you who visit our offices in Norman will notice some changes. Although our main office suite remains the same, our geological staff has much improved, but dispersed, office space. Our print shop has also moved and is directly across from the main office. We greatly appreciate this demonstration that we are a key part of the Mewbourne College of Earth and Energy.

Workshops, Fieldtrips, and Meetings

Michele Summers again organized a series of very successful workshops, fieldtrips, and activities at professional meetings. We were, in fact, involved in about 25 such activities. Our two Mississippian workshops created a crush of interest and were packed, as was our Shales Moving Forward workshops. The Mid-Continent section meeting of the American Association of Petroleum Geologists in Oklahoma City was a big event for us as was the Osage Oil & Gas Summit in Tulsa. In most cases, we had numerous involved in a team effort necessary to make these events successful.

Funded Research Projects

We have several ongoing funded research projects. These include a geothermal resource evaluation led by Rick Andrews and funded by the Department of Energy. Our STATEMAP project is a major continuing effort funded by the USGS and led by Tom Stanley, who is assisted by Julie Chang and Russell Standridge. Jane Weber continues to lead our data preservation grant, which is funded by the USGS. Brian Cardott continues to lead our Coal Resource Appraisal effort, which is also funded by the USGS. Several of these projects include funding for student assistants. Kyle Murray brought a grant with him that is an investigation of a water resource geospatial infrastructure for oil shale development. It is funded by the Department of Energy via a grant to the Colorado School of Mines.

Other Research Projects

We have many ongoing research studies and new projects that we intend to pursue. For example, Ken Luza continues to be involved in the Pitcher Superfund site; Stan Krukowski studies and keeps track of Oklahoma's mineral resources including aggregates and rare earths; Neil Suneson continues to study the Ouachita Mountains - Arbuckle Uplift - Wichita Mountains area, and I continue to study these areas, as well as, the deep structure of the state and surrounding areas. Kevin Crain and Vikram Jayaram are leading our group's effort to build 3-D geological models based on geological and

A Look at 2011. . ., continued from p. 1

geophysical constraints. We recently featured our Osage County project at a professional meeting.

Publications

We continue to produce a wide variety of publications for the geological community as well as the public. Jim Anderson and Russell Standridge (Cartography), Sue Crites (graphic design/editing), Paul Smith and Richard Murray (printing), and Joyce Stiehler and Sue Palmer (sales) compose the effective team that produces and distributes our publications.

Website

An ever increasing number of our publications appear on our website free of charge. Connie Smith is our Webmaster and also handles publicity and media interactions. We are receiving a very high number of "hits" and downloads of documents from our website so have a look at all of the "goodies" at <http://www.ogs.ou.edu>.

Earthquakes

Needless to say, the earthquake activity in Oklahoma this year is a very hot topic. The magnitude 5.6 event in eastern Lincoln County on November 5th was felt over about a third of the state and did significant damage to a number of homes and businesses. Austin Holland, Ken

Luza and I have been inundated by calls from the media and public. In cooperation with the U. S. Geological Survey, Austin and Dr. Katie Keranen of the School of Geology and Geophysics have deployed almost 30 portable seismographs in the epicentral area. The Oklahoma Corporation Commission has provided a lot of valuable information, and we are also receiving valuable input about the structure of the area from industry. We will know a lot more about this earthquake sequence when we have had enough time to analyze all of these data so stayed tuned.

Energy Libraries On-Line

Led by Dan Boyd, the OGS worked with the Energy Libraries On-Line effort to make a number of advances this year. Our staff did a great deal of the work needed to digitize 500 detailed cross sections that were constructed by long-time Tulsa geologist J. Glenn Cole, who died in 2008. His family donated them to the Tulsa Geological Society, and now, they are preserved as his lasting legacy on the ELO website - <http://energylibrariesonline.com/>. Electric logs, which show what kind of rock is encountered in a well, are the foundation of Cole's work, but what makes the collection unique is the meticulous detail and consistency he employed during this massive effort.

Another major development was that we were able to obtain a \$100,000

donation from Marathon Oil to support the advancement of the ELO effort.

We continue to scan paper records and donate them to the ELO effort. In another major development this year, Jane Weber organized our mud log collection and we are scanning it.

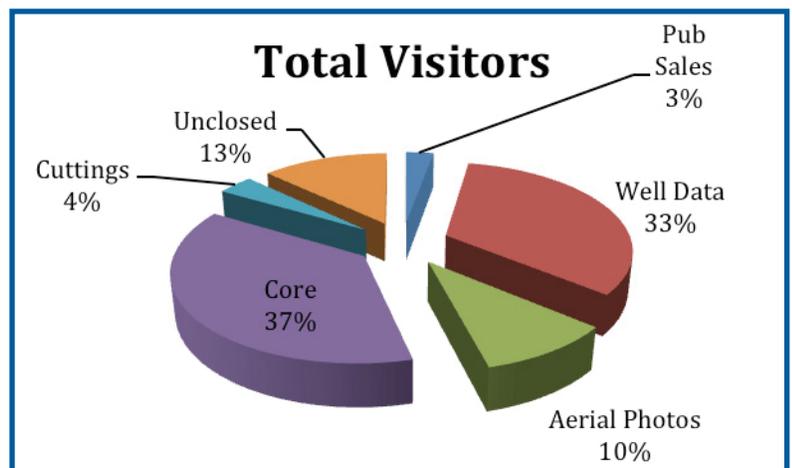
Newspapers in Education Outreach

Thanks to the support of the Oklahoma City Geological Foundation and the tireless efforts of Connie Smith, we were able to produce two inserts for the Oklahoman's Newspapers in Education (NIE) program this year. One was the third in the series of 16-page newspaper supplements for classrooms and was released in October with the theme being how Oklahoma's geologic history has produced the great variety of landscapes we see in the state. OKLAHOMA ROCKS! The Making of a Landscape featured an introduction and overview and separate sections on Southeast Oklahoma and the Ouachita Mountains, South Central Oklahoma and the Arbuckle Mountains, Southwest Oklahoma and the Wichita Mountains, Northwest Oklahoma and Black Mesa, Central and Western Oklahoma and the Red Beds, and Northeast Oklahoma and the Ozarks. Maps, illustrations, photos and a geologic time scale were included to help readers put the text in context.

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Oklahoma Petroleum Information Center (OPIC) Visitors January through November 2011.

OGS seismologist Austin Holland also authored a series of four lessons on the general aspects of earthquakes which appeared in *The Oklahoman* in the spring of 2011.

Oklahoma Petroleum Information Center (OPIC)

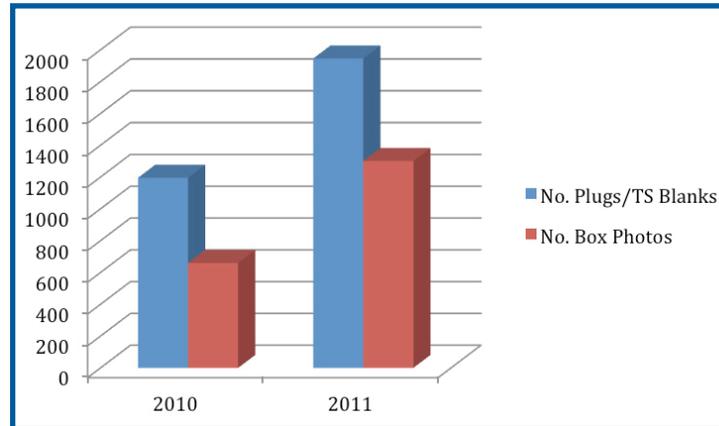
Last and most certainly not least, we were able to make many improvements at our Oklahoma Petroleum Information Center that is ably managed by Gene Kullmann. The University of Oklahoma has played a more active role in the maintenance of the facility and provided \$500,000 to replace the roofs over a portion of the building complex. We are working hard to identify funds to replace other roofs in the complex.

Devon Energy generously funded many improvements including: the new Spectral Gamma Logger that scans cores as they pass through it on a conveyor belt; as well as, several other nice pieces of equipment including an improved imaging tube for the x-ray imaging lab along with an image processor. Construction is also underway to enclose the core viewing area. This is an approximately 5,000 sq. ft. enclosure with heat, air and Wi-Fi that will house 450ft of core layout tables and the 30ft core photography setup. Anyone who has viewed core in the summer or winter will understand what a wonderful improvement this is! We cannot thank Devon Energy enough for their support, which benefits all of the users of this important facility.

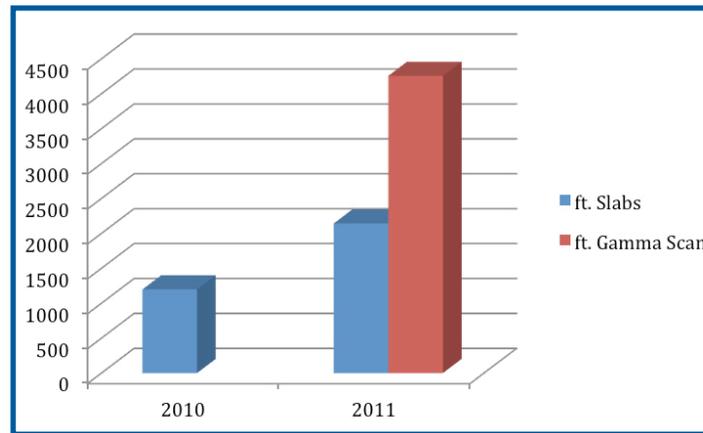
We have also made some improvements in the data and log library effort. We hired Richard Tarver and 2 part-time students who are kept busy adding to the collection. In addition to hiring personnel, microfiche and log scanners were acquired.

The number of visitors and the distribution of data resources they use has been basically constant for the last three years; however, core lay-

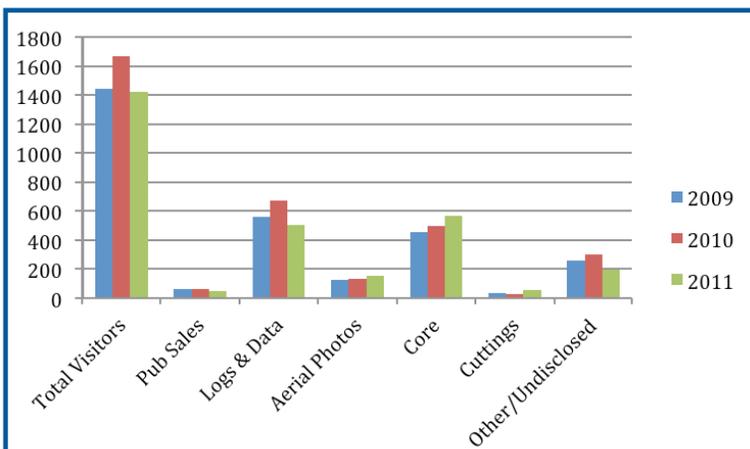
outs, cores plugged, and cores slabbed are up significantly over previous years. Wi-Fi is now available in all customer areas, both lay-out areas, the data library and the log library. The new Spectral Gamma Logger has been very busy. Led by Vyetta Jordan, the staff in this area, 2 full- and 5 part-time, have been kept very busy and have received numerous letters of praise for their expertise and professionalism.



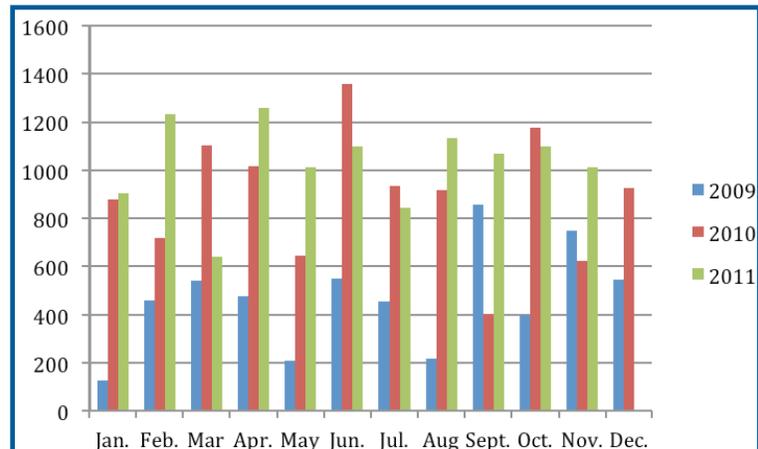
OPIC Number of Plugs Extracted, Thin Section Blanks Cut and Boxes of Core Photographed ~ A 62% increase in plugs extracted and a 97% increase in boxes photographed.



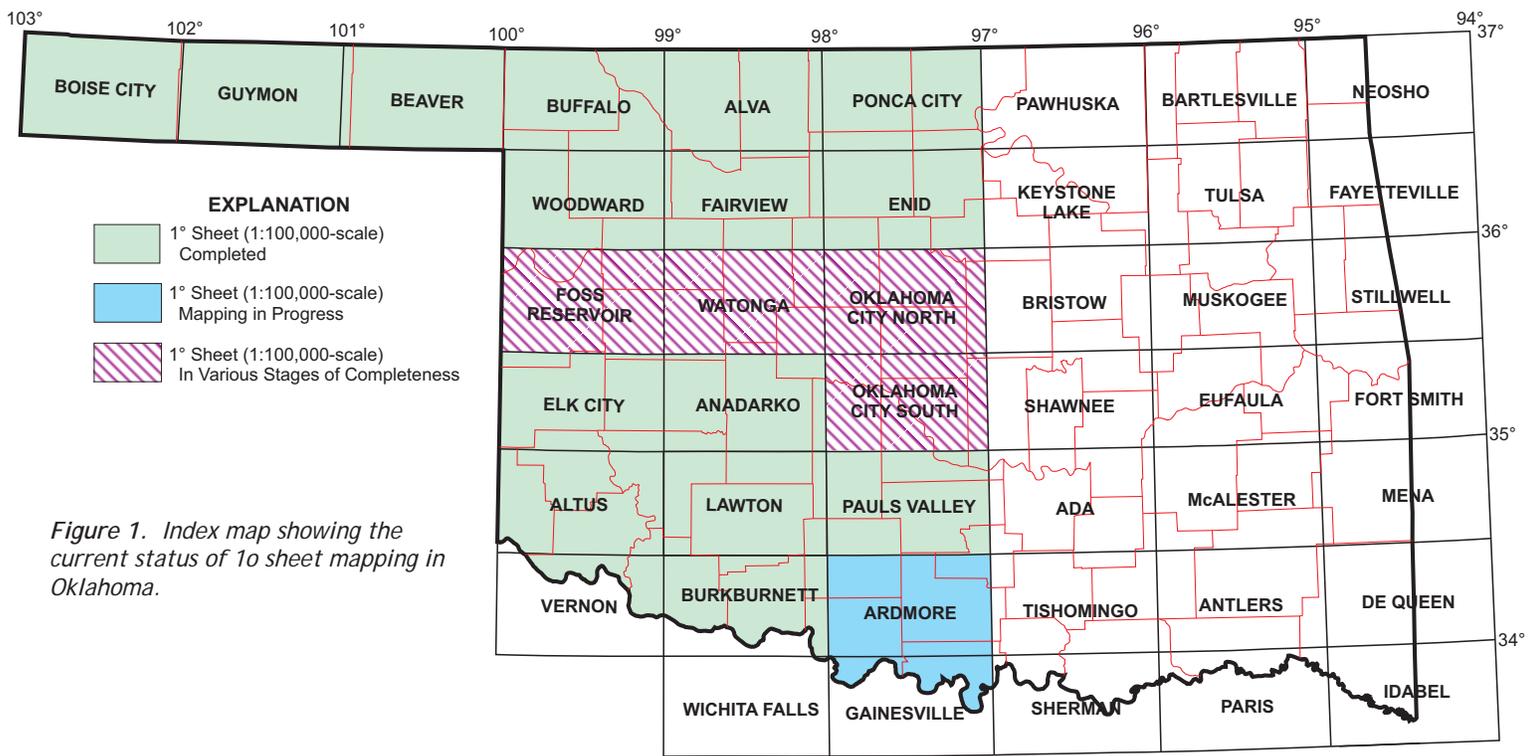
OPIC Number of Feet Slabbed and Gamma Scanned ~ 78% increase in footage of core slabbed.



OPIC Visitor Comparison 2009-2011.



OPIC Core Boxes Pulled and Laid-Out in 2011 ~ A 15% increase over 2010.



STATEMAP: Mapping the Ardmore 1° Sheet and the Oklahoma Part of the Gainesville 1° Sheet, Oklahoma

Julie M. Chang, OGS Geologist III; and Thomas M. Stanley, PI STATEMAP, OGS

Field geologists involved in the STATEMAP program in Oklahoma are currently mapping the Ardmore 1° sheet and the adjacent Oklahoma part of the Gainesville 1° sheet. The STATEMAP program is a partnership between the U.S. Geological Survey and state geological surveys to produce new digital geologic maps of areas determined to be of important economic, social, or scientific interest to individual states.

The Ardmore and Gainesville 1° sheets are located in south-central Oklahoma and northern Texas (Figure 1). The Gainesville 1° sheet covers areas in Oklahoma north of the Red River and in Texas south of the Red River. The Oklahoma part

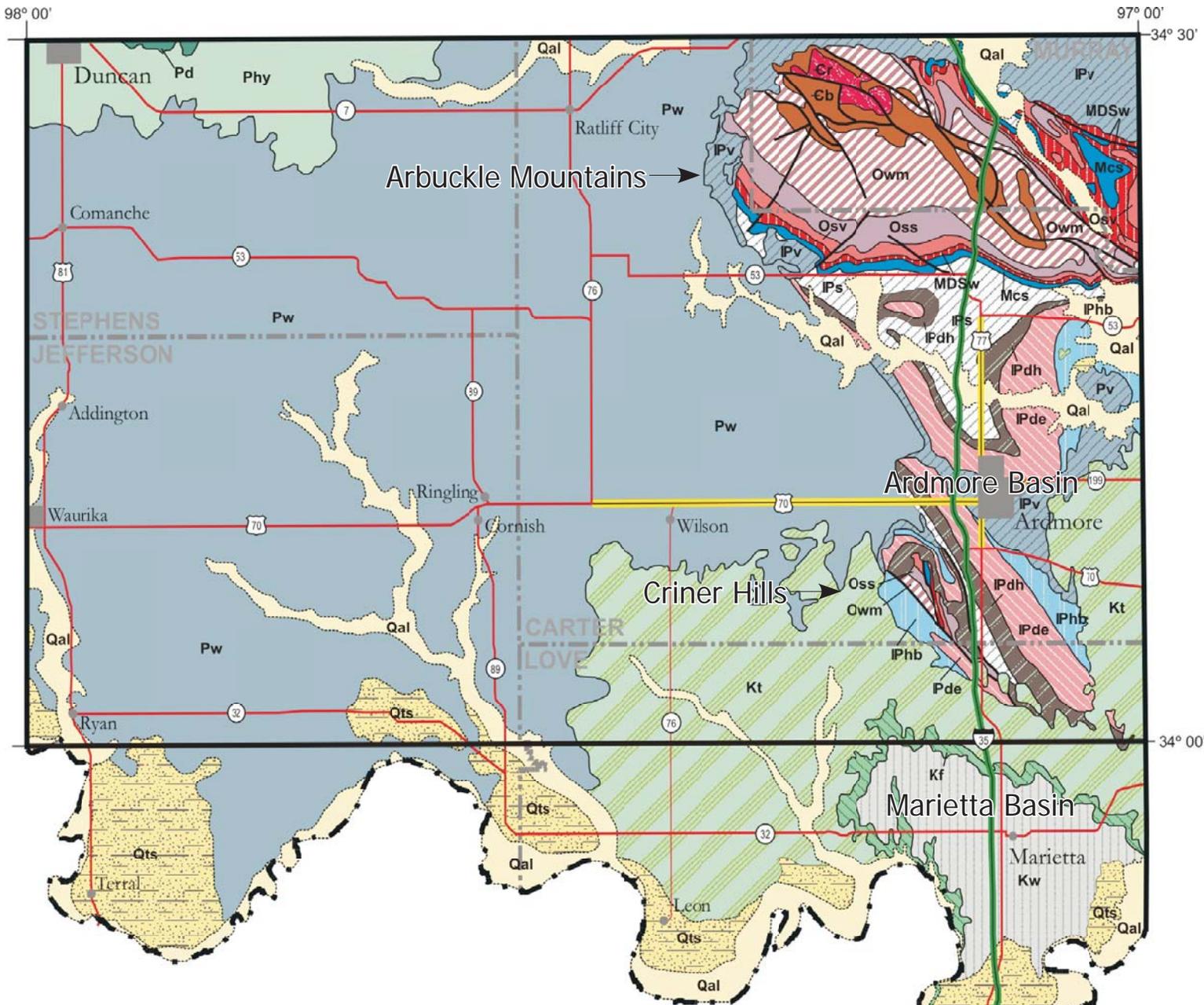
of the Gainesville sheet is being mapped for this project.

Mapping 1° sheets (1:100,000-scale quadrangles) involves (1) compiling existing map data from previous mapping onto thirty-two 7.5' quadrangles and (2) field checking the existing map data. Changes are then made if necessary.

Important geological features in the map area include the Arbuckle Mountains, the Criner Hills, the Ardmore Basin, and the Marietta Basin (Figure 2). Previous mapping of the Arbuckle Mountains was done by Ham et al. (1954) and updated by Johnson (1990). A map of the Criner Hills was published by Frederickson (1957) and includes infor-

mation from student theses done in the area. The important petroleum resources of the Ardmore Basin resulted in surface mapping by numerous authors, including Duchin et al. (1955), Cromwell (1974), Dionisio, Jr. (1975), and Ghazal (1975). The Marietta Basin is included in the map of Love County by Bullard (1925).

Much of the field area adjacent to the Arbuckle Mountains, Criner Hills, and Ardmore Basin contains rocks of Early Permian age. Many of these rocks are terrestrial to marginal marine, being deposited between continental rocks to the north and marine rocks to the south in Texas. Continental rocks to the north include the Pontotoc



EXPLANATION

Quaternary

- Qal Alluvium
- Qts High terrace and sand dune deposits

Cretaceous

- Kw Washita Group
- Kf Fredricksburg Group
- Kt Trinity Group
- IPb Hoxbar Formation
- IPde Deese Formation
- IPdh Dornick Hills Formation
- IPs Springer Formation
- Mcs Caney, Sycamore, Welden Formations

Upper Paleozoic

- Pd Duncan Formation
- Phy Hennessey Formation
- Pw Wichita Formation
- IPv Vanoss Formation

Lower Paleozoic

- MDSw Woodford Shale, Hunton Group
- Osv Sylvan, Fernvale, Viola Formations
- Oss Simpson Group
- Owm Upper Arbuckle Group
- Cb Lower Arbuckle, Timbered Hills Groups
- Cr rhyolite

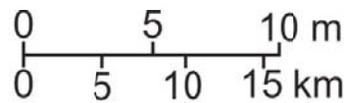


Figure 2. Geologic map of the field area with important structural features labeled. Modified from Miser (1954).

Group (Stillwater and Vanoss Formations), the Sumner Group (Garber and Wellington Formations), and the Hennessy Formation. Correlative rocks to the south in Texas include the Bowie (Cisco), Wichita (Albany), and Clear Fork Groups (Hentz, 1985). Correlation of rocks in the study area to those to the north and south has been problematic due to the transitional nature of the rocks and the absence of marker beds (e.g., Bowker, 1982). One important component of our mapping of the Ardmore and Gainesville quadrangles will be to document this transition.

The Ardmore and Gainesville quadrangles are also interesting geologically in that they contain rocks of Cretaceous age. South-central, southeastern, and northwestern Oklahoma (panhandle) are the only locations in Oklahoma that contain Cretaceous rocks. Approximately 110 million years ago, southeastern Oklahoma was located along the edge of a proto-gulf coast. Beginning at this time, sediments were deposited that were later lithified to sandstone, shale, and limestone. One important Cretaceous unit is the Antlers Formation, which is predominantly composed of loosely consolidated sand and sandstone. The Antlers Formation is a valuable aquifer for southern Oklahoma and also hosts Cretaceous-aged dinosaur fossils, including *Tenontosaurus*; *Deinonychus*; *Acrocanthosaurus*, the Oklahoma state dinosaur; and *Sauroposeidon*, which is thought to be the tallest dinosaur that ever lived (Wedel and Cifelli, 2005).

Cretaceous limestones, particularly the Goodland Limestone, are important economically and have been quarried at many locations east of the mapping area, including near the towns of Hugo (Bryan County), Ft. Towson (Bryan County), and Idabel (McCurtain County), for use as agricultural lime, road material, concrete aggregate, and

building stone (Huffman et al., 1975; Huffman et al., 1978; Sune-son, 1997).

Mapping of the 1° sheets will help in identifying areas that may need to be mapped in more detail in the future, for environmental and engineering purposes such as land-use planning in areas of population growth, evaluating industrial mineral reserves, and identifying and protecting groundwater resources. Additionally, the 1° sheets, when completed, will be added to the ongoing compilation of a new 1:500,000-scale geologic map of the entire state of Oklahoma.

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Evaluating Oklahoma's Gas Shales in the Field

Stan Paxton, USGS; and Brian Cardott, OGS Geologist IV

Fall is a great time of year to get out of the office to examine rocks "in the field". To fill this need, the Oklahoma Geological Survey (OGS) organized and conducted a gas-shale field trip to the Arbuckle Mountains area for twelve geoscientists from Continental Resources. The trip was held on October 13, 2011. Stan Paxton (U.S. Geological Survey, USGS Oklahoma Water Science Center) and Brian Cardott (OGS) served as field-trip leaders. Logistical support was provided by OGS's Michelle Summers and Sue

Crites. The field party examined properties of Woodford Shale (Upper Devonian-Lower Mississippian) at locations across the Arbuckle anticline and south into the Criner Hills of the Ardmore Basin. The trip also included a brief stop to look at the qualities of the Sylvan Shale (Upper Ordovician) on the northern limb of the Arbuckle anticline. Technical detail about the shale at each of the field stops is available in **OGS Open File Report 2-2008**. Figures highlighting several of the field trip stops are included at



Figure 1 - The tip of the red staff (upper right of photograph) indicates the position (yellow dashed line) of the basal contact of the Upper Devonian-Lower Mississippian Woodford Shale with the underlying Lower Devonian Hunton Group limestone. This outcrop is located on the north limb of the Arbuckle Anticline along US 77-D in the Arbuckle Mountains. The beds are slightly overturned, revealing the underside of chert beds in the Woodford Shale (chert beds are light gray in color, black dots) and the Hunton Group limestone (yellow-brown, area of white dots shown in the central-right part of the image). The vertical succession includes a 1) limestone breccia (g) filling fractures in the uppermost Hunton Group limestone beds (white dots), 2) soft, laminated, yellow-brown shale (x), 3) poorly sorted greenish sandstone containing glauconite and rare gravel (tip of red staff), 4) dark-gray shale with molds and casts of brachiopods and pelecypods (y), and finally, 5) dark gray to black shale with thin chert beds (black dots). The unconformity surface occurs at the base of the greenish sandstone (tip of red staff). A strong gamma-ray response, typical of black shales, occurs about 3.5 feet (or 1.1 meters) from the top of the Hunton Group limestone. The basal contact of the Woodford Shale, known as the Acadian Unconformity, is a regionally extensive surface throughout much of North America. (Photo by Sue Britton Crites, OGS Staff)

the end of this summary.

Field trip participants gathered the afternoon before departure to the field (October 12) to discuss trip logistics, safety, and to receive a series of lectures. The intent of the pre-trip lectures was to provide participants with the technical background necessary to gain maximum benefit from a day in the field looking at shale. The lectures included (1) overview of the field trip guidebook; (2) introduction to the geology of the greater Arbuckle Mountains; (3) review of the field-trip stops; (4) overview of Woodford and Caney shales; (5) overview and geological interpretation of full-scale spectral gamma-ray logs for shales; and (6) application of vitrinite reflectance to four Woodford gas-shale plays in Oklahoma.

A primary purpose of the field trip was to observe the properties of shale in outcrop with an emphasis on mineralogy and rock type (chert versus fissile shale), color, organic matter, shale density, bedding (fissility), and tendency of the shale in outcrop to contain fractures

and joints. Ideally, thermally mature gas shale contains abundant oil-prone organic matter and is mechanically brittle. In practice, however, gas shale is commonly a collection of different rock types or lithologies that vary in terms of mineralogy, bedding, and organic matter. As a result, the mechanical properties of gas shale, which are important to the effectiveness of a hydraulic fracturing program, are strongly related to the proportions of the different rock types that make up any given gas shale. The proportions and distributions of silt, clay, and chemical sediments (particularly diagenetic silica or quartz) influence the susceptibility of gas shale to fracturing. Shale without a significant proportion of chemical sediment in the groundmass tends to exhibit ductile behavior. These types of shales do not respond as effectively to hydraulic fracturing.

A secondary purpose of the trip was to relate the outcrop properties to synthetic spectral gamma-ray profiles previously compiled for the outcrops visited during the field trip. The tool used for measuring the gamma-ray



Figure 2 - Slightly overturned beds of Woodford Shale are inspected by field-trip participants along US 77-D in the Oklahoma Arbuckle Mountains. The character of the Woodford Shale in the outcrop above helps participants distinguish bedding planes, fracture surfaces, and lithology (beds of chert versus fissile shale). This locality is also instructive for convincing fieldtrip participants that the cycles in the internal lithology (or rock types) of the Woodford Shale correspond closely to a synthetic vertical gamma-ray profile constructed for this outcrop. The high-frequency gamma-ray cycles from this location can be correlated with a synthetic gamma-ray log constructed for a Woodford Shale outcrop located in the spillway of the Lake Classen YMCA Camp (about 2.4 kilometers or 1.5 miles away). (Photo by Sue Britton Crites, OGS Staff)

Figure 3 - The purpose of this stop is to acquaint participants with the nature and scale of joints, fractures, and faults exposed in a nearly vertically standing wall of Woodford Shale along US 77-D. Above, the field team inspects faulting and breccia associated with a faulted kink band developed in the bedding planes of the Woodford Shale (arrow = fault, k = kink). Fracture orientation and fracture density at this and other locations is observed to vary directly with the lithologies (or rock types) that make up the Woodford Shale. The scale of fracture density can change over short vertical distances depending on bed thickness and proportion of brittle chert and ductile fissile shale present in the succession. (Photo by Sue Britton Crites, OGS Staff)



response in the outcrop is an Exploranium GR-320 spectrometer. The instrument has a handheld detector (three-inches in diameter) that is placed against the face of the outcrop. Data (counts) are collected for 60 seconds per measurement. Each measurement represents a hemispherical volume of shale (one-half cubic meter) beneath the surface of the outcrop. The output from the spectrometer includes potassium in percent, and uranium and thorium, each in parts per million. Conventionally, the potassium contribution to the total gamma-ray response is proportional to the amount of clay minerals in the shale (such as Illite). The uranium contribution to the gamma-ray response is an indicator of organic matter in the shale. Thorium is commonly associated with clay minerals and some heavy minerals.

Study of shale in outcrop may appear to be of limited value because of the impact of surface weathering. However, in contrast, weathering of shale in outcrop actually provides insight to the mineralogy and texture of shale that may not be readily apparent in subsurface core. Surface weathering tends to bring out subtle compositional and textural differences in shale which in turn enhances the visibility of bedding contacts, laminations, and organic matter types present in most shales. Moreover, the occurrence and distribution of fractures, fracture lengths, and joints observed in the outcrop can be clearly associated with the mineralogy and shale rock types present in the outcrop. Clay-rich shale formations, such as the Ordovician Sylvan Shale, weather quickly and uniformly in outcrop exposures. In contrast, shale formations

containing discrete concentrations of chemical or diagenetic silica, carbonate, and phosphate minerals that are dispersed in silt and clay-rich groundmass tend to exhibit differential weathering patterns that actually promote or enhance the technical description of shale in outcrop.

The outcrop gamma-ray measurements, taken every 6 inches (or about 15 centimeters) from the base to the top of the exposures, yield a high-resolution vertical gamma-ray response suggestive of cyclical patterns of shale deposition. The cycles, defined by layered admixtures of detrital silt, clay, organic matter, and chemical sediments (diagenetic silica, carbonate, and phosphate) are interpreted geologically to reflect responses to changing sea-level, sedimentation rate, and/or chemical oxidation-reduction conditions within the depositional environment



Figure 4 - One highlight of the field trip was a hike up through a complete vertical section of Woodford Shale exposed along a stretch of Henry House Creek on the southern limb of the Arbuckle Anticline. The outcrop, 230 feet (70 meters) in vertical thickness, contains fissile shale and some chert beds in the lower third of the outcrop, fissile shale in the middle third, and chert beds with some fissile shale and phosphate nodules in the upper third. The image above highlights part of the middle portion of the Woodford Shale. Because the middle portion of the Woodford is characteristically fissile and contains few chert beds, the middle portion of the Woodford weathers quickly relative to the lower and upper parts of the section. As a result, the middle interval is rarely exposed in outcrop. The lithology around the area of the white dot (above) is shown in greater detail in Figure 5. (Photo by Sue Britton Crites, OGS Staff)

Figure 5 - The image above highlights a portion of the fissile Woodford Shale exposed along Henry House Creek in the southern Arbuckle Mountains of Oklahoma. The middle portion of the Woodford at this locality contains very few chert beds. As a result, the style of bedding and natural fracturing differs markedly from the adjacent portions of the section. Two thin and incompletely developed chert beds are indicated by the arrows. Comparison of the above photograph to the chert-bed rich section shown in Figure 2 (inset, rotated and cropped) highlights the pronounced lithological variation common to the Woodford Shale in and between outcrops. (Photo by Sue Britton Crites, OGS Staff)



of the ancient ocean. The gamma-ray patterns collected from the outcrops in the Arbuckles and Criner Hills can be correlated between the field-trip stop locations. Provisionally, the synthetic gamma-ray response patterns can also be correlated into the subsurface of the Ardmore and Arkoma basins and onto the Cherokee platform.

Study of shale in outcrop, particularly with the aid of a handheld gamma-ray spectrometer, can improve the description of rock properties that have a direct bearing on gas-shale prospectivity. Because gamma-ray profiles from the outcrop can be correlated to subsurface geophysical logs, knowledge about gas-shale properties determined from the outcrop can help define the physical and chemi-

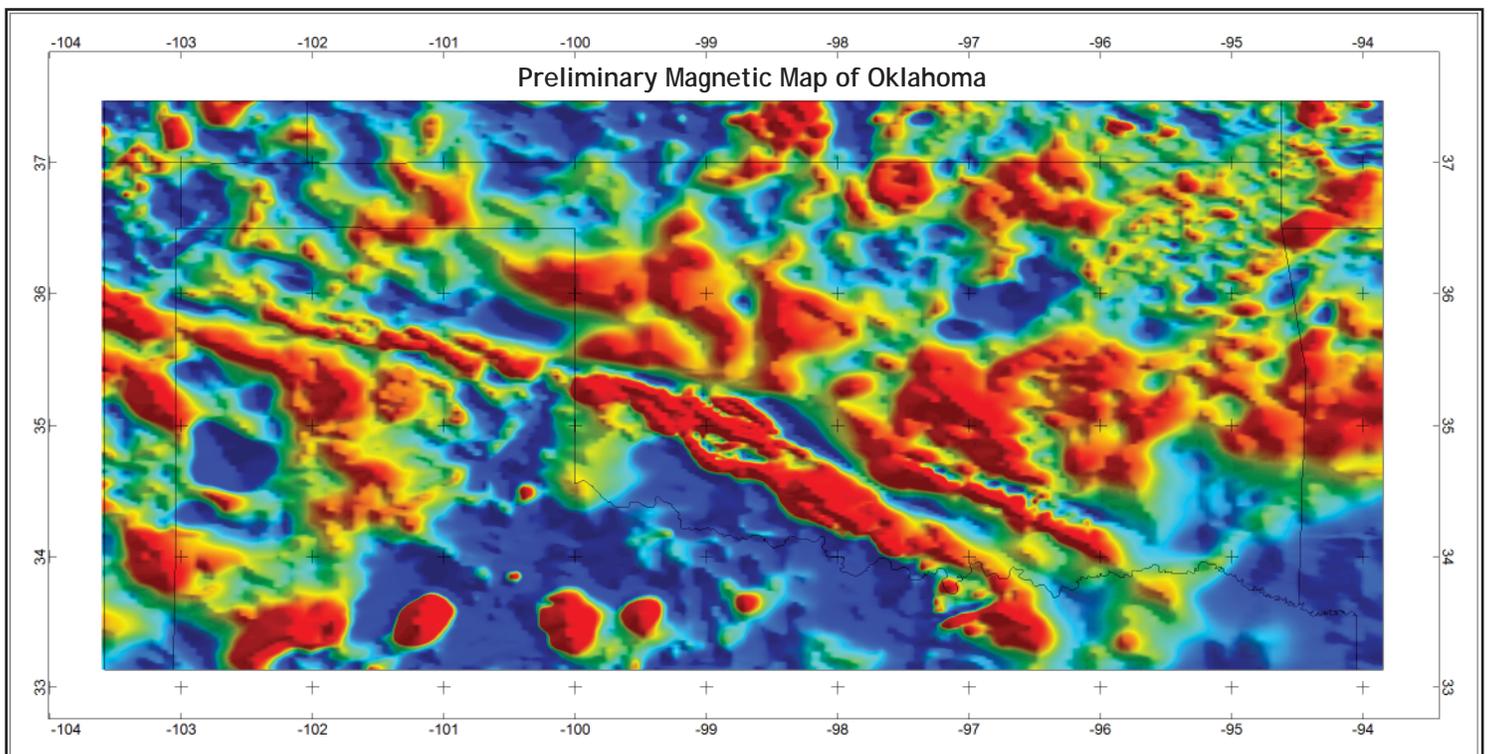
cal conditions responsible for the origin and quality of gas-shale on a regional basis. Walking through a vertical succession of gas shale in outcrop while armed with a synthetic gamma-ray log and data for total organic carbon, organic matter type, density, and mineralogy associated with key gamma-ray markers in the shale proves to be very instructive to geoscientists and engineers responsible for gas-shale productivity. Field-trip participants who are responsible for geosteering of gas-shale lateral wells are particularly enthusiastic about the benefits of seeing and touching gas-shale in outcrop.

Progress Report on the NGDS Geothermal Project

Rick Andrews, OGS Lead Geologist for the NGDS project

The Oklahoma Geological Survey (OGS) in cooperation with the American Association of State Geologists (AASG) is participating in geothermal research, mapping, and database management. These projects are part of a 3-year program sponsored and funded by the National Geothermal Data System (NGDS). After one year, the OGS has delivered several products including databases revealing subsurface depths of the Arbuckle Group and "basement" rocks. From this data, an Arbuckle structure map was prepared revealing the deep

structure and depth of burial of this group of carbonate formations. Additionally, wells were identified that have cored the Arbuckle and from these, analytical reports containing porosity and permeability data were captured in PDF formats. Another year-1 deliverable consisted of redefining the trace of the Meer's Fault in southern Oklahoma. Major structural features such as this may align with hot spots containing hydrothermal waters suitable for geothermal energy development.



Quarterly Earthquake Report 2011— 3rd Quarter

Austin Holland, OGS Research Seismologist; Amie Gibson, OGS Research Scientist II

The Oklahoma Geological Survey recorded well over 1000 earthquakes in Oklahoma from July 1, through September 30, 2011. The data analysis for this quarter is not complete in part because there was a swarm of several hundred earthquakes in Coal County. Most of these earthquakes were so small as to only be detectable on the Transportable Array station X36A, which is nearly directly on top of the hypocenters for these earthquakes. The swarm is a continuation of activity that began in 2010, but in early July there was a major uptick in activity. A temporary station was installed north of Tupelo. This station in combination with X36A will allow us to learn more about the processes occurring within this earthquake swarm.

There were 14 felt earthquakes for the 3rd quarter of 2011, the largest of which can be seen in Table 1. At the moment we have located 282 earthquakes with 207 earthquakes occurring in Oklahoma county, 25 in Lincoln county, 16 in Coal county and 15 earthquakes in Pottawatomie county. The earthquakes processed so far for this quarter are located within 13 different counties and are shown in Figure 1. We will continue to analyze this large dataset and the latest versions will be available online.

The National Science Foundation Earthscope US Array Transportable Array (TA) is winding down in Oklahoma. Nearly half of the stations in the state have now been

removed. All TA stations west of Interstate 35, except for two, adopted by the OGS, have been removed. The stations will continue to be removed, and all of them should be gone by the summer of 2012. In total the OGS will adopt four TA stations. For two stations we are adopting the complete state of the art seismic station, and for the other two we are adopting the high quality vault and supplying our own seismic monitoring equipment. Austin Holland issued an open-file report (OGS OF1-2011) on an earthquake sequence that occurred earlier in 2011 titled "Examination of Possibly Induced Seismicity from Hydraulic Fracturing in the Eola Field, Garvin County, Oklahoma". Austin Holland presented at the Oklahoma Corporation Commission conference and at the Oklahoma Emergency Managers conference. We gave two public tours of the Leonard Observatory, and we also supported a number of media interviews.

Looking forward the Oklahoma Geological Survey will be participating in "The Great Central U.S. Shake Out" on February 7, 2012. This is a great opportunity for your family, your place of employment, or civic group to learn what to do in the event of an earthquake. Just like with any emergency practice can be key in not only saving lives but also helps people remain calm in uncertain situations. Please consider joining OGS and millions others in the Shake Out exercise. More information can be found at: <http://shakeout.org/centralus/>.

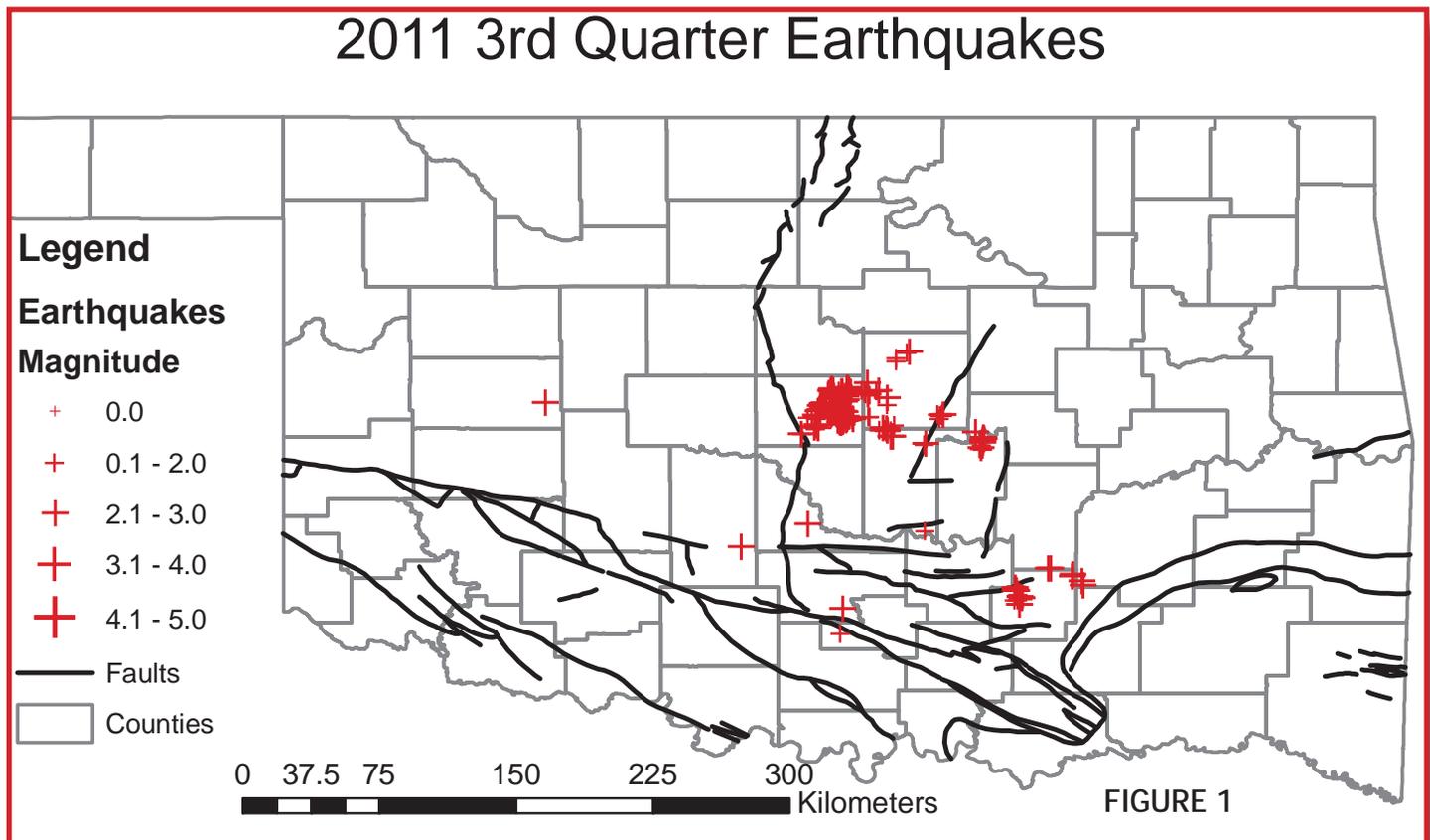


Table 1 - Largest Felt Earthquakes for July 1 - September 30, 2011

Origin Time (UTC)	Longitude	Latitude	Depth (km)	Magnitude	Mercalli Intensity	County	
7/30/11 3:45	-97.2492	35.4991	7.8	2.7	Md	IV	Oklahoma
7/30/11 3:56	-97.2566	35.4991	7.6	2.6	Md	III	Oklahoma
8/1/11 1:20	-97.2258	35.5223	5	3	ML	IV	Oklahoma
8/7/11 13:01	-97.3717	35.4802	3.8	2.5	Md	II	Oklahoma
8/18/11 16:50	-97.7441	34.881	5	2.9	ML	II	Grady
8/22/11 22:38	-97.3659	35.5258	5	2.5	ML	IV	Oklahoma
8/23/11 22:40	-97.364	35.521	7	2.9	ML	III	Oklahoma
8/31/11 19:58	-97.25	35.4977	3.1	3	ML	III	Oklahoma
9/5/11 1:40	-97.2216	35.6645	3.1	2.7	ML	III	Oklahoma
9/5/11 13:51	-97.3752	35.5242	3.3	2.8	ML	IV	Oklahoma
9/6/11 0:19	-97.0453	35.466	5	3	ML	III	Pottawatomie
9/12/11 15:35	-97.2442	35.6292	3.4	3.3	ML	III	Oklahoma

“The Big Quake” — Response and Preliminary Analysis of the November 5, 2011, Magnitude 5.6 Earthquake Sequence

Austin Holland, OGS Research Seismologist; Katie Keranen, Conoco Philips School of Geology and Geophysics, Mewbourne College of Earth and Energy, University of Oklahoma; and Estalla Atekwana, Boone Pickens School of Geology, Oklahoma State University

On Saturday, November 5, 2011 at 10:53 PM (CDT) a magnitude 5.6 earthquake rattled Oklahoma and a large portion of the Central US. The earthquake occurred in southeastern Lincoln county on the northeast-southwest striking Wilzetta fault. The earthquake was preceded by a magnitude 4.8 earthquake which occurred about 20 hours earlier at 2:12 AM (CDT). There were at least six magnitude 3.0 earthquakes between the magnitude 4.8 foreshock and the mainshock. In response to the foreshock, Dr. Katie Keranen deployed three temporary stations within the epicentral area northwest of Prague, Oklahoma. These temporary stations recorded foreshocks and the mainshock, although for the mainshock the nearby instruments went off-scale. On November 7, at 8:47 PM (CDT) the largest aftershock of the sequence occurred with a magnitude 4.8. To date, there have been several hundred earthquakes in this sequence. Although most are too small to feel, a large number have been felt by local residents. These earthquakes occurred near the location of a magnitude 4.3 event that occurred on February 27, 2010, with associated aftershocks. The location of the historical seismicity and recent seismicity can be seen in Figures 1 and 2.

Additional seismic monitoring equipment provided by Dr. Keranen was installed on Sunday November 6th and through November 8th. We requested ten additional instruments through the IRIS Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) Rapid Array Mobilization Program (RAMP). These instruments were deployed on November 9th and 10th and are currently operating in the area surrounding the earthquakes. In addition, the USGS installed three temporary stations, with data sent to the USGS National Earthquake Information Center in near-real-time, and also installed ten seismic stations in a linear array stretching ~100 km from the epicentral region. Some of the temporary seismic station locations can be seen in Figure 2.

The mainshock was felt in Chicago, IL and Omaha, NE, and south to central Texas and Louisiana, westward into New Mexico and Colorado, and eastward to the Mississippi river valley. According to estimates by both the USGS and the OGS, peak ground accelerations may have been in excess of 1 g in the immediate epicentral area. Damage was light to moderate and is consistent with a maximum Modified

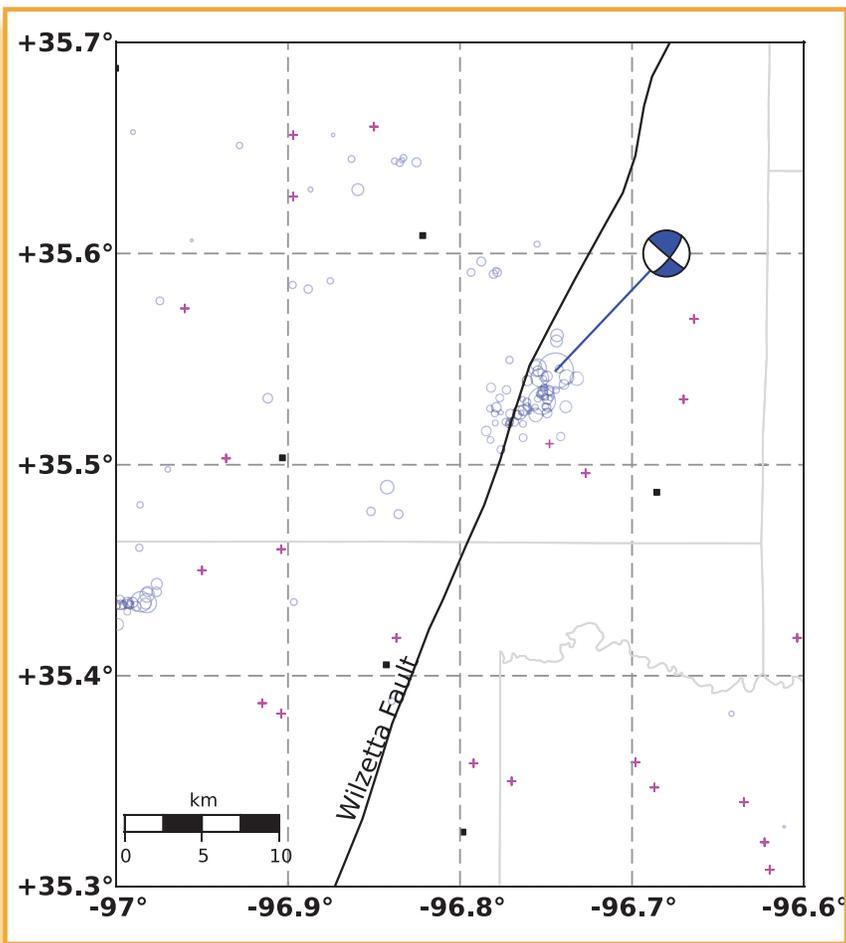


Figure 1 - Historical seismicity from the OGS database earthquakes from 1897 through 2009 shown as +. Cities in the area are shown as small black squares for reference. Earthquakes from January 1, 2010 to November 4, 2011 shown as blue circles with size scaled relative to magnitude. The focal mechanism is for the 2/27/2010 magnitude 4.3 earthquake from the USGS and Saint Louis University regional moment tensor database. The Wilzetta fault is shown as a thick black line and labeled. County boundaries are shown as thin grey lines.

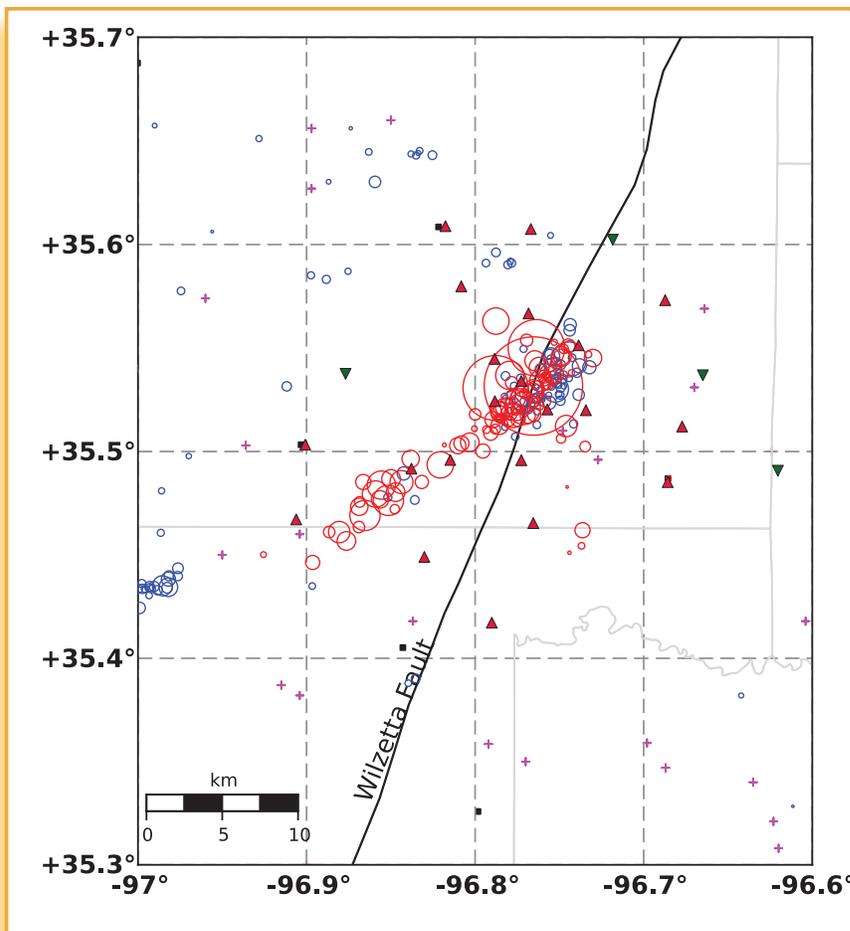


Figure 2 - Earthquakes for the November 5, 2011, earthquake sequence (shown as red circles scaled relative to magnitude). Crimson triangles represent seismic stations deployed by the authors, and inverted green triangles indicate some of the seismic stations deployed by the USGS within the region. Historical seismicity from the OGS database earthquakes from 1897 through 2009 shown as +. Cities in the area are shown as small black squares for reference. Earthquakes from January 1, 2010 to November 4, 2011 shown as blue circles with size scaled relative to magnitude. The Wilzetta fault is shown as a thick black line and labeled. County boundaries are shown as thin grey lines.

Mercalli Intensity between VII and VIII. Most of the damage occurred to chimneys and brick façade and un-reinforced masonry. Headstones in cemeteries were toppled.

The locations of the aftershocks appear consistent with a rupture of a 14 km long fault, with the best-constrained earthquakes occurring between 4 km and 8 km depth. This rupture area is consistent with the moment magnitude Mw 5.6 determined by the USGS moment tensor solution and commonly used relationships for strike-slip faults and rupture area. Applying these relationships, the average slip on the fault may have been on the order of 5 cm (~2 inches). Focal mechanisms for the largest earthquakes are consistent with the earthquakes occurring on the Wilzetta fault or associated structures and are well-oriented within the regional stress field.

The temporary seismic stations will allow us to improve the locations and the associated uncertainties for all earthquakes within this sequence. The earthquake locations in

Figures 1 and 2 are mostly determined from the regional seismic stations and a few of the USGS temporary stations, the uncertainties for these locations are on the order of a kilometer to a few kilometers. From these accurate locations, we will learn more about the Wilzetta fault and the mainshock rupture. We may also learn about the local basement structure.

We would like to recognize all the students who helped make the temporary station deployment and operation possible. From the University of Oklahoma we would like to thank students Gabriel Mattei, John Leeman, Rachel Yates, Matt McGuire, Christopher Toth, Cullen Hogan, and all the others who joined for some fieldwork. From Oklahoma State University we would like to thank Byron Waltman, Tim Sickbert, Eric Akoko, Andrew Katumwehe, and Farag Mewafy. We would also like to thank all of the OGS and OSU staff who helped support this effort including Vikram Jayaram, Steve Holloway, and Tim Sickbert (OSU).



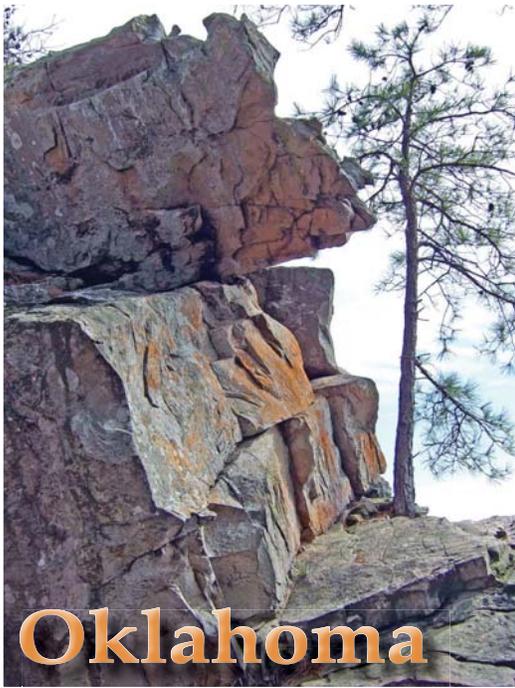
In Memoriam Robert A. Northcutt May 22, 1928 – Dec. 2, 2011

OGS lost a good friend and colleague with the recent passing of geologist Robert “Bob” Northcutt. Farewell, Bob, you will be missed.

This photo of the “Lunch Bunch” was taken in June 2011. From left to right, bottom row: Bob Northcutt, Rick Andrews (OGS); top row: Jock Campbell (OGS retired); Dan Boyd (OGS); and Ray Suhm.

Visit <http://www.ogs.ou.edu/pubs.php> to see which OGS publications are available for download! You may also view the full OGS publications list online...

Created by the Oklahoma Territorial Legislature in 1890, the University of Oklahoma is a doctoral degree-granting research university serving the educational, cultural, economic and health-care needs of the state, region and nation. The Norman campus serves as home to all of the university’s academic programs except health-related fields. The OU Health Sciences Center, which is located in Oklahoma City, is one of only four comprehensive academic health centers in the nation with seven professional colleges. Both the Norman and Health Sciences Center colleges offer programs at the Schusterman Center, the site of OU-Tulsa. OU enrolls more than 30,000 students, has more than 2,400 full-time faculty members, and has 20 colleges offering 163 majors at the baccalaureate level, 166 majors at the master’s level, 81 majors at the doctoral level, 27 majors at the doctoral professional level, and 26 graduate certificates. The university’s annual operating budget is \$1.5 billion. The University of Oklahoma is an equal opportunity institution.



Oklahoma

Structural and Stratigraphic Oil & Gas Workshop
 March 7, 2012

Sponsored by Oklahoma City Geological Society & Oklahoma Geological Survey, this workshop will address the needs of geologists, consultants, engineers, geophysicists, and landmen of all experience levels by providing more detailed information on the varied structure and stratigraphy throughout Oklahoma as they relate to oil and gas exploration. This event will contain a structural & stratigraphic overview of the Arkoma Basin, the Cherokee Platform, Southern Oklahoma and the Anadarko Basin, along with specific field examples presented by experienced Oklahoma exploration geologists.

Brochure with list of speakers available at <http://www.ocgs.org/>

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