Oklahoma Geology Notes

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The University of Oklahoma MEWBOURNE COLLEGE OF EARTH & ENERGY

Horizontal Drilling In Oklahoma: Forcing Conventional Oil to Swim Upstream

Dan T. Boyd, Qatar Petroleum

The petroleum industry in Oklahoma is preoccupied today with low-permeability reservoirs that horizontal drilling and completion technology have made attractive targets. This activity began in earnest about ten years ago with horizontal production from the Hartshorne coal in the Arkoma Basin (**Figure 1**). Horizontal drilling of this coal accelerated through the early part of the decade with the Hunton dewatering play, which is located mostly in central Oklahoma. The two plays were followed in 2006 by the Woodford Shale, which has undergone horizontal development in the western Arkoma, Ardmore, and eastern Anadarko Basins. There is now an ever-lengthening

Figure 1

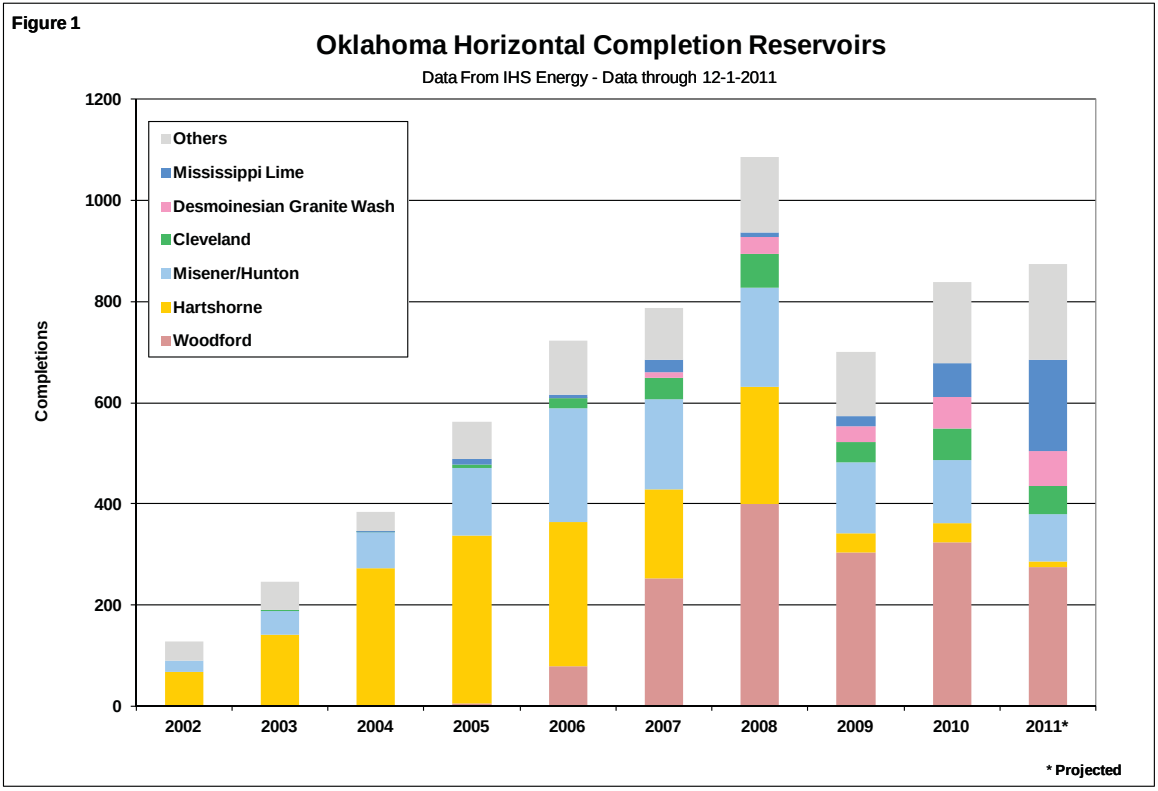

Figure 1. Major Oklahoma Horizontal Drilling Plays (> 100 completions) and other horizontal drilling from 2002 to 2011. Data from IHS Energy (2011) through December 1, 2011.

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Former OGS Petroleum Geologist Dan Boyd, now with Qatar Petroleum.

Dan Boyd and the Oklahoma Geological Survey

Rick Andrews and Neil Suneson, OGS Geologists

Dan Boyd came to the Oklahoma Geological Survey (OGS) 11 years ago after a nationwide search for a petroleum geologist. He topped the list of about 30 candidates, largely as a result of his industry training and experience and his enthusiasm for working in a state with such a rich petroleum history. He approached every project in a practical manner with professionalism, integrity, and urgency, assisting the OGS in gaining national recognition as an authority for the oil and gas industry and the State of Oklahoma.

Dan's enthusiasm was fueled by ambition and an attitude that caused him to undertake projects beyond the immediate scope of his assignments. When he first started at the Survey, the OGS had no current map identifying boundaries of oil and gas fields in the state, the last published in 1985. Dan compiled a series of maps that now are used industry-wide (**GM 36, 37, 38**). Similarly, the Survey did not have a stratigraphic guide to oil and gas reservoirs until Dan made one (***SP 2008-1***).

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list of other unconventional targets that lend themselves to horizontal drilling and completion techniques. In addition to dozens of lesser reservoirs, the most active include the Cleveland Sandstone, Desmoinesian Granite Wash, and now the Mississippi Lime, whose potential prospective area, which extends from northern Oklahoma through central Kansas, could become the largest of them all (**Figure 2**) (IHS Energy, 2011).

Horizontal drilling plays are attractive for many reasons. Because they exist in low-permeability reservoirs in which fluid separation is not possible, the accumulations are continuous and the geological risk of a dry hole is essentially zero. Blanket reservoirs that are often quite thick also contain exceedingly large in-place gas and/or oil volumes, making the potential target large. Relatively small drainage areas, even after extensive fracture stimulation, means that many wells must be drilled to develop such reservoirs adequately. This allows companies to carry proved undeveloped reserve volumes that are two to seven times those booked for the first well in the drilling unit. The result is a 'dream scenario' for large operators whose regional leasing programs have captured hundreds of thousands or even millions of net mineral acres. With drainage areas established, locations are permitted and wells are drilled based on lease expiration. Large numbers of dedicated drilling rigs are able to then turn reserve bookings into an assembly-line process in which the primary risk is largely mechanical. The thousands to tens-of-thousands of development locations generated from this 'exploratory' drilling create proved-undeveloped reserve volumes that quickly become astronomical.

Even horizontal plays are sensitive to oil and gas prices, however. Early production declines are very steep and drilling, operational (including water disposal) and acreage costs

From the Director...

G. Randy Keller, Oklahoma State Geologist

2012 has begun on a positive note with the exception of the departure of **Dan Boyd** to assume a leadership position in Qatar. He made many contributions over the years that are a legacy to his time with us. His leadership on our efforts to support the Energy Libraries Online project will have a long-lasting impact. We greatly appreciate his 11 years with us and wish him nothing but the best in his new endeavor. He has been sending us pictures of the skyscrapers from his office window in Doha, the capitol.

Ken Johnson is receiving an award that not only recognizes his many years of service to the OGS (11 as Associate Director) but also his service to the Association of American State Geologists (AASG). He will be awarded a Distinguished Service Award at the annual AASG meeting this summer. Ken has been retired from OGS for over 10 years, but we continue to be able to tap his many years of experience and broad knowledge of Oklahoma geology.

We are really excited by the improvements at the **Oklahoma Petroleum Information Center** (OPIC). The first phase of the re-roofing project is complete, the state of our voluminous paper records continues to improve and become more digital, and new equipment to analyze cores and cuttings continues to arrive. The really exciting development is the completion of the core viewing room. It is simply wonderful with great lighting, air conditioning and heating, and numerous other amenities. This is all thanks to the generosity of Devon Energy.

The earthquake activity in Oklahoma continues to draw a lot of national attention and keeps us on our toes. We making further improvement to our seismic network, and Oklahoma is now home to 5 broadband state-of-the-art seismic stations.

In This Issue. . .

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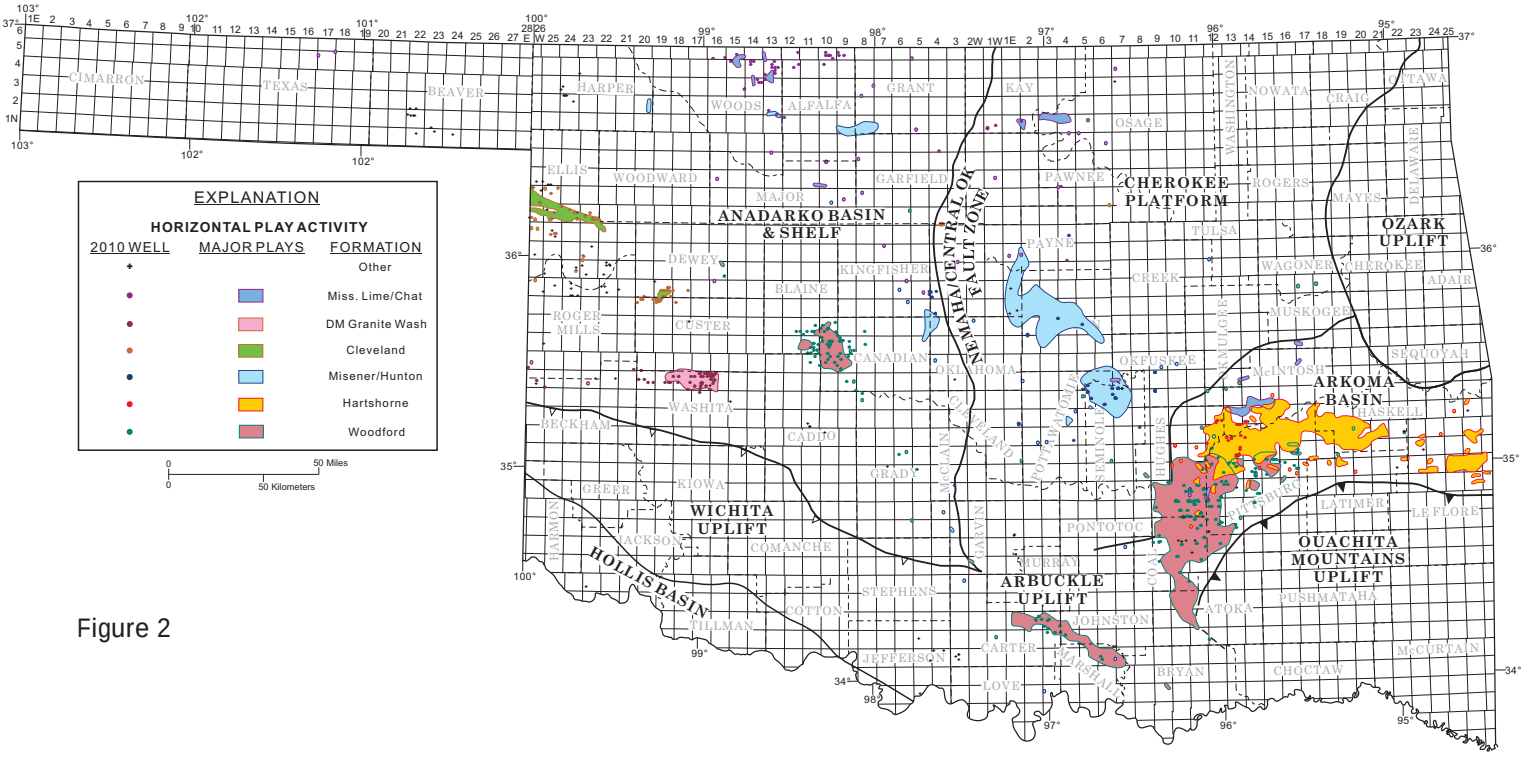


Figure 2

Figure 2. Map of horizontal drilling play production and 2010 horizontal drilling in Oklahoma. Shaded areas denote limits of contiguous production for major plays (> 100 completions). Geological province boundaries are modified from Northcutt and Campbell (1995).

are high. Although most horizontal plays have 'sweet spots' that will remain economic in almost any price environment, the vast majority of the prospective areas appear to be economically marginal in all but higher price scenarios. With the fall in natural gas prices in late 2008, Woodford and especially Hartshorne drilling fell sharply, forcing operators to focus on horizontal plays that are more liquids-rich (oil-condensate-natural gas liquids). Since this time Woodford activity has moved away from the dry gas areas and Hartshorne coal bed methane has disappeared as a play (**Figure 1**). Unfortunately, only oil with a high level of dissolved gas can move through such low-permeability reservoirs. This means that the barrel-of-oil-equivalent production for even the richest of these plays is still nearly half natural gas. With spot gas prices hovering around $3 per MCF, operators appear to have forgone short-term economics in favor of a strategy of holding acreage by production. Development drilling on this acreage can then be delayed until prices rise above whatever economic threshold the operator deems necessary to justify future activity.

The advent and continued rise in horizontal drilling activity has given the State of Oklahoma its first significant increase in oil (hydrocarbon liquids) production since the 1980s. Horizontal drilling now accounts for about 40% of total drilling and the vast bulk of new oil production. Unfortunately this activity has also taken money and activity away from the State's many conventional oil reservoirs — these deserve far more attention than they are receiving. This is true both from an exploratory standpoint as well as in efforts to improve recovery in existing fields. The latter is a grossly underexploited development opportunity in which under-performing fields are identified by using the recovery factors in the best-managed analog fields as a benchmark. This allows one to tailor a reservoir management program based on the primary, secondary, and/or enhanced recovery techniques that have proven themselves the most effective. These best-managed analog fields invariably utilize refined geologic models and modern technology that did not exist when the poorest performing fields were developed. This strategy permits a systematic review of oil fields of various reservoir and trap types and their placement into an incremental recovery hierarchy based on price/economic parameters.

The State's original oil in-place volume for conventional reservoirs is about 84 billion barrels of oil (BBO), with long-term decline projections indicating an estimated ultimate recovery of about 16 BBO (**Figure 3**). The resulting 19% aggregate ultimate recovery is due to a combination of many factors, but these can be grouped into two main categories. A primary cause was poor (or no) reservoir management in the early days. Many fields were grossly over-drilled and produced, with gas caps and all or most associated gas vented or flared. This rapidly reduced reservoir energy, produc-

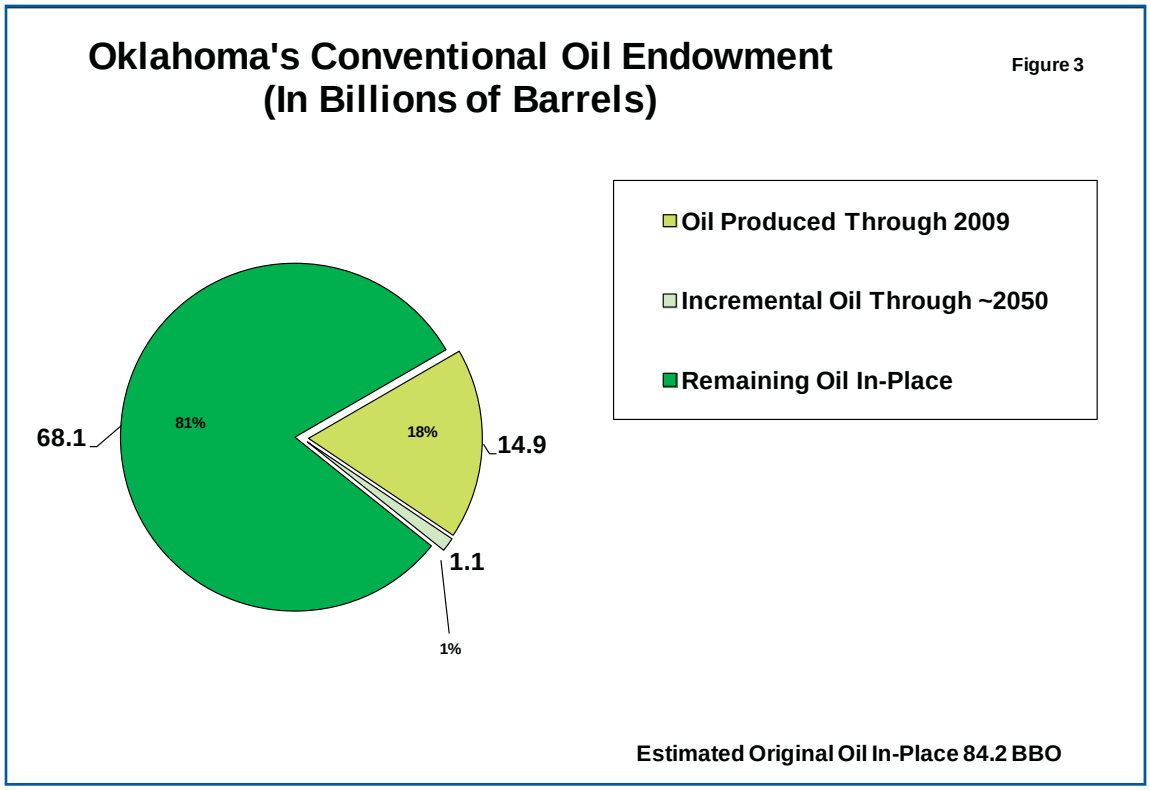


Figure 3. Oklahoma's Conventional Oil Endowment — Showing Oil Production and Remaining Oil Relative to Original Oil In-Place.

tion rates, and ultimate recovery. In addition, complex reservoir geometries, especially in the compartmentalized channel-fill sandstones of the Fluvial-Dominated Deltaic reservoir class which predominate in the State, have left many parts of these fields poorly swept or undrained (Boyd, 2008).

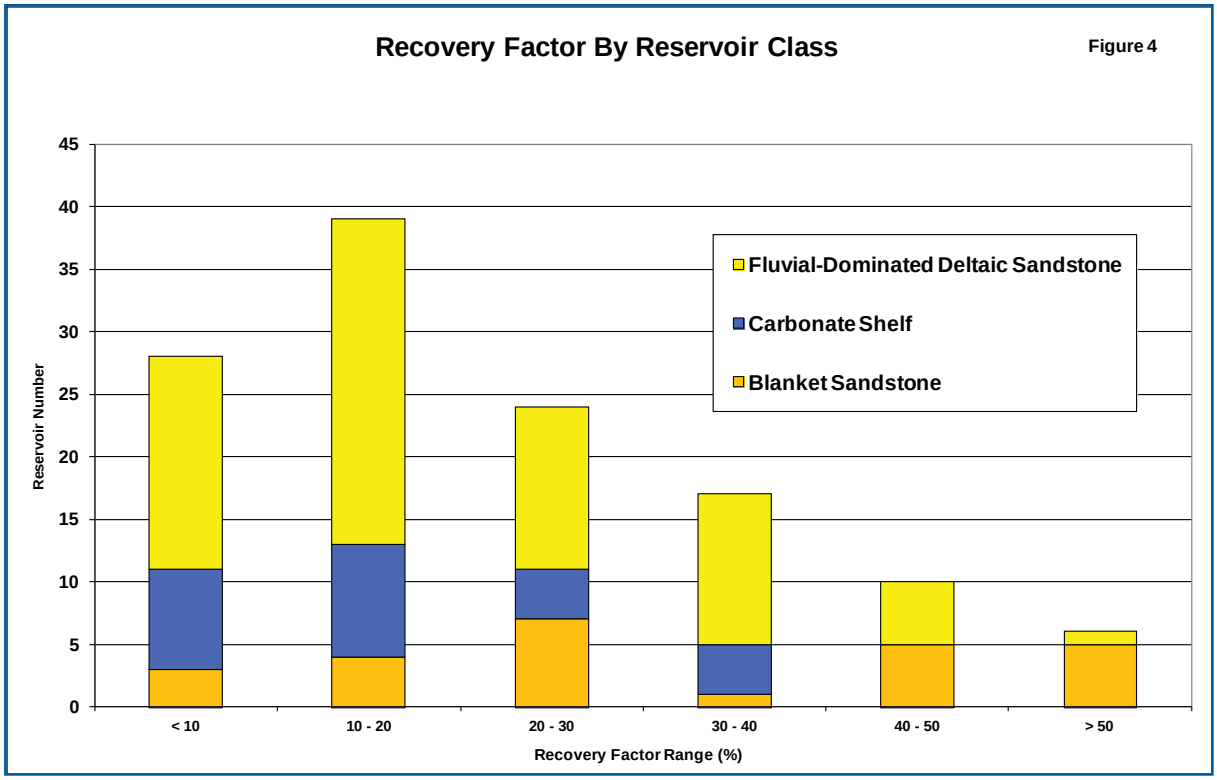
The average ultimate recovery factors calculated for Oklahoma's three major reservoir classes are as follows: Blanket Sandstone – 44%, Carbonate Shelf – 10%, and Fluvial-Dominated Deltaic Sandstone – 21% (Boyd, 2008). Each class has a wide range of recovery factors with many fields performing far below what would be expected given their average porosity and permeability. Although the factors that brought about low recovery factors will vary from field to field, certainly a large percentage in all three reservoir classes have significant potential for improvement. The 123 fields that were used to generate these statistics are scattered throughout the State. If they are even remotely representative of the State as a whole, there are many opportunities – using simple (but modern) techniques – to recover additional oil economically (**Figure 4**).

Based on recent mapping, the most attractive targets appear to be in fields producing from fluvial reservoirs, whose defining characteristic is their limited aerial extent and complex subsurface plumbing system. Although well-managed fields commonly have recovery factors in the 30% range, the median ultimate recovery factor for the fields in this class is only about 17% (**Figure 3**). As a class the channel-fill sandstone reservoirs in Oklahoma are the shallowest, representing between 2/3rds and 3/4ths of all conventional oil produced in the State, and accounting for the largest share of the State's oldest and most poorly managed fields. Even more important, they contain well over half the total oil that may be left in the ground at abandonment.

The incremental reserve additions that can be realized thorough a systematic reassessment of the State's conventional oil fields is impossible to estimate reliably. However, with a projected remaining oil in-place volume of 68 BBO, even modest improvements to average recovery factors yield large volumes of incremental oil. For a conservative case in which the average net improvements in recovery factor are 1% – 2% for each of the reservoir classes, which is significantly below levels that are routinely achieved in the better-managed fields, the incremental volume of producible oil is still a staggering 1.4 BBO.

Horizontal drilling has dramatically increased reserves and holds promise in many areas of the State. However, it has also focused much of the industry into huge leasing expenditures that in turn are driving large drilling programs designed to hold this acreage. In the current price environment many of these wells appear to be, at best, marginally economic. Horizontal plays have their place, but their reliance on natural gas prices argues for a balanced exposure to conventional oil reservoirs. Given the oil produced already and the volume that is already mapped and still in the ground, a systematic program designed to improve the recovery in Oklahoma's many under-performing fields is certainly justified.

Figure 4. Recovery factor by reservoir class for conventional oil fields in Oklahoma.



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IHS Energy, 2011, Well Data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, December1, 2011, all rights reserved. http://energy.ihs.com/

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Dan Boyd and the Oklahoma Geological Survey, *cont.*

Dan's insight regarding the needs of the Survey to optimize its petroleum research motivated him to formulate an agreement with IHS that gives OGS access to their well and production data. Additionally, he guided the Survey into a mutual agreement with TGS for retrieval of on-line well logs. Dan also arranged with Geomap for OGS to acquire professional display maps that now are used by staff petroleum geologists.

Public assistance and service to the local petroleum industry are tangible activities in which Dan excelled. With his extraordinary organization of information and references, Dan routinely provided valuable data to the public by e-mail or via phone conversations. During the past seven years, Dan created an immensely popular and interesting summary of Oklahoma's oil and gas activities published annually in the Oklahoma City Geological Society's ***Shale Shaker***. Because he genuinely believed in helping the state's petroleum industry, he became the Board Chairman of ELO – Energy Libraries Online – the organization that undertook scanning thousands of old sample logs and making those data available on its website.

Early in Dan's OGS career, he conducted a popular spring symposium that resulted in ***Circular 108***, **"Finding and Producing Cherokee Reservoirs in the Southern Mid-continent, 2002."** Dan edited this publication and also authored one of its papers, **"Oklahoma Oil and Gas: Three Moments in Time"**. Dan investigated a major petroleum reservoir; this resulted in a popular play-based study of the **"Booch Gas Play in Southeastern Oklahoma"** (***SP 2005-1***). The companion publication co-authored with Neil Suneson — **"Guidebook to the Booch Sandstones"** (***GB35***) — became one of the best OGS field trips to a conventional reservoir. ***GB35*** dealt with surface to subsurface characterization and correlation of the many depositional facies contained in the Booch.

As the role of the OGS evolved with its incorporation into the Mewbourne College of Earth and Energy, Dan lent his expertise and industry experience to teaching. He started as co-leader with Neil Suneson and Rick Andrews of a field trip for GEOL 3003, "Structural

Continued on pg. 6

Dan Boyd and the Oklahoma Geological Survey, *cont.*

Geology and Stratigraphy for Petroleum Engineers," that viewed different kinds of reservoir rocks in the Arkoma Basin and Arbuckle Mountains. This led to team-teaching a practical course in petroleum geology. The course, GEOL 4233, "Subsurface Methods," is required of students seeking an undergraduate geology degree with a petroleum emphasis and has become increasingly popular during its four-year tenure.

An unrealized ambition of Dan's was for the State to recognize that hard data is necessary for exploration and development of Oklahoma's petroleum resources. Dan unceasingly tried to recover old data, particularly production data, and post it online for explorationists. He believed that we already know where most of Oklahoma's oil is – the old, poorly produced oilfields – and that if we could apply modern reservoir analysis to those fields and had accurate production data, we could determine how much oil remained in the ground, ready for clever geologists and engineers to extract it.

We are happy that Dan is pursuing a long-standing dream of returning to the international petroleum arena with his departure to Doha, Qatar. Already, there are so many moments we miss and so many questions we would like to ask him. (Thank goodness for the internet, because we will!) We would like to express our gratitude for his unselfish contributions, his generous and highly valued professional opinions, and his unwavering dedication to the Survey. And on a personal note, we would like to thank him for all he taught us, and for his friendship.

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Oklahoma Structural and Stratigraphic Oil & Gas Workshop:

Had Something to Teach Newcomers to Oklahoma Petroleum Geology, as well as to Veteran Geologists!

Suzanne Rogers, Sandstone Energy

A large crowd attended the OCGS-OGS sponsored Oklahoma Structural and Stratigraphic Oil and Gas Workshop which featured geologists who actively work various provinces in Oklahoma. Overviews of the Anadarko Basin, Arkoma Basin, Southern Oklahoma and the Cherokee Platform were presented along with a field study for each province (**Figure 1**).

For example in the Cherokee Platform one of the producing horizons is the Senora in the southern part of the Cherokee Platform, equivalent to the Skinner Sand in the northern part of the Platform. Reference **Figure 2** for the Deer #1 well in Seminole County, OK.

Speakers discussed geologic analyses of prospects as wells were drilled. The event featured Greg Riepl, Walt Hendrickson, Ron Woods, Bob Allen, Cole Hines

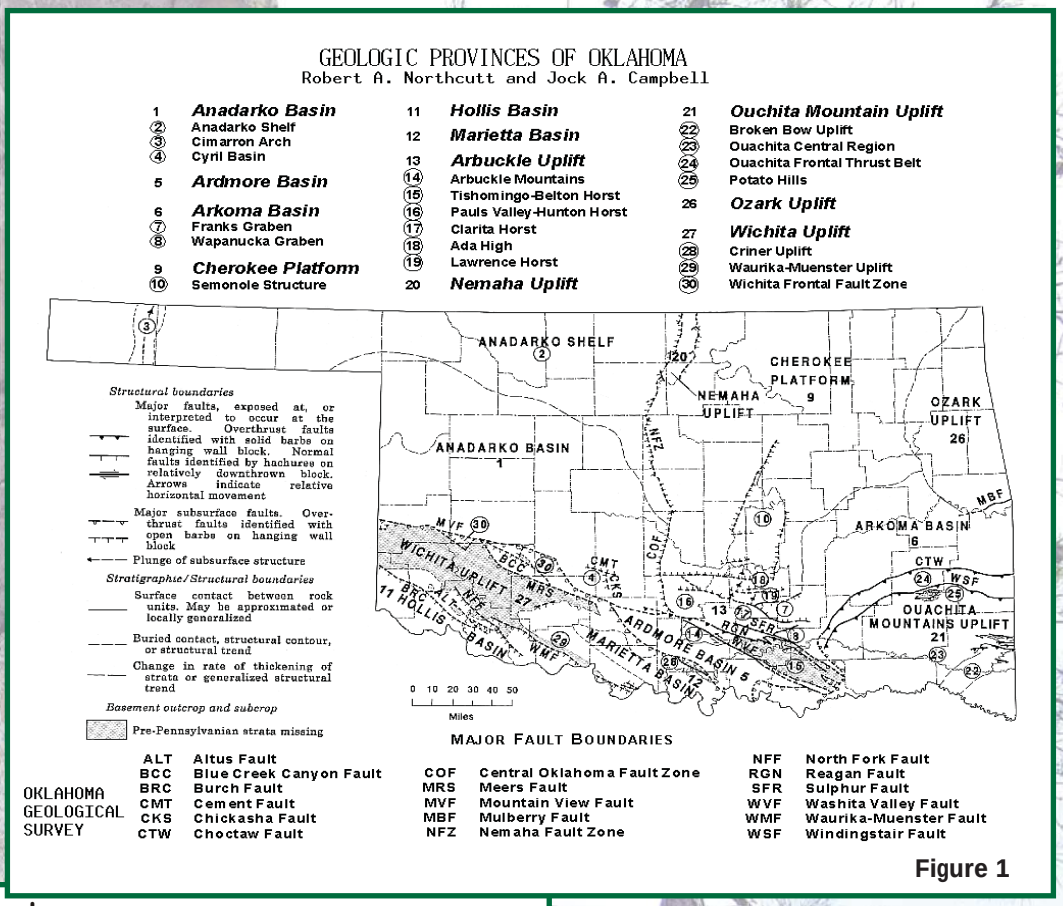
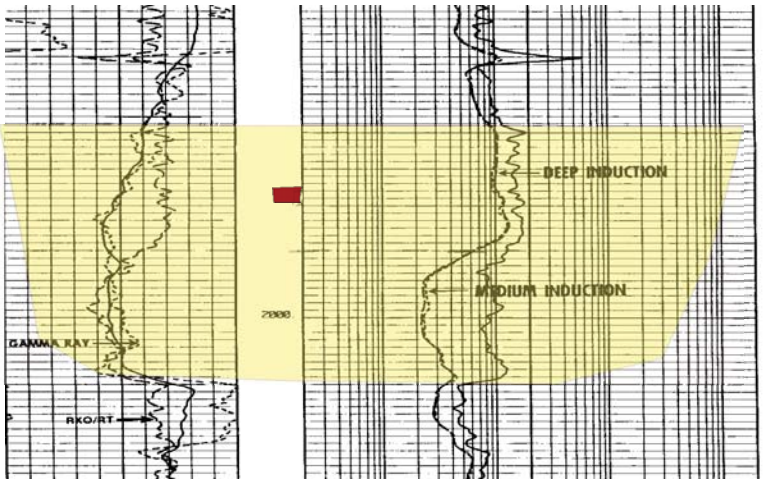


Figure 1

Sentinel Petroleum, Inc.
Deer #1
SE SE SW, Section 34-10N-8E
Seminole County, OK



Senora Sand

c. 5-27-83, TD 2079'
Perf 1966-1970'.
IPF 230 BOPD, 115 MCFD, NW
Cum to 184,413 BO, 58,707 MCF
Current: 5 BOPD, 20 BW

Figure 2

Oklahoma Structural and Stratigraphic Oil & Gas Workshop... *cont.*

substituting for Bill Coffey, Neil Suneson, John Mitchell, Randy Keller, and Suzanne Rogers. In Riepl's talk he stressed regional mapping as the key to understanding the depositional systems and finding good prospects. **Figure 3** (courtesy of Greg Riepl) illustrates what one can discover with meticulous work in an area (*see the cross-cutting channel which separates the main channel illustrated in color*). Such events can compartmentalize a productive sand body and are certainly important if one wants to drill more wells or waterflood a field.

The information provided was enlightening for geologists with limited experience as well as those with many years on the job.

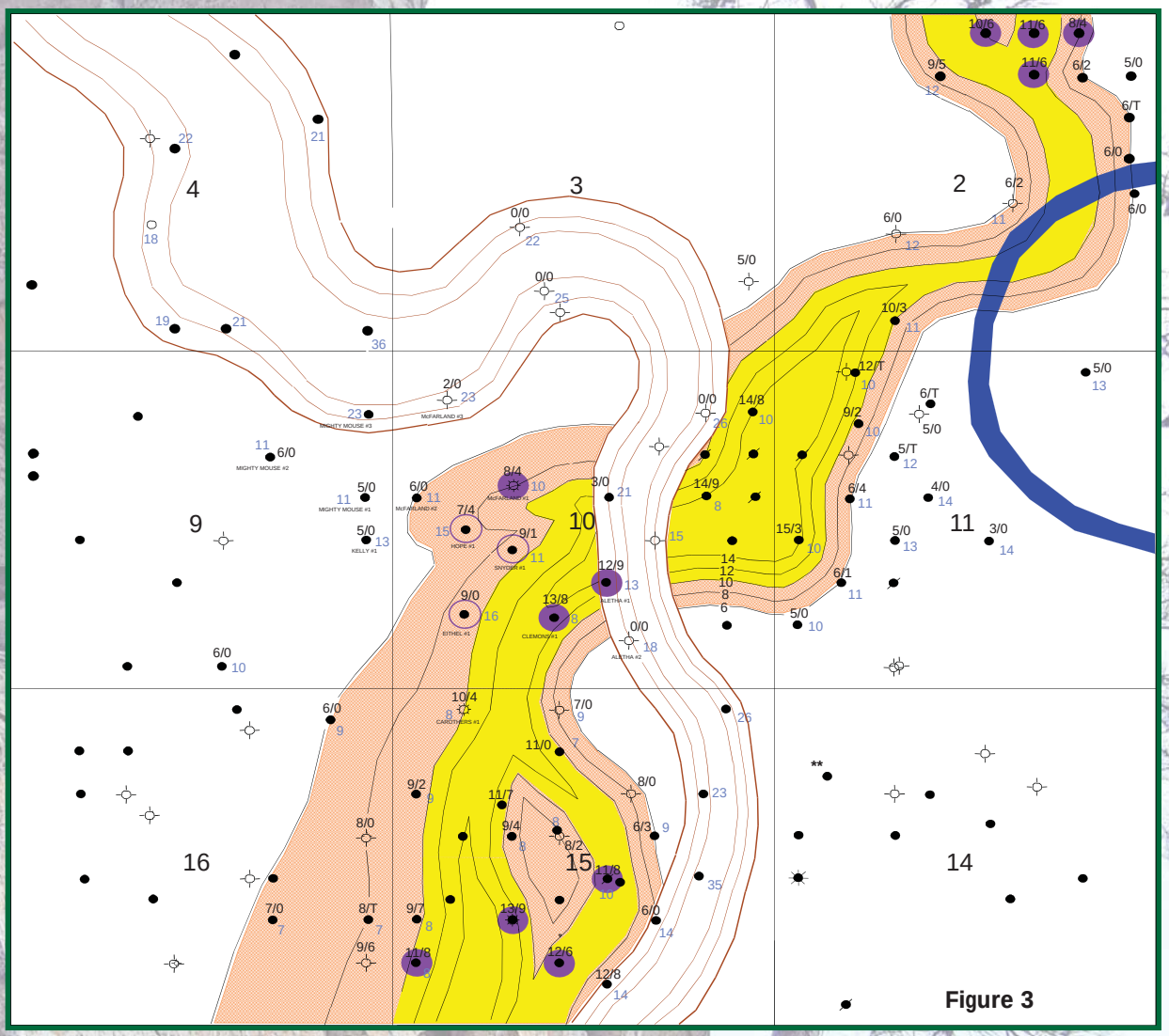


Figure 3

Oklahoma Geological Survey Mission Statement:

The Oklahoma Geological Survey is a state agency for research and public service located on the Norman Campus of the University of Oklahoma and affiliated with the University of Oklahoma Mewbourne College of Earth and Energy. The Survey is chartered in the Oklahoma Constitution and is charged with investigating the state's land, water, mineral, and energy resources and disseminating the results of those investigations to promote the wise use of Oklahoma's natural resources consistent with sound environmental practices.

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. www.ou.edu/eoo

Oklahoma Geological Survey Participates in the Oklahoma Aggregates Association 11th Annual Meeting and Field Trip

Stanley T. Krukowski, Industrial Minerals Geologist

The 11th annual meeting of the **Oklahoma Aggregates Association (OKAA)** was held on January 24–25, 2012 at the Magnuson Hotel & Meridian Convention Center in Oklahoma City. The OKAA annual meeting provides an opportunity for its members to review, in an open forum, important issues that affect the aggregates industry. Aggregates industry professionals including producers, plant superintendents, contractors, engineers, consultants, associate members, and interested government officials attend.

The 11th annual meeting was moderated by Chairman Randy Beeson with Executive Director Jim Rodriguez providing behind-the-scenes support and direction. Topics at the meeting this year included the Comprehensive Statewide Water Plan, management and regulation of wetlands disturbance and stream relocations, crushed stone use in reinforced concrete construction, and other issues. OGS Industrial Minerals Geologist Stan Krukowski spoke about sourcing aggregates today for society's requirements. This year the meeting featured a panel discussion on land use planning highlighting cooperation of quarry operators, land owners, property developers, and city officials in the northeast Oklahoma cities of Tulsa and Owasso. Panel members were as follows:

1. Bob Ford and Tony Bauer—Bauer-Ford Reclamation Landscape Architects and Planners, Inc. of Lansing, Michigan
2. Hank Harbaugh, Manager—Greenhill Properties, LLC, Tulsa, Oklahoma
3. David Charney—Owasso Land Trust, Owasso, Oklahoma
4. Rodney Ray, City Manager—City of Owasso, Oklahoma
5. John Curtis, President—Greenhill Materials Co., Inc., Catoosa, Oklahoma

The panel discussed how abandoned aggregate mine lands can be successfully reclaimed and developed into residential and recreational properties. The project shows how diverse groups with apparent divergent interests can come together to reach a common goal. And while these developments are occurring, the mine owner continues to mine the remaining resource, following a good-neighbor policy with all stakeholders. The mine-land reclamation project is a prime example of how sustainable development theory is put into practice with all parties benefitting and in apparent agreement. Plans are in the making so that this project a stop for next year's field trip. Founded in 2001, the OKAA mission statement declares that it provides *"the medium through which the members may coordinate their efforts in discussing and resolving various problems of common concern and interest within the State of Oklahoma. The Association speaks for all forums of aggregates, dimension stone, construction material producers, and allied industries in a unified effort."*

The Oklahoma Geological Survey (OGS) has participated actively in the OKAA annual meeting since 2003. The OGS participation also includes a booth in the OKAA annual meeting exhibition hall called the Market Place. In 2004 the OGS began coordinating and conducting annual meeting field trips. Typically OKAA members showcase new operations or facilities at each field trip stop. Examples include the Dolese Bros. Co. sand plant in Mustang, Oklahoma, along the Canadian River; the Martin Marietta Materials, Inc. North Troy quarry and the Texas Industries, Inc. Mill Creek crushed stone operation both near Mill Creek, Oklahoma; and the Boral Bricks Inc. brick plant north of Union City, Oklahoma.

Additionally mine service companies, OKAA affiliate members, participate by acting as hosts at field trip stops at their facilities. In the past, OKAA field trip stops have included Terex Corporation road-building equipment factory and training center in Oklahoma City; and this year Evans Enterprises, Inc. laid down the red carpet for the OKAA visit.

The **11th annual meeting field trip** took place on January 24, 2012. The first stop was Hanson Pipe and Precast LLC at 6504 South Interpace St., Oklahoma City. Walt Catlett, Regional Engineer, and Poncho Rey, Plant Manager, hosted OKAA at the Hanson stop. Hanson concrete products manufactured at this locality include concrete box culverts and concrete pipe storm drain culverts. After mandatory health and safety site-specific instruction, the field trip participants were escorted through the Hanson Pipe manufacturing process.

Constructed to ASTM standards and customer specifications, the precast concrete pipe and box design begins with an internal framework (cage) of welded reinforcement steel (**see Figure 1a-1f**). This assembly is then placed into a large steel-hinged mold into which fast-setting concrete is poured. In a process called centrifugal projection forming, a long drill-like screw descends into the mold, its high-speed rotating blade forces the concrete to the outside wall of the mold forming the concrete pipe. The damp concrete pipe is then transported to the drying warehouse where the drying/setting of the concrete occurs in a sauna bath at about 60°C and 100% relative humidity until it is hardened after 12 hours. Sample pipe is then subjected to pressure testing to insure that the precast concrete pipe can withstand the pressure of overburden during burial (**Figure 2**).

Evans Enterprises, Inc. hosted the next stop on the January 24 field trip. Chris Stubbs, Outside Sales, made all the arrangements for the Evans stop. Evans CEO and President, Syndy Evans-Thrash, was the host for the OKAA visit along with David Brantley, Vice

Figure 1a. *Reinforced steel cage under construction in welding machine at the Hanson Pipe and Precast Manufacturing Plant in Oklahoma City. (Photograph by Stan Krukowski, OGS.)*

Figure 1b. *Finished reinforced steel cage for concrete pipe manufacture. (Photograph by Stan Krukowski, OGS.)*

Figure 1c. *Hanson Pipe and Precast tour guide explaining manufacture of concrete box culvert. Foreground: steel reinforced cage prior to concrete injection; background: finished concrete box culvert. (Photograph by Stan Krukowski, OGS.)*

Figure 1d. *Steel concrete pipe mold prior to injection and rotation of concrete. (Photograph by Stan Krukowski, OGS.)*

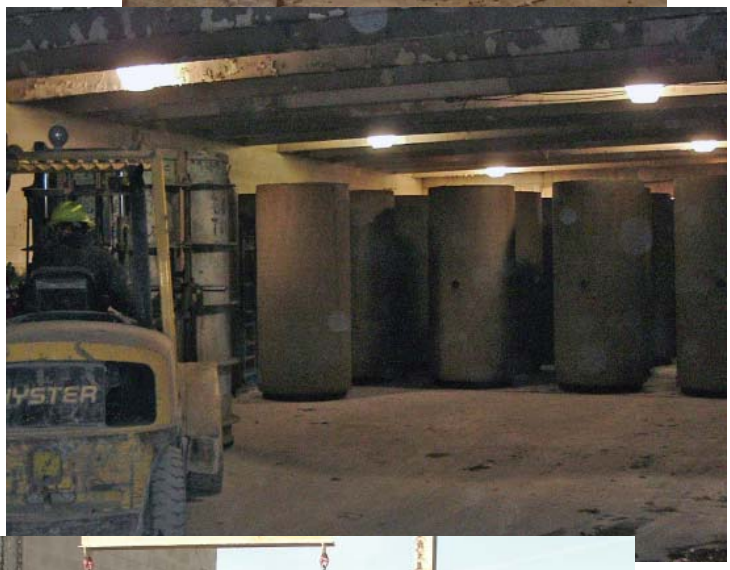


Figure 1f. *Concrete pipe undergoing drying and setting in drying warehouse sauna at 60°C and 100% relative humidity. (Photograph by Stan Krukowski, OGS.)*

Figure 2. *Hanson Pipe and Precast LLC plant in Oklahoma City. Concrete pipe is undergoing pressure testing to meet ASTM standards. (Photograph by Stan Krukowski, OGS.)*

President, and Jim Dockery, Assistant Sales Manager. Evans sells, services, and supports all types and sizes of electrical motors and generators, controls, and related driven equipment. You can visit the Evans web site at **http://www.goevans.com/index.html** to view the video to see their full range of operations. Field trip attendees saw all of Evans' capabilities from small motor repair and assemblage to large electric motor restoration. The large motor shop was working on an OKAA member ball mill motor as the tour was taking place (**Figure 3**), a highlight for many of the miners and plant managers in attendance. Evans provided a barbecue lunch and, along with other service companies, distributed door prizes to field trip participants.

Immediately after lunch, the field trip stopped at the Oklahoma (North Canadian) River dam and lock at May Avenue in southwest Oklahoma City (**Figures 4 and 5**). Jess Shumway of the City of Oklahoma City Public Works showed the OKAA group the dam and lock here, providing a practical demonstration of how the lock can lower and raise small watercraft to either level of the two river basins. In addition, the engineers in the crowd were thrilled to visit and to inspect the pump house and controls for the lock.

Seven miles of the North Canadian River was converted into a series of "river lakes" with landscaped banks and trails and recreational facilities. Now known as "The Oklahoma River," the various segments of the river are separated by a series of dams and locks that control the water flow and level. The locks at Western and May avenues allow boats to navigate the entire 7-mile length of the river project. Many field trip attendees

Figure 3. *OKAA field trip at Evans Enterprises. Giant motor being repaired is from an OKAA member manufacturing plant's ball mill. (Photograph by Stan Krukowski, OGS.)*

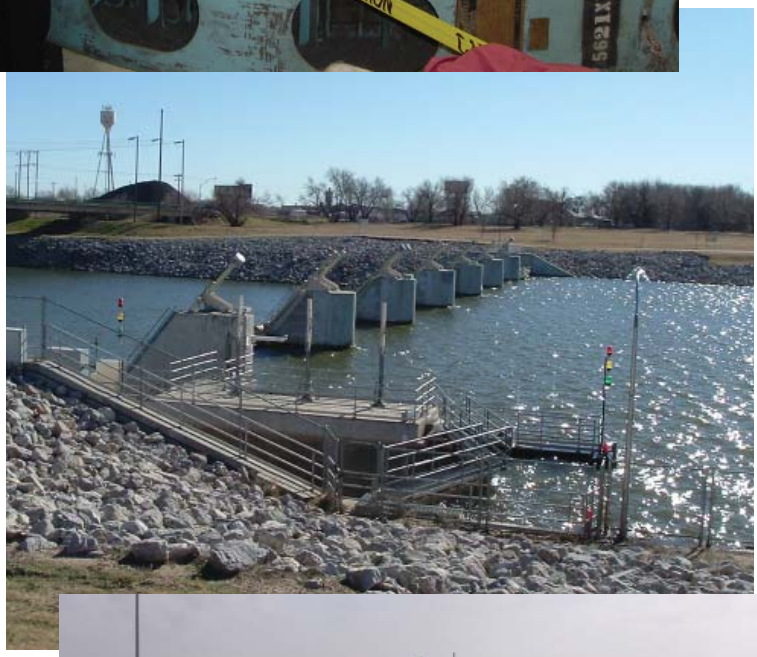


Figure 4. *Dam and lock on the Oklahoma River at May Avenue Southeast. (Photograph by Stan Krukowski, OGS.)*

Figure 5. *OKAA field trip attendees inspect May Avenue SE lock and dam along the Oklahoma River. Note riprap lining north bank of the Oklahoma River in foregraund. (Photograph by Jim Rodriguez, OKAA.)*

had a chance to examine up close the riprap-lined banks of the Oklahoma River (**Figure 5**); obviously a product of the industry of which they are a part. Joggers, walkers, skaters, and bikers use the trails extensively. Fishing along the river is another popular pastime; a city fishing permit and state fishing license are required. Noodling is prohibited in the Oklahoma River; however, for the more adventuresome, it is allowed from the NW 10 Street Bridge downstream to the MacArthur Bridge.

The final field trip stop was the newly constructed Devon Boathouse on the north bank of the Oklahoma River (**Figure 6**). Tracy Woodie, Boathouse General Manager, greeted the OKAA field trip participants. The Devon Boathouse is the home of Oklahoma City University rowing and canoe/kayak programs. It also serves as headquarters for the OKC National High Performance Center (OKCNHPC). The Center is one of the premier training facilities for rowing and canoe/kayak in the world. Its goal is centered about training successive generations of first-class athletes to represent the United States in international competition including the Olympics. The OKCNHPC is the headquarters for USRowing's Lightweight National Team operations and was named the National Adaptive Training Center for Rowing.

The OKAA group was given the grand tour of the high-tech training equipment and facilities as well as meeting and training rooms (**Figure 7**). City of Oklahoma City officials were on hand to explain further the plans for the future of the Boathouse District.

The four-story Chesapeake Finish Line Tower is the newest structure along the Oklahoma River. Participants on the field trip visited its welcome center, officiating deck, media and race control rooms, and a VIP viewing gallery and observation deck. From the observation deck, many attendees again noticed and remarked about the riprap-lined banks of the Oklahoma River. Readers can learn more about the Oklahoma City Boathouse District and the OKCNHPC at **http://boathousedistrict.org/and http://okc-nhpc.org/**, respectively.

Figure 6. *Devon Boathouse and Chesapeake Energy Finish Line Tower along the north bank of the Oklahoma River. (Photograph by Stan Krukowski, OGS.)*

Figure 7. *Devon Boathouse tour guide instructs OKAA field trip attendees in the proper method of using the rowing erg machine. (Photograph by Stan Krukowski, OGS.)*

Aggregates Day at the State Capitol

Following the OKAA annual meeting February 28th, the association conducts **Aggregates Day at the State Capitol**. The industry is represented by its members and several have exhibits to showcase their companies and their products. Several government agencies that play a key part in regard to the aggregates and mining industries also are invited to participate with exhibits. The vital role that the aggregates industry plays in society's current standard of living is stressed to State legislators and other government officials. The aggregates industry touches every aspect of our lives, from the roads on which we drive to the homes we live in to the parks and buildings where we recreate. The OGS has participated every year at **Aggregates Day at the Capitol** since its inception. The OGS booth informs legislators, other officials and the general public of the importance of the geological resources of the State of Oklahoma. The OGS is responsible—mandated—to investigate the geologic and water resources of the State of Oklahoma and to disseminate to its citizens that information. The OGS participation in Aggregates Day at the Capitol illustrates that the OGS is indeed dedicated to that mission.

Figure 8. *Stan Krukowski, OGS Industrial Minerals Geologist, with Randy Beeson (past chairman OKAA) and Paul Holzmer (OKAA Board of Directors). (Photograph by Sue Britton Crites, OGS.)*

Earthquake Report 4th Quarter 2011

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

The Oklahoma Geological Survey (OGS) recorded more than 600 earthquakes in Oklahoma from October 1 through December 31, 2011. The most significant earthquakes occurred in Lincoln County during the Prague earthquake sequence in which a magnitude 4.7 (MW) foreshock occurred about 20 hours prior to a magnitude 5.6 (MW) mainshock. The largest aftershock was another MW 4.7 earthquake. All three of these earthquakes damaged structures in the area. Most damage occurred due to the magnitude 5.6 with minor damage associated with the two magnitude 4.7 earthquakes.

There were more than 300 earthquakes in Lincoln County. Damage assessment teams from Oklahoma Emergency Management, FEMA and the Small Business Administration (SBA) assessed damage in Lincoln and Pottawatomie Counties. They identified six homes that were destroyed, 20 homes that suffered damage, and a total of 174 homes were identified as having damage associated with the earthquakes. St. Gregory's University's Benedictine Hall, built in 1915, suffered the greatest damage estimated at $2.8 million the SBA estimates that it will issue about $1.7 million in loans and grants for earthquake damage in the area. This earthquake sequence is actually quite similar to the 1952 El Reno Earthquake with an estimated magnitude of 5.5. Both earthquakes have similar areas over which the earthquake was felt and damage occurred. Damage actually occurred over greater distances in the 1952 El Reno Earthquake.

There were 63 felt earthquakes for the 4th quarter of 2011, the largest of which can be seen in **Table 1**. The OGS has located 178 earthquakes occurring in Oklahoma county, 313 in Lincoln County, 32 in Logan County, 26 in Pottawatomie County, 16 in Seminole County, and 11 earthquakes in ongoing activity in Coal County. The earthquakes for this quarter are located within 14 different counties, and are shown in **Figure 1**.

The National Science Foundation Earthscope US Array Transportable Array (TA) continues to

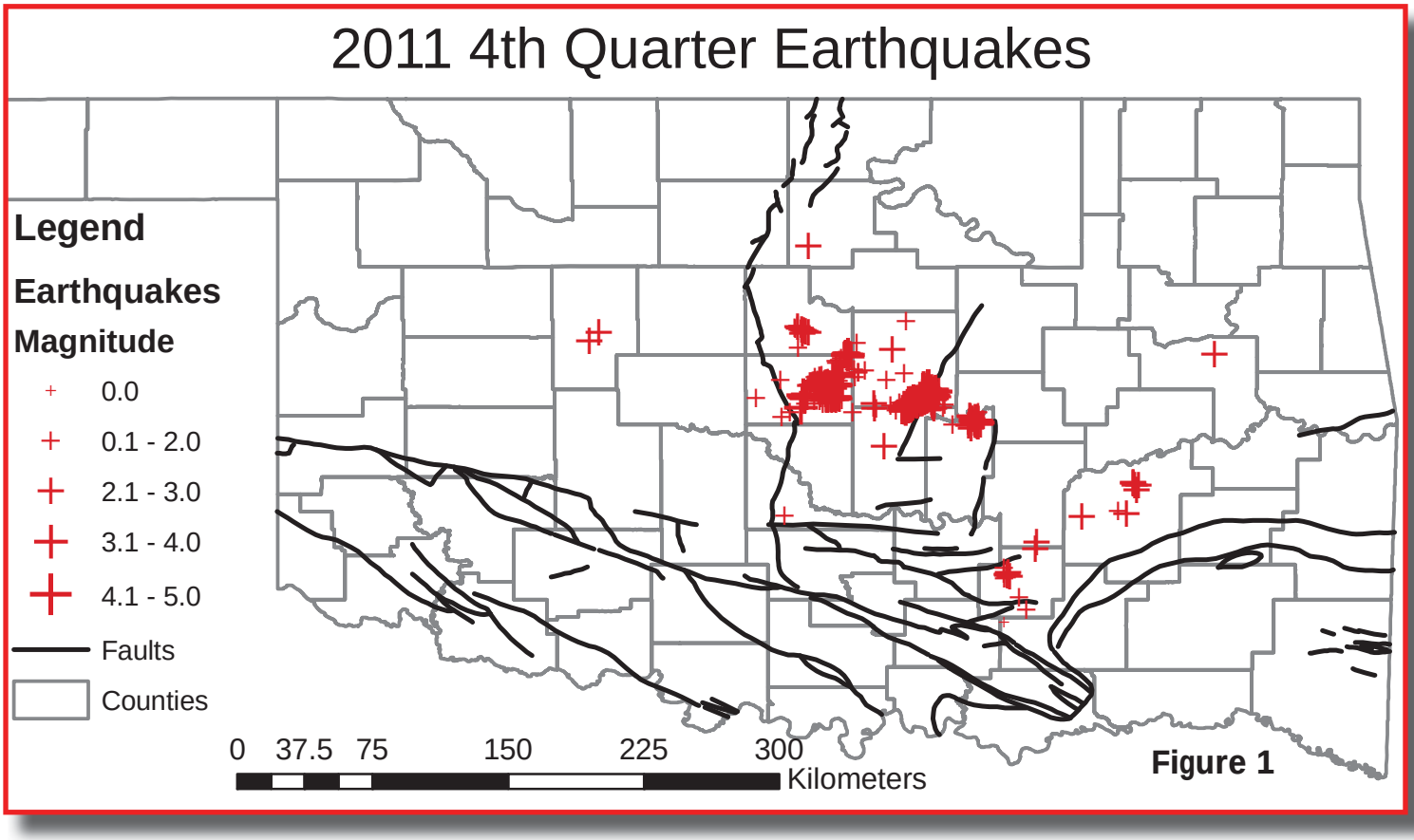


Figure 1

Table 1 - Largest Felt Earthquakes for July 1 through September 30, 2011.
MMI is the maximum reported Modified Mercalli Intensity.

Origin Time (UTC)	Longitude	Latitude	Depth km	Magnitude	Type	MMI	County
10/5/11 10:40	-97.2324	35.5042	3.2	3.0	ML	II	Oklahoma
10/18/11 5:51	-97.3986	35.4653	3.1	3.3	ML	III	Oklahoma
10/28/11 6:24	-97.3803	35.5181	3.2	3.2	mbLg	III	Oklahoma
10/28/11 9:18	-97.3864	35.5254	5.0	3.4	mbLg	V	Oklahoma
11/5/11 7:12	-96.7637	35.5501	3.1	4.8	MW	VI	Lincoln
11/5/11 7:27	-96.7646	35.5439	3.2	3.3	ML	III	Lincoln
11/5/11 9:12	-96.7657	35.5282	5.0	3.3	ML	III	Lincoln
11/5/11 11:24	-96.7731	35.5252	5.0	3.4	ML	III	Lincoln
11/5/11 13:42	-96.7656	35.5303	5.0	3.2	ML	V	Lincoln
11/5/11 14:36	-96.7776	35.5175	5.0	3.6	ML	V	Lincoln
11/6/11 3:53	-96.7654	35.5316	5.2	5.6	MW	VII	Lincoln
11/6/11 6:31	-96.8591	35.4794	5.0	3.7	ML	V	Lincoln
11/6/11 7:32	-96.8471	35.4803	5.0	3.2	ML	V	Lincoln
11/6/11 8:14	-96.7713	35.5252	5.6	3.1	ML	IV	Lincoln
11/6/11 9:22	-96.8437	35.4852	5.0	3.5	ML	IV	Lincoln
11/6/11 9:39	-96.8543	35.4726	1.3	3.9	ML	III	Lincoln
11/6/11 9:39	-96.8653	35.4691	5.0	3.7	MW	V	Pottawatomie
11/6/11 10:52	-96.7794	35.5368	3.1	3.6	MW	V	Lincoln
11/6/11 11:03	-96.8383	35.4964	5.0	3.1	ML	V	Lincoln
11/6/11 15:07	-96.8556	35.4838	5.0	3.8	MW	V	Lincoln
11/6/11 17:52	-96.8207	35.4936	5.0	3.4	MW	IV	Lincoln
11/6/11 18:26	-96.8687	35.4733	3.1	3.1	Md	V	Lincoln
11/7/11 1:17	-96.7778	35.5222	4.0	3.0	Md	IV	Lincoln
11/7/11 1:26	-96.7857	35.5183	3.1	3.0	Md	V	Lincoln
11/7/11 13:50	-96.8564	35.4769	3.1	3.1	Md	V	Lincoln
11/8/11 2:46	-96.7879	35.5307	5.0	4.8	MW	VI	Lincoln
11/8/11 19:05	-96.7702	35.5259	3.0	3.5	MW	V	Lincoln
11/9/11 12:08	-96.7613	35.5342	5.0	3.4	ML	III	Lincoln
11/10/11 8:36	-96.8499	35.4868	3.3	3.2	Md	III	Lincoln
11/12/11 1:18	-96.7301	35.5452	3.9	3.1	ML	II	Lincoln
11/13/11 9:49	-96.8764	35.4568	4.8	3.2	ML	III	Pottawatomie
11/14/11 5:31	-96.7824	35.5214	3.1	3.2	ML	III	Lincoln
11/16/11 17:10	-96.8032	35.5045	5.0	3.2	ML	IV	Lincoln
11/18/11 7:41	-96.762	35.5407	7.5	3.3	ML	II	Lincoln
11/21/11 21:46	-96.8103	35.5028	5.0	3.0	ML	III	Lincoln

wind down in Oklahoma with stations beginning to be removed east of US Interstate 35. The stations will continue to be removed until all of them are gone by the spring of 2012. *"The Great Central U.S. Shake Out"* occurred on February 7, 2012, and participation in Oklahoma increased from less than 10,000 individuals in 2010 to more than 63,000 in 2011. The Shake Out is an annual exercise; please consider joining OGS and millions of others in the Shake Out exercise next year. More information can be found at, **http://shakeout.org/centralus/**.

Download the 2011 4th quarter earthquake file and complete list of felt earthquakes (CSV) at:

http://www.ok-geosurvey1.gov/media/quarterlies/2011_qt4.csv

http://www.ok-geosurvey1.gov/media/quarterlies/2011_qt4_felt.csv

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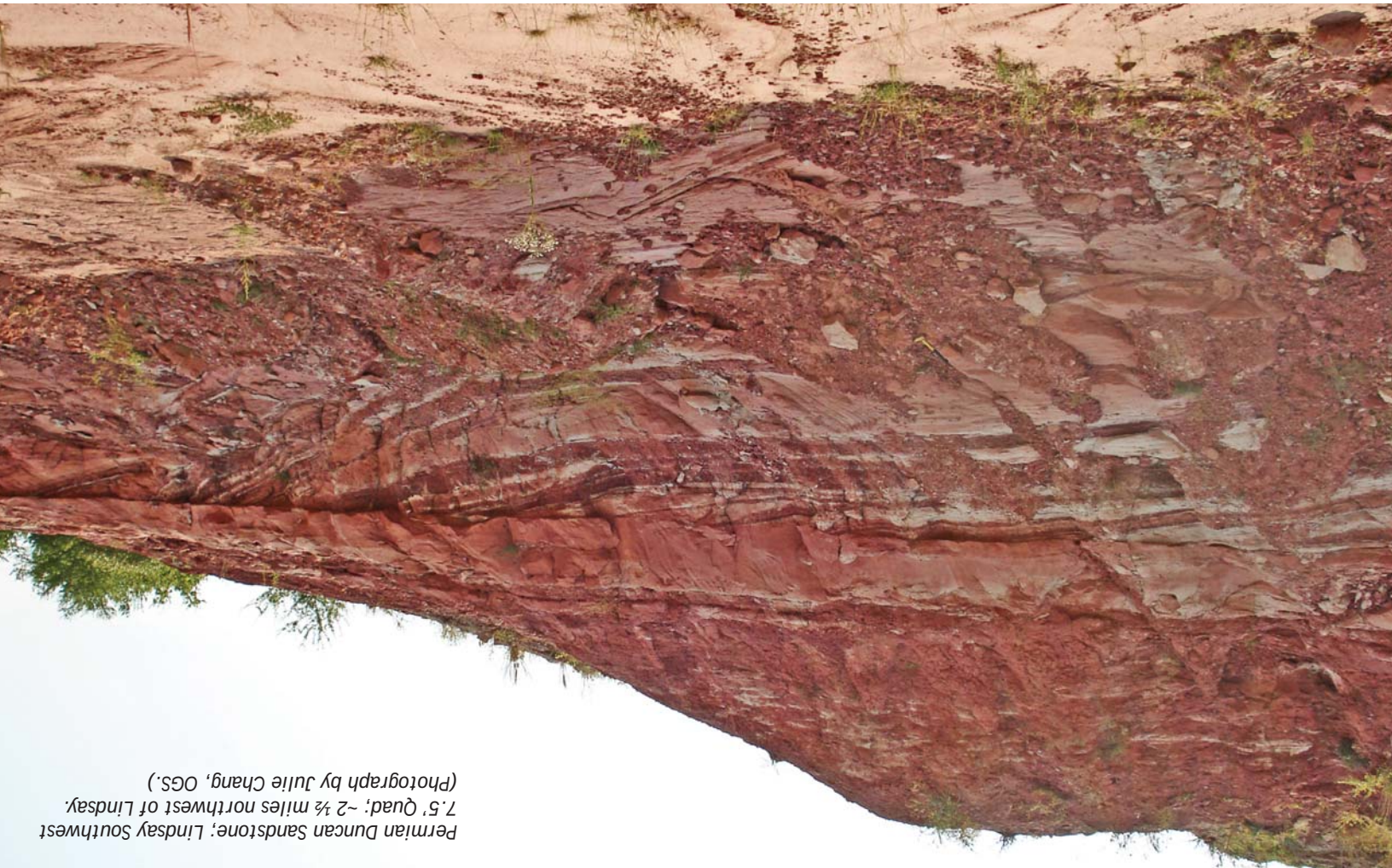

Permian Duncan Sandstone; Lindsay Southwest 7.5' Quad; ~2 ½ miles northwest of Lindsay. (Photograph by Julie Chang, OGS.)