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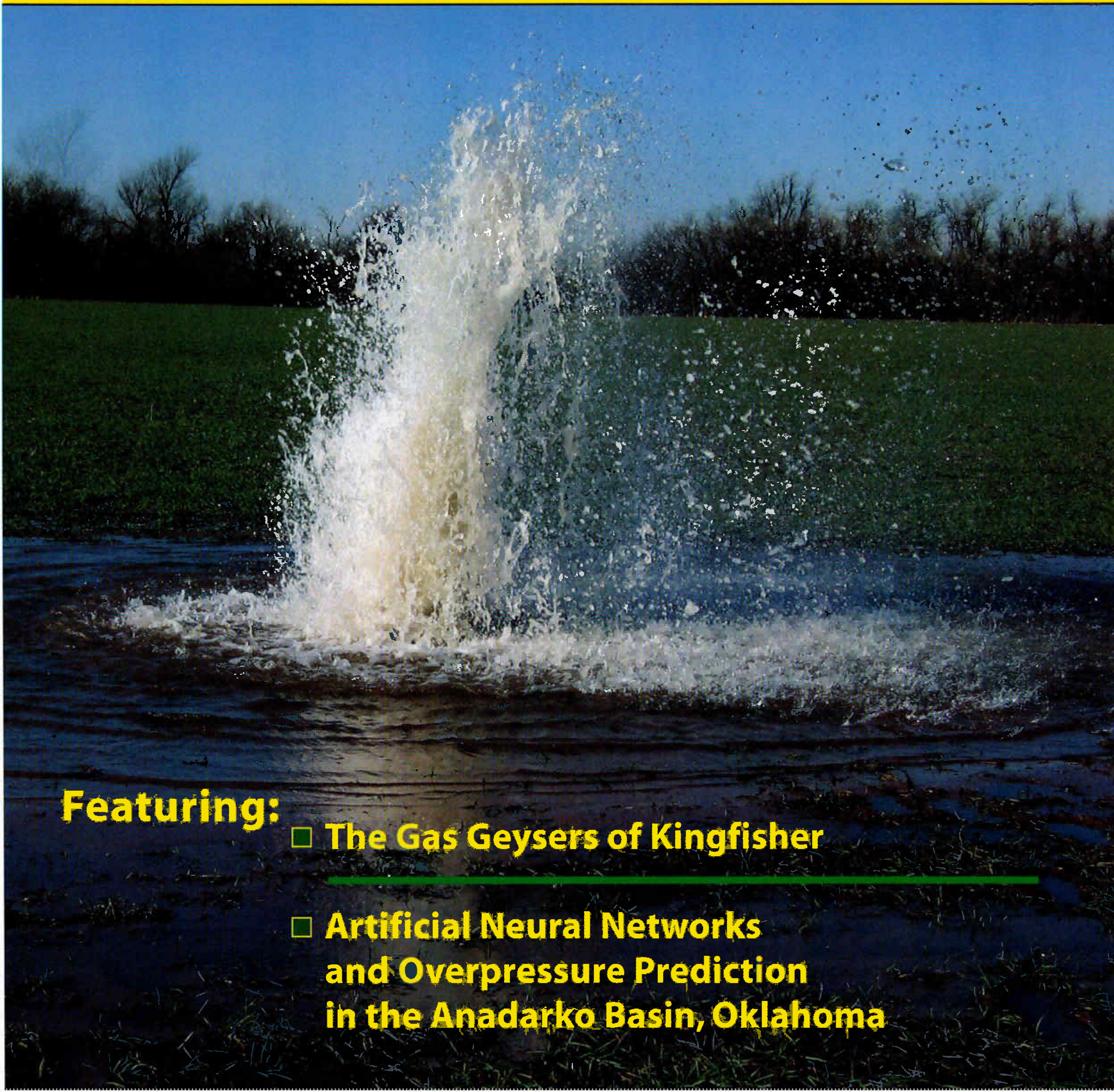

Featuring:

- The Gas Geysers of Kingfisher
- Artificial Neural Networks and Overpressure Prediction in the Anadarko Basin, Oklahoma

—On the Cover

Most people associate geysers with hydrothermal activity. The American Geological Institute's *Glossary of Geology* (Fifth Edition; 2005) defines *geyser* as "a type of hot spring that intermittently erupts jets of water and steam, the result of groundwater coming into contact with rock or steam hot enough to create steam under conditions preventing free circulation..." The Kingfisher, Oklahoma, geysers, however, probably were created when natural gas, under high pressure, escaped from its reservoir and came into contact with lotic waters or a high water table. The purge point, or place where the gas vented at the surface, created an eruption of gas, water, and, in some cases, mud. For a more comprehensive story, see "The Gas Geysers of Kingfisher" by Galen Miller on page 52.

Cover photo by Sue Britton Crites

Oklahoma Geological Survey

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OKLAHOMA GEOLOGY notes

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The Gas Geysers of Kingfisher

Galen W. Miller
Oklahoma Geological Survey

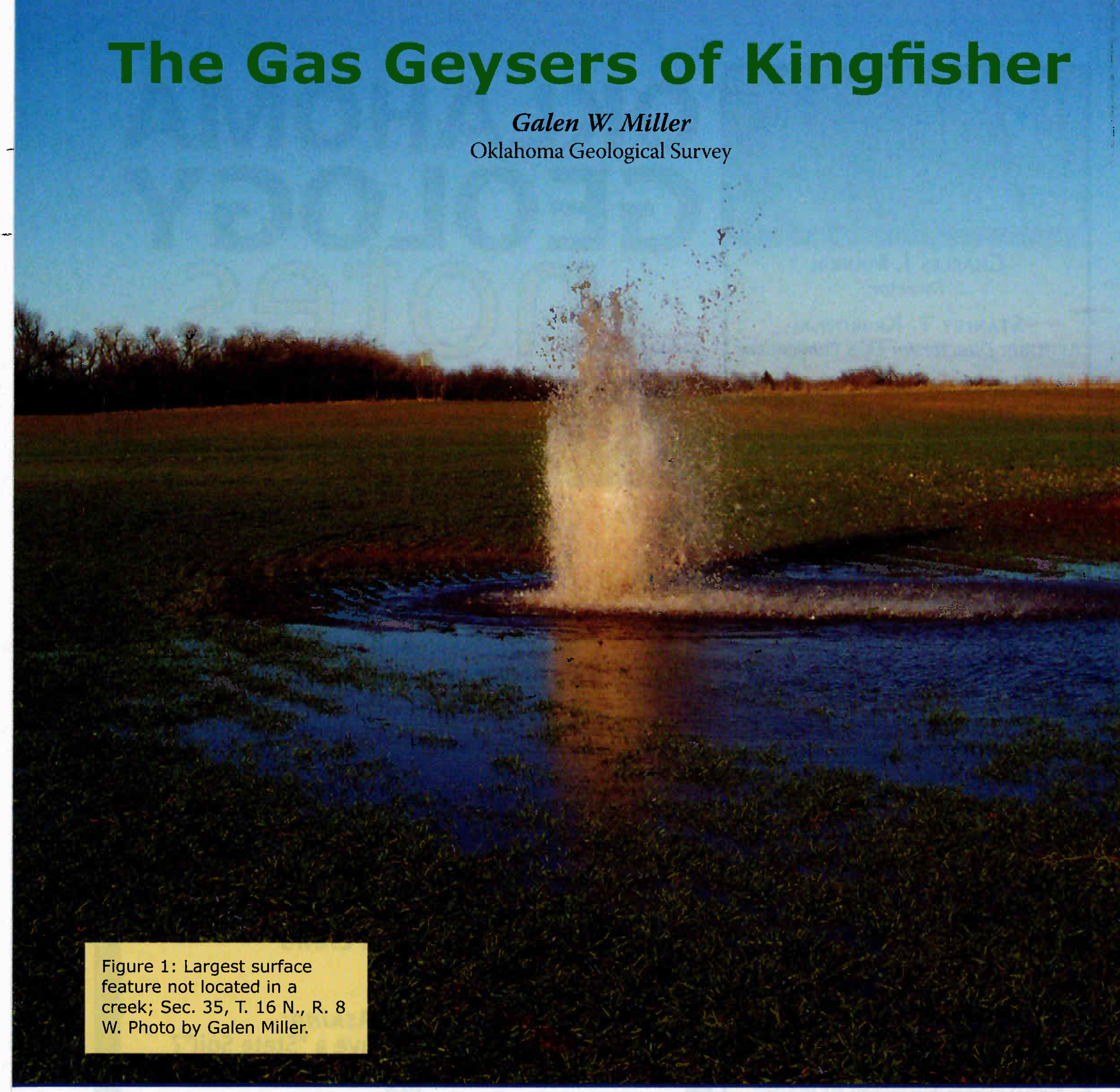

Figure 1: Largest surface feature not located in a creek; Sec. 35, T. 16 N., R. 8 W. Photo by Galen Miller.

INTRODUCTION

Natural gas bubbles and geysers erupted near Kingfisher, Oklahoma, on or about December 9, 2005 (Fig. 1). A hunter discovered the geysers along Winter Camp Creek formerly known as Dead Indian Creek. The geysers erupted along a ten-mile stretch of Winter Camp Creek and occurred in clusters along a bearing perpendicular to the regional strike of the sedimentary beds (Fig. 2). The Oklahoma Corporation Commission, Kingfisher Civil Defense, and Kingfisher Fire Marshall monitored the gas geyser eruptions for obvious safety issues.

Oklahoma last witnessed such a phenomenon on January 30, 1980, when a well in southern Woods County lost mud circulation. The gas migrated through a fracture system in an evaporite unit in the Permian Flowerpot Shale, and finally escaped at the surface forming a gas geyser (Preston, 1980).

GEOLOGIC SETTING

The Edmundson Trust #1-33 well is located in southwest Kingfisher County. The well is spudded in the very top of Permian Flowerpot Shale (Fig. 3). The Flowerpot Shale is part of the El Reno Group, which consists regionally of the (youngest to oldest) Dog Creek Shale, Blaine Formation, Flowerpot Shale, and the Cedar Hills Sandstone (Stanley and Miller, 2003). Locally, the El Reno Group includes the Chickasha Formation and the Dog Creek Sandstone (Carr and Bergman, 1976).

The Flowerpot typically is 437 – 465 feet thick in Blaine County northwest of the area of geyser eruptions. The Flowerpot is conformable with the overlying Blaine Formation and consists of four sub units (Fay and others, 1962). The Flowerpot Shale, in the study area, is composed of two parts separated by the Chickasha Formation. The upper Flowerpot Shale is interbedded reddish-brown clay shale with and without satin spar and selenite veins, and impure dolomite and gypsum beds not more than 2–3 inches thick. The lower Flowerpot Shale unit is a red–brown blocky mudstone with green–blue siltstone beds (Stanley and Miller, 2003).

The Chickasha Formation is composed of fine-grained cross-bedded sandstone and predominately red-brown to purple-maroon mudstone conglomerates. The Chickasha tongue grades into the Hennessey Group towards the

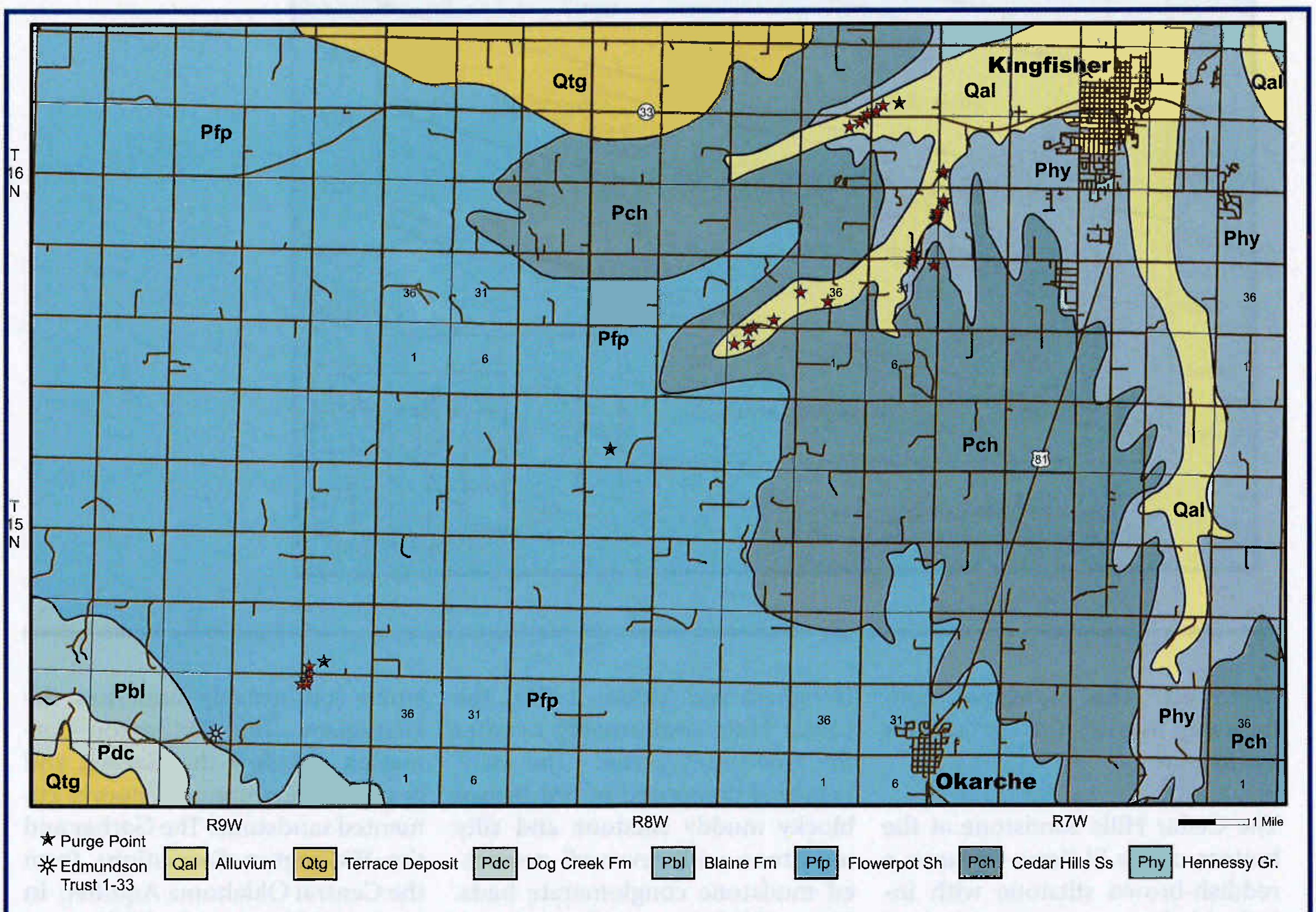

Figure 2. Geologic map is marked with surface features.

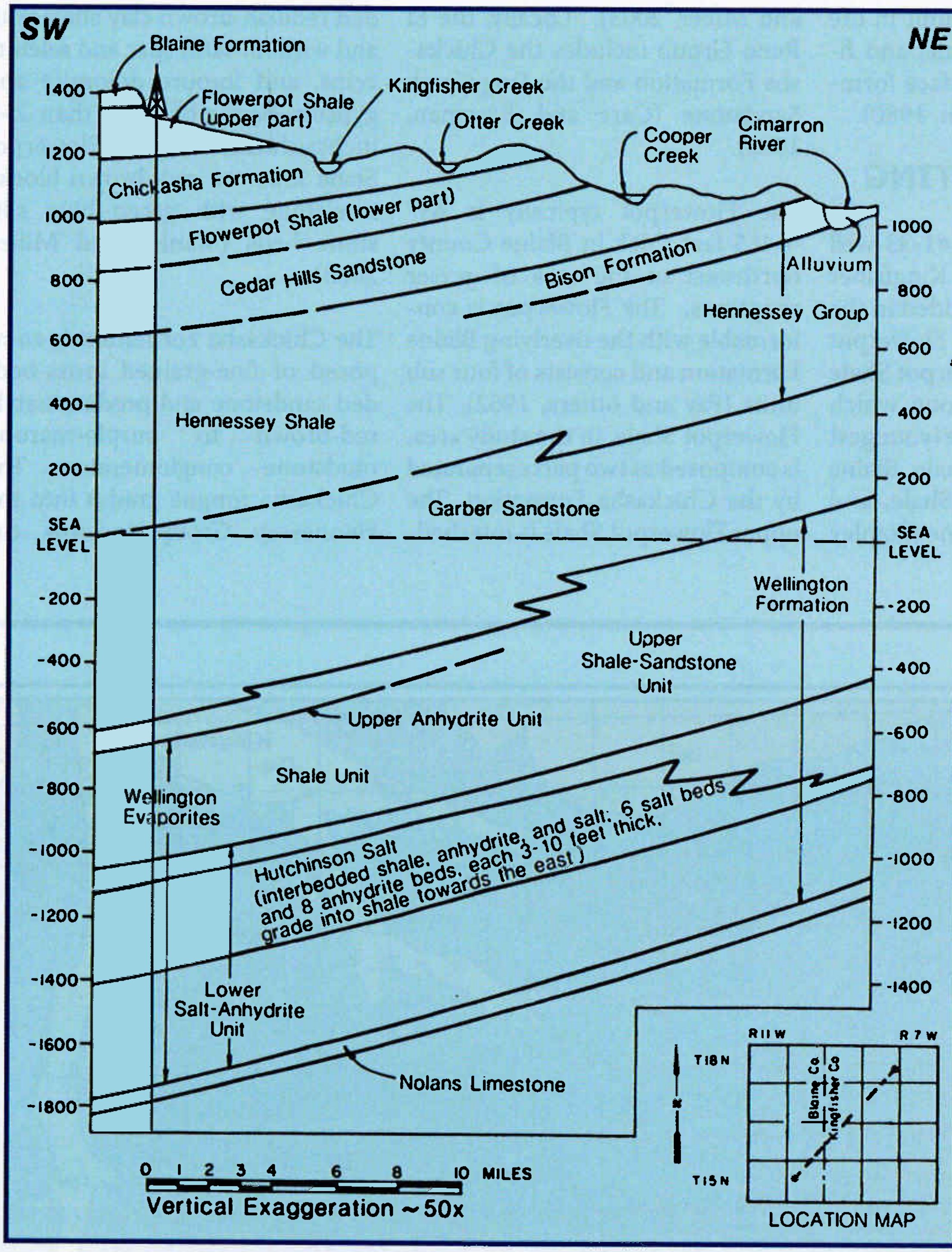

Figure 3: Cross section shows the subsurface geology acting as a conduit for the escaping gas. Modified from Luza and others (1989).

northwest. The Flowerpot conformably overlies the Cedar Hills Sandstone.

The Cedar Hills Sandstone at the bottom of the El Reno Group is a reddish-brown siltstone with interbedded green-gray siltstone and very fine-grained sandstone (Bingham and Moore, 1975). The Cedar Hills conformably overlies the Hennessey Shale. The Hennessey is composed of red-brown blocky muddy siltstone and silty mudstone with few well cemented mudstone conglomerate beds. The reddish-brown, fine-grained, poorly cemented Garber Sandstone conformably underlies the Hennessey. The Wellington Formation is below the Garber, and is mostly fine-grained, poorly cemented sandstone. The Garber and the Wellington Formations form the Central Oklahoma Aquifier. In western Oklahoma the Wellington contains several evaporite units.

The gas is thought to have escaped somewhere at the level of the Garber and Wellington Formations (Fig. 3).

WHAT IS KNOWN

Chesapeake Energy Corp. reported that they encountered a high pressure pocket of natural gas about 9,400 feet below the surface while drilling the Edmundson Trust #1-33 well in Sec. 33, T. 15 N., R. 9 W. Chesapeake reported gas escaping into the formation wall between 1,300 and 1,700 feet. The gas appears to flow toward the surface along the surface casing. The gas somehow migrates through the Hennessey Shale possibly through fractures in the overlying Cedar Hills Sandstone, and escapes into the atmosphere (purge points) where the Cedar Hills is exposed at the surface. The Cedar Hills exposures occur mainly in creek beds where streams have eroded down through the overlying Flowerpot Shale. The surrounding surface is composed of the Permian Flowerpot Shale and Quaternary wind-blown silt deposits. Gas geysers erupt along a bearing of 040-050°, perpendicular to the regional strike (Fig. 2). It is thought that the Hennessey fails to trap the gas because there are no eruptions or other surface features northeast of Kingfisher where the Hennessey Shale/Garber Sandstone contact occurs (see Figs. 4-7). The author collected gas samples from the Edmunson Trust #1-33 well and a gas eruption site. Dr. Paul Philp from the School of Geology and Geophysics at the University of Oklahoma in Norman analyzed the gas samples. The gas analyses from the

Figure 4: Eruption or surface feature is closest to the Edmundson Trust #1-33 well. The "Caldera" is approximately 10 feet across. Sec. 35, T. 15 N., R. 9 W. Photo by Galen Miller.

Figure 5: One of the larger eruptions is approximately 15 feet wide. Sec. 2, T. 15 N., R. 8 W. Photo by Galen Miller.

Figure 6. Mudflow is a result of an eruption. Figure 5 is located in the creek behind the mudflow in Sec. 2, T. 15 N., R. 8 W. The feature in Figure 5 is in the creek behind the mudflow. Photo by Galen Miller.

Figure 7: Surface feature erupting along a fracture oriented 140-150°; Sec. 30, T. 16 N., R. 7 W. Photo by Galen Miller.

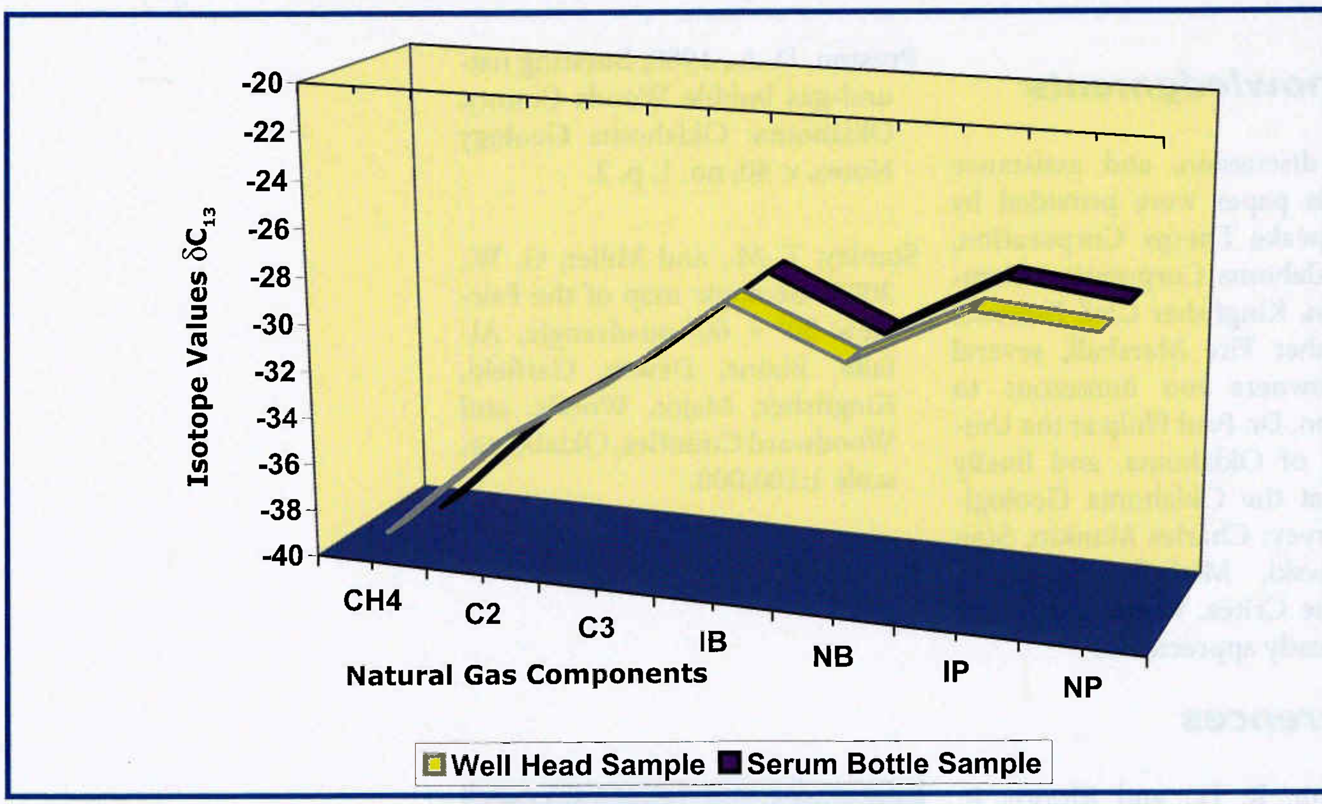

Figure 8: Serum Bottle and Well Head Samples analyzed by Dr. Paul Philp, School of Geology & Geophysics, University of Oklahoma. The gas analyses from the eruption site and the well site show that the gas samples most likely share the same source.

eruption site and the well site show that the gas samples most likely share the same source (Fig. 8).

CONCLUSIONS

The gas bubbles and geysers near Kingfisher started to diminish in volume and strength after capping the original well and drilling an offset well. The mode of gas transport through the Hennessey Group is not properly understood. If the gas migrated along a small fracture system, gas geysers and bubbles at the surface likely would form an uneven fan-like pattern rather than the observed linear pattern. Other possible explanations include gas emerging at the surface casing; along an unknown fracture system perpendicular to the regional strike and in the near surface; in association with dissolution of evaporite materials; or along some other unknown pathway.

Acknowledgments

Data, discussion, and assistance for this paper were provided by Chesapeake Energy Corporation, the Oklahoma Corporation Commission, Kingfisher Civil Defense, Kingfisher Fire Marshall, several land owners too numerous to mention, Dr. Paul Philp at the University of Oklahoma, and finally those at the Oklahoma Geological Survey: Charles Mankin, Stan Krukowski, Michelle Summers, and Sue Crites, whose assistance was greatly appreciated.

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Artificial Neural Networks and Overpressure Prediction in the Anadarko Basin, Oklahoma

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ABSTRACT

Many sedimentary basins throughout the world exhibit areas with abnormal pore-fluid pressures (higher or lower than normal or hydrostatic pressure). Predicting pore pressure and other parameters (depth, extension, magnitude, etc.) in such areas are challenging tasks. The compressional acoustic (sonic) log (DT) is often used as a predictor because it responds to changes in porosity or compaction produced by abnormal pore-fluid pressures. Unfortunately, the sonic log is not commonly recorded in most oil and/or gas wells.

We propose using an *artificial neural network* (ANN) to synthesize sonic logs by identifying the mathematical dependency between DT and the commonly available logs, such as normalized gamma ray (GR) and deep resistivity logs (REID). The ANN process can be divided into three steps: (1) supervised training of the neural network; (2) confirming and validating the model by blind-testing the results in wells that contain both the predictor (GR, REID) and the target values (DT) used in the supervised training; and (3) applying the predictive model to all wells containing the required predictor data and verifying the accuracy of the synthetic DT data by comparing the back-predicted synthetic predictor curves (GRNN, REIDNN) to the recorded predictor curves used in training (GR, REID).

ANNs offer significant advantages over traditional deterministic methods. They do not require a precise mathematical model equation that describes the dependency between the predictor values and the target values and, unlike linear regression techniques, neural network methods do not over-predict mean values and thereby preserve original data variability. One of their most important advantages is that their predictions can be validated and confirmed through back-prediction of the input data.

This procedure was applied to predict the presence of overpressured zones in the Anadarko Basin, Oklahoma. The results are both promising and encouraging.

Introduction

It is well documented (e.g., Ortoleva, 1994; Surdam, 1997; Mitchel and Grauls, 1998; and Huffman and Bowers, 2002) that in many sedimentary basins the pore-fluid pressure measured at a certain depth is either higher (overpressure) or lower (underpressure) than the normal (hydrostatic) fluid pressure at that depth. A sedimentary basin experiencing one or both of these situations is said to have abnormal pressure regimes. Overpressured zones are far more common than under-pressured zones.

Abnormal pore-fluid pressure and abnormal pressure regimes always have been recognized as important factors in the evolution of hydrocarbon provinces (e.g., Mitchell and Grauls, 1998; Huffman and Bowers, 2002; and Poston and Berg, 2002). Until recently, however, the ability to predict their presence, location, magnitude, and distribution was limited by two critical factors: limited knowledge of those regimes and their physics; and lack of sufficiently robust technologies for predicting pressures in the subsurface. Historically, abnormal pressure evaluation used basic data such as mud weight, repeat formation testing (RFT), and drill-stem testing (DST). Seismic velocities, wireline logs, and resultant porosity estimations can provide an indirect method of evaluating pore pressure.

The compressional acoustic (sonic) log (DT) has been used to characterize areas with abnormal pore fluid pressure via effective rock stress estimations. The DT log seems to be preferred due to its accuracy and sensitivity to changes in rock stress produced by abnormal pore-fluid pressures, especially in shale layers (Hearst and others, 2000; and Asquith and Krygowski, 2004). Determining trends in acoustic transit time on sonic logs has become a conventional method of detecting anomalous pressures in shales. Because the velocity of a compressional wave in sedimentary rock is dependent on the effective rock stress, an increase in transit time is interpreted as indicating a lower effective rock stress and, therefore, overpressure (Surdam and others, 1997).

The calculation of abnormal pressure from log data is based on the relationship between observed acoustic values of shales and a trend line reflecting normal compaction (see e.g., Heppard and others, 1998; Hsu and Belaud, 1998).

In spite of its intrinsic value for studying and analyzing abnormal fluid pressures, the sonic log is not commonly available in oil and gas wells. This may happen either because a full suite of logs is not recorded or because of problems en-

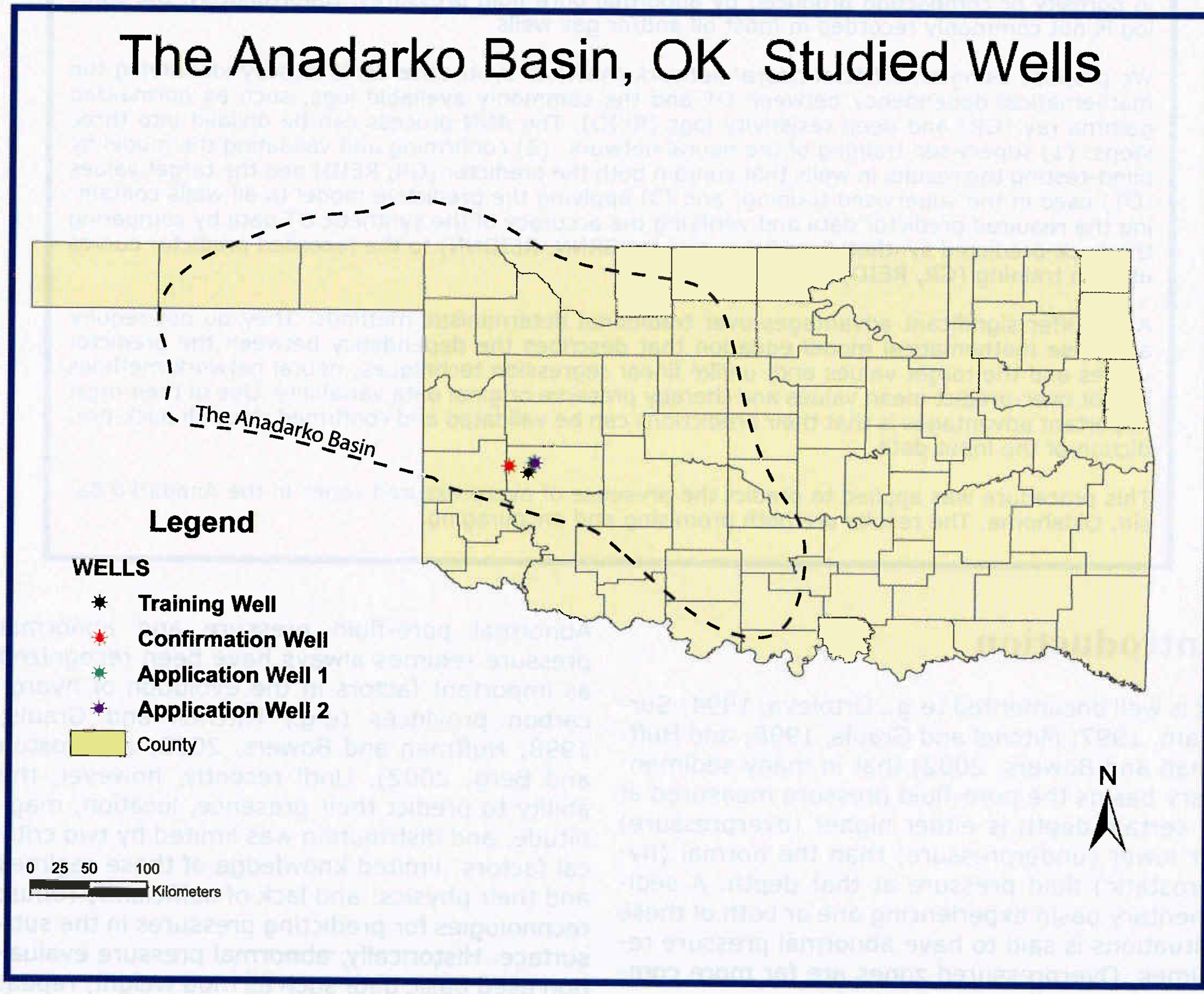


Figure 1. The Anadarko Basin, Oklahoma, and the wells used in the artificial neural network.

countered in repeat logging, such as damaged, faulty logging instruments, or poor logging conditions in any of the logging runs. As a result, some wells may lack the sonic log entirely or the log is only partially recorded.

Artificial neural networks (ANNs) are used to accurately synthesize missing DT data, increase the density of the control data, and more effectively map changes in pore pressure in the Anadarko Basin of Oklahoma, a basin well-known for its overpressured compartments (Fig. 1) (Al-Shaieb and others, 1990, 1994a,b, Cranganu, 2004).

Artificial Neural Networks — Background Solutions

ANNs are computational systems that mimic the biological neural networks of the mammalian brain. The human brain contains about 100 billion neurons (neural cells), interconnected in a complex manner via synapses (a junction between axons and dendrites), thus constituting a network. ANNs are grossly simplified models of living neural networks (Rogers and others, 1995). They are also an exploration and development tool that allows an easy transformation of log data into any desired output parameter.

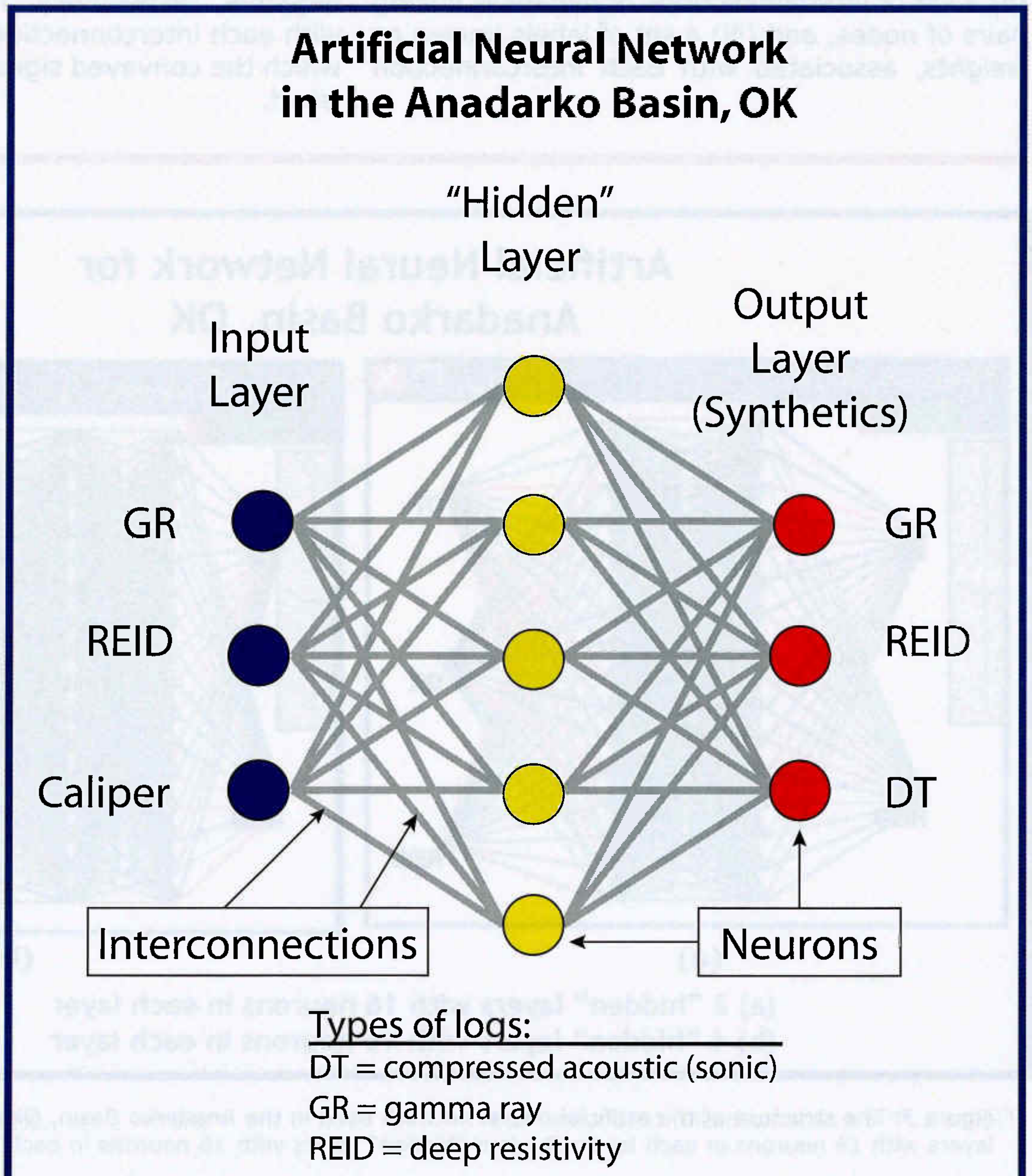


Figure 2. Artificial neural network architecture used in the Anadarko Basin, Oklahoma (from Cranganu, 2005a and Cranganu, 2006).

Specific mathematical relationships between predictors (logs) and target values (rocks) need not be known.

Since the ANNs mimic the human brain's problem-solving processes they can use knowledge gained from past experiences and apply that knowledge to new problems and situations. The ANNs, in effect, use a training experience to build a system of neurons and weight links that allow them to make new decisions, classifications, and predictions (Arbogast and others, 2000).

To be able to mimic the human's brain neural system, it is necessary for an ANN to comprise (Fig. 2) (i) a set of nodes (artificial neurons) where the nodes perform simple computations, (ii) a set of interconnections or synapses linking pairs of nodes, and (iii) a set of labels known as *weights,* associated with each interconnection and identifying some property of interconnection. These weights correspond to the synaptic efficiency of the biological neurons (Aristodemou and others, 2005).

The neurons in the network perform two simple tasks. The first task builds a weighted summation of the input data. The second task applies a function to this summation to yield an output that can serve as an input to other neurons or that can go to the output layer. An *activation function* limits the amplitude of a neuron by squashing the permissible amplitude range of the output signal to some finite value. The neuronal model of Figure 2 also includes an externally applied *bias* (threshold) that increases or decreases the net input of the activation function, depending on whether it is positive or negative, respectively. The weights associated with each interconnection indicate the extent to which the conveyed signal is amplified or diminished.

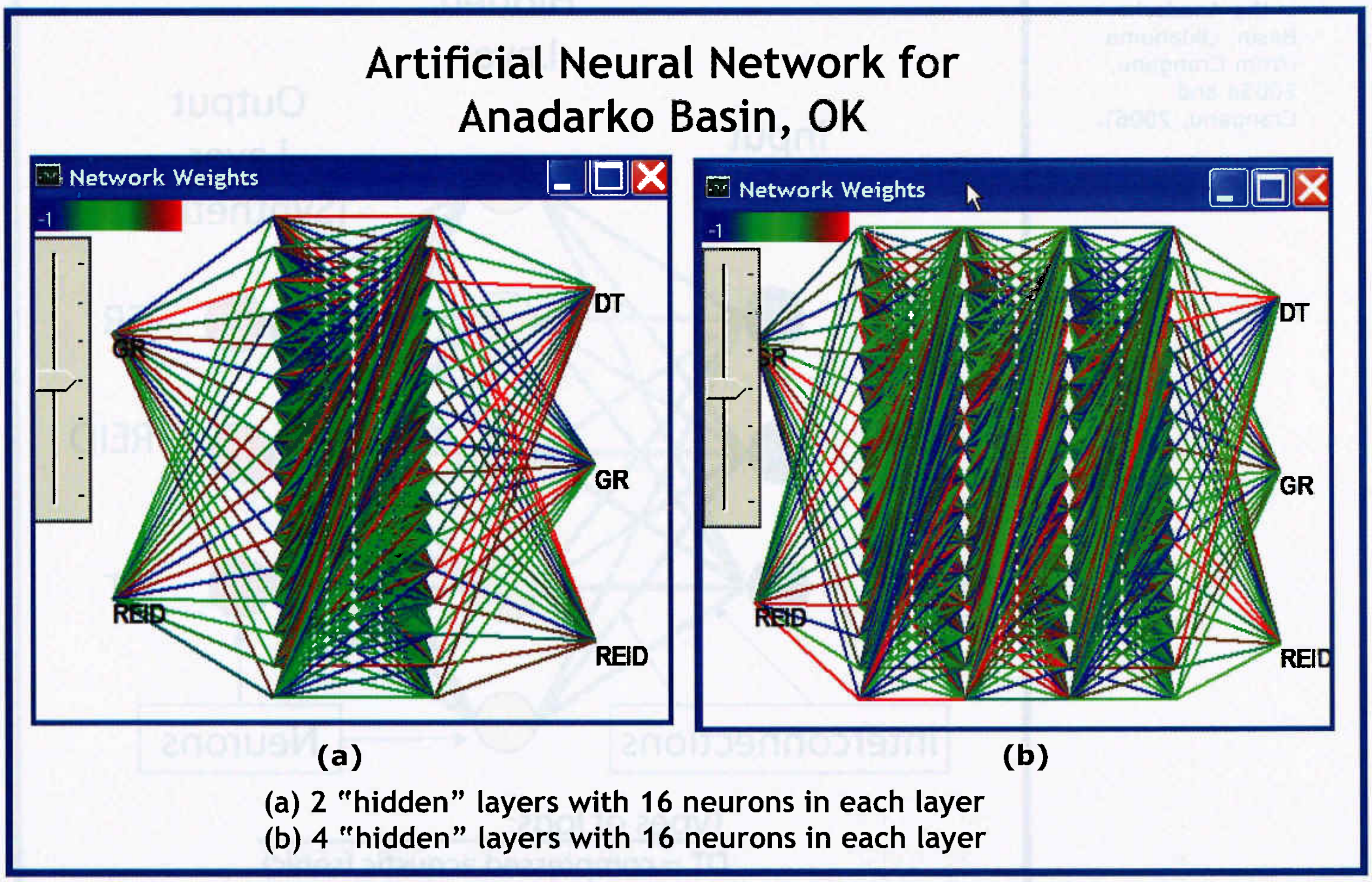
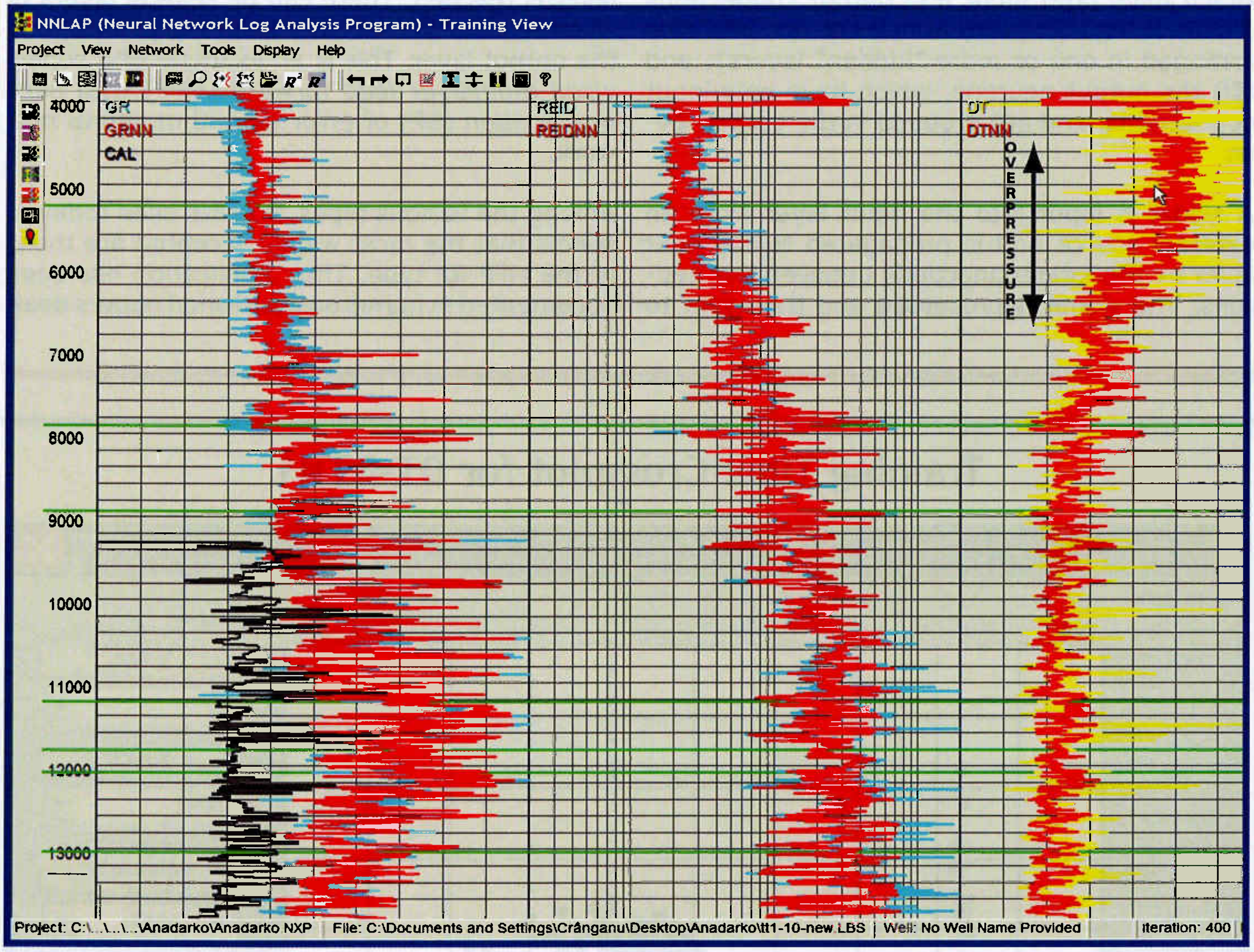


Figure 3. The structure of the artificial neural network used in the Anadarko Basin, Oklahoma: (a) two "hidden" layers with 16 neurons in each layer; (b) four "hidden" layers with 16 neurons in each layer.

Training Well T & T 1-10



Log Types
GR = gamma-ray
REID = deep resistivity
DT = compressional acoustic (sonic)

NN Suffix designates calculated curves

Colors
Red: calculated curves
Blue and yellow: training curves
Black: reference curve (CAL)

Figure 4. The training well (T&T 1-10, 35.268 N, -99.197 W) logs (GR, REID, and DT) are shown from 4,000 to 14,000 feet.

The activation function is often a sigmoidal (S-shaped) function, but other functions have been used (Heaviside or threshold or piece-wise linear). Given a network whose weights are initially random and assuming that we know the task needed to be accomplished by the network, a *learning algorithm* is required to determine the values of the weights that will achieve the desired task.

Considering an ANN, three types of neurons can be distinguished depending on their function (Fig. 2): (i) the input neurons, found in the input layer, where the input values are given (these units do not have input connections but only output ones); (ii) the "hidden" neurons, which have both input and output connections ("hidden" neurons vary in number and could be arranged in one or more "hidden" layers); and (iii) the output neurons, which have only input connections, and are grouped in the output layer.

A signal is input into the input layer from an external source and is propagated to the next layer by the interconnections between the neurons. The signal is processed and then sent to the next layer. The processing and then transmitting of the signal continues until the output layer is reached. There can be several layers of "hidden" neurons between the input layer and the output layer. This is an example of a *supervised multilayer feed forward* (MFF) with *back propagation* (BP) of error algorithm neural network.

Among the various types of ANNs used today, it seems that the most widely accepted are those of the MFF-BP type. Their application has been documented in numerous published papers deal-

Training Time Crossplot for DT-DTN1

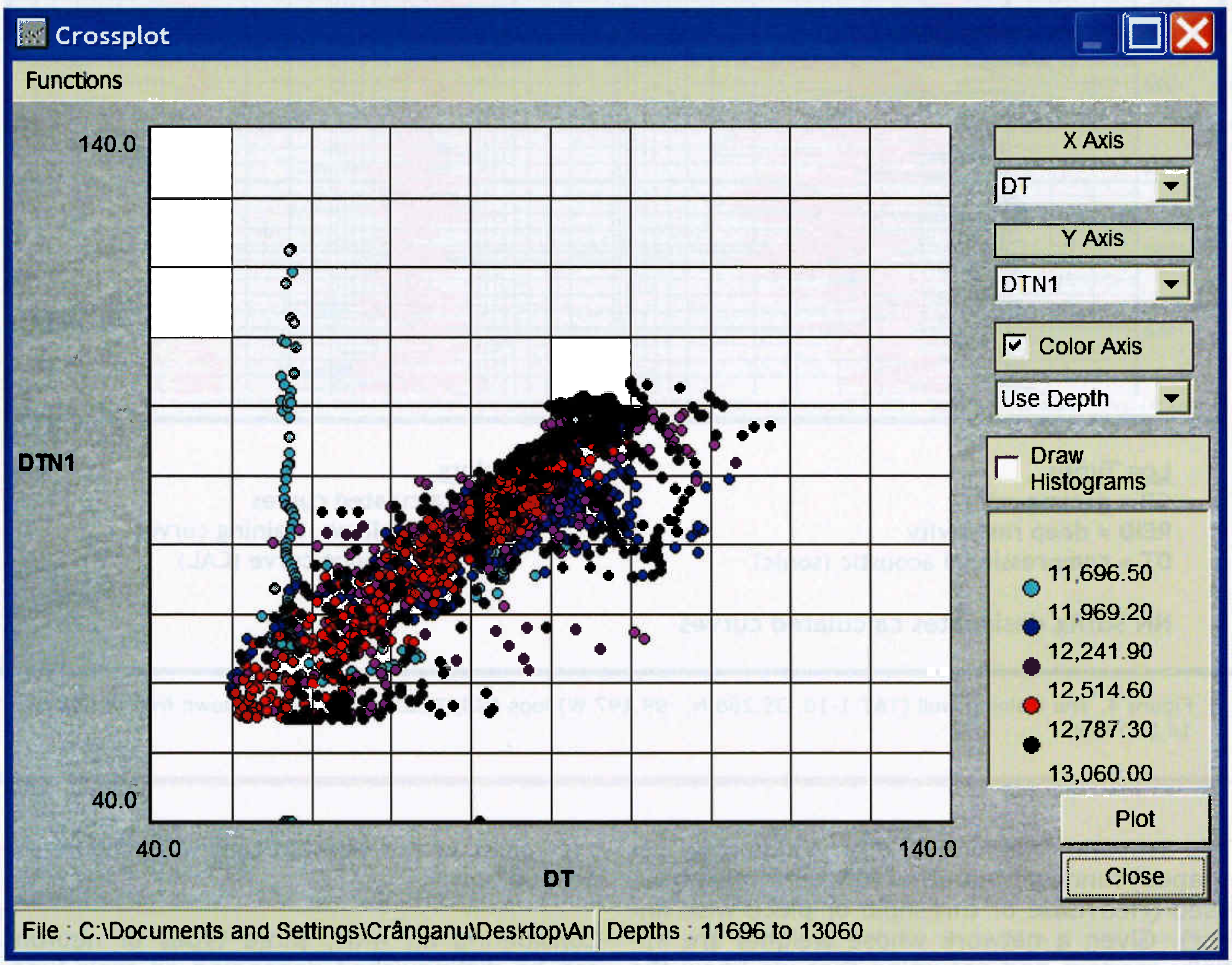
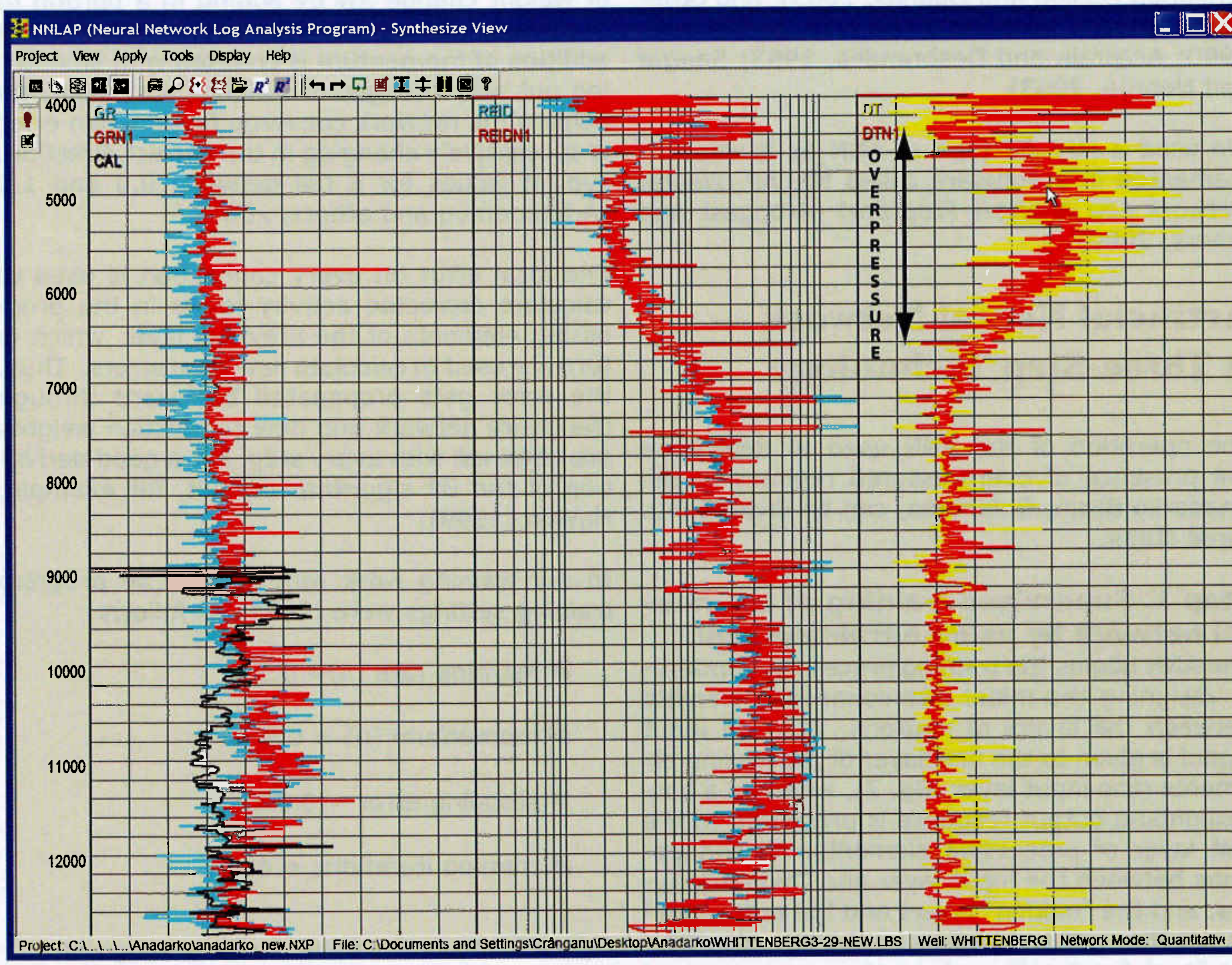


Figure 5. Crossplot of DT-DTN1 (depth interval 11,969 ft – 13,060 ft) in the training well that uses input and simulated data for training time.

Confirmation Wells (Whittenberg 3-29) Used to Confirm the Trained Neural Network



Log Types

GR = gamma-ray
REID = deep resistivity
DT = compressional acoustic (sonic)

NN or N1 designates calculated curves

Colors

Yellow: recorded DT Curve
Red: synthetic DT curve
Blue: training curves
Black: reference curve (CAL)

Figure 6. The confirmation and validation well (Whittenberg 3-29, 35.316 N, -99.342W).

ing with estimating lithology (Rogers and others, 1995; Benaouda and others, 1999; Saggaf and Nebrija, 2000), porosity and permeability (Rogers and others, 1995; Huang and others, 1996; Schuelke and others, 1997; Ali and Chawathe, 2000; Wong and others, 2000, and Ligtenberg and Wansink, 2003), fractured reservoir characterization (Zellou and Ouenes, 2003), and other reservoir rock properties (Baldwin and others, 1990; Accarain and Desbrandes, 1993; Saggaf and Nebrija, 2003).

We used a MFF-BP type of ANN as it was implemented in a software called NNLAP *(Neural Network Log Analysis Program)* (Arbogast and others, 2000)

Artificial Neural Network — A Three-Step Technology

The operation of the ANN used to determine the presence of overpressured regimes in the Anadarko Basin, Oklahoma, can be divided into three steps.

Step 1. Supervised training of the neural network by using a training well.

The ANN begins the training process by randomly assigning the initial interconnection weights between the layers of neurons. Then an input signal is given to the first layer of processing elements (the input layer, Fig. 2), whereas a corresponding output response is presented to the last layer of processing elements. All connections between the input layer and "hidden" layers, and the "hidden" layers and the output layer, are then adjusted using an objective function (or "cost function") such as the mean squared error (MSE) (Arbogast and others, 2000), the sum squared error (SME; Aristodemou and others, 2005) or the global error (*E;* Luhti and Bryant, 1997).

In BP networks, the weight adjustment for every connection is computed in a gradient descent method in weight space and a correction to the previous weight is made through two parameters: *learning rate* n and *momentum* α.

The learning rate n is a small number ($.1<n<1.0$; Aristodemou and others, 2005) that controls the amount of the error that will be added, negatively, to the interconnection weights for the next cycle. If n is large, then large charges are allowed in weight changes. Conversely, if n is small, only small changes are allowed, which can increase learning time.

Momentum α is a term that dampens the amount of weight change Δw by adding in a portion of the weight change from the previous cycle. The addition of momentum is credited with smoothing out wild changes of weights, and also with helping the network converge faster when error is successively changing in the correct direction. Typical values for α fall between 0.0 and 1.0 (Aristodemou and others, 2005).

The local error on every connection is used to calculate corrected activity levels in the processing elements of the previous layer, which in turn are used to calculate new local errors. Thus, the error gets propagated backward through the entire network and new connection weights are obtained with every step. For a good derivation of the BP algorithm consult, for example, Haykin (1999).

In our training work with the NNLAP program *training settings* were chosen as follows:

- learning rate (n)= 0.5
- momentum (α) = 0.9
- stopping error = 0.0001
- training iterations = 400

Figure 3 shows the main *design settings* included the number of hidden layers (2 or 4) and the number of neurons per "hidden" layer (16). The training and design settings mentioned above were determined from trial-and-error experimentation during which an optimum network performance was sought. Attempts to vary these values did not produce discernable differences in output results. The selection of the input curves used in training and the location of the representative training examples were more important to obtain robust and consistent results. The NNLAP program stops the learning process when the local errors drop to a satisfactory level or when a reasonable number of training iterations are reached. Limiting the number of train-

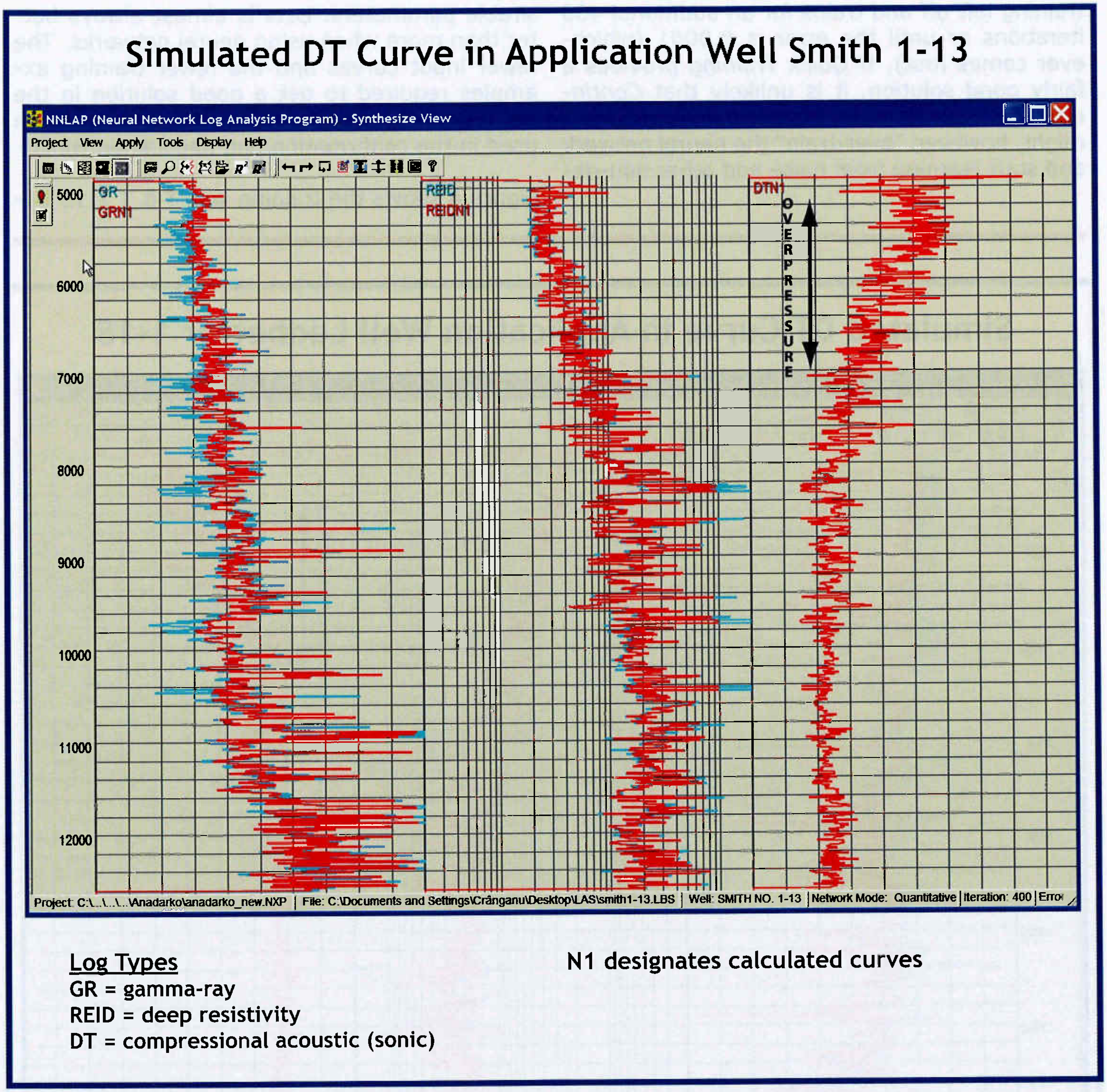


Figure 7. Simulated DT curve estimated in application well 1 (Smith 1-13, 35.341N, -99.162W) from GR and REID time input curves.

ing iterations can prevent "over-training."

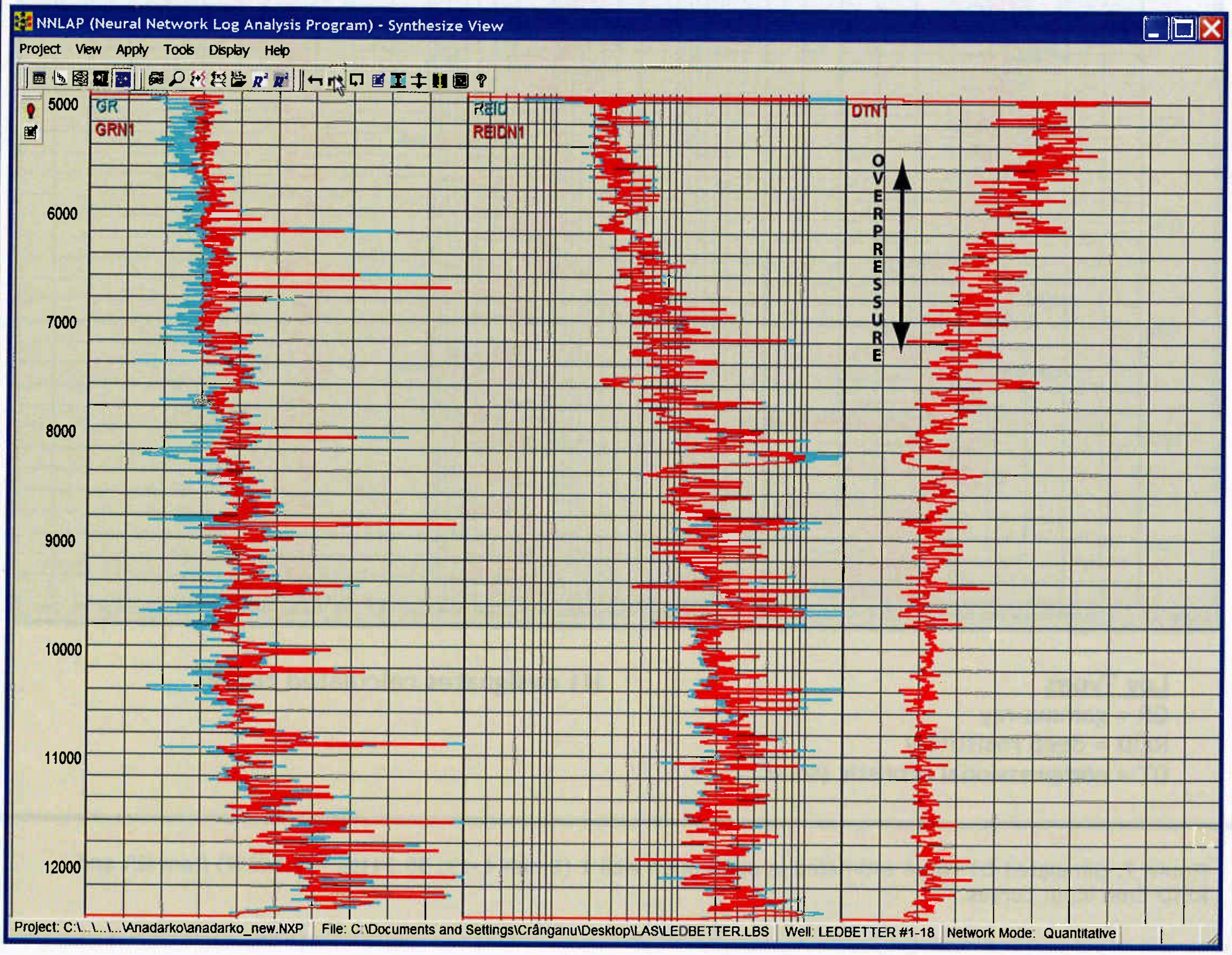
The NNLAP program has two types of training:

(1) *Quick Training* starts with a new neural network (new random numbers on all of the interconnection weights, etc.) and then it trains the neural network until, at the training examples chosen, the error is 0.0001 or until 400 iterations have been made (whichever comes first). The possibility of choosing one's own training examples is a great asset of the program and may reduce substantially the training time.
(2) *Continued Training* starts where the last

training left off and trains for an additional 400 iterations or until the error is 0.0001 (whichever comes first). If *Quick Training* provides a fairly good solution, it is unlikely that *Continued Training* will make major improvements. It might, however, "over-train" the neural network and start learning from noise and other non-desirable parameters. Less is almost always better than more when using neural networks. The fewer input curves and the fewer training examples required to get a good solution in the training well, the more robust the solution when used in the confirmation and application wells.

Figure 4 shows the training well T & T 1-10 be-

Simulated DT Curve in Application Well Ledbetter 1-18



Log Types

GR = gamma-ray

REID = deep resistivity

DT = compressional acoustic (sonic)

N1 designates calculated curves

Figure 8. Simulated DT curve estimated in well 2 (Ledbetter 1-18, 35.341N, -99.144W) from GR and REID input curves

tween 4,000 and 14,000 ft and the curves used for training: GR (gamma-ray), REID (deep resistivity), and DT (sonic) logs. The training curves are shown in blue or yellow color. The calculated (synthetic) curves have a NN or N1 suffix (GRNN, GRN1, REIDNN, REIDN1, DTNN, and DTN1) and displayed in red color. The six green horizontal lines represent the training examples. The black curve CAL (caliper) was not used as a predictor curve but only as a reference curve so that training could be avoided in zones with invalid data caused by washouts, mud cakes, etc.

GR and REID were chosen as input training curves to simulate DT curves because GR and REID were the most common logs in the available data set. Additionally, the Data Mining menu of NNLAP software was used to decide the selection of input curves. In the Data Mining menu, the user defines the output (target) curve and puts a check mark in the boxes next to all available input curves; then the program ranks the available curves based on their correlation coefficient relative to the target curve. After running the program, an accurate selection of a particular log as the network input curve was not necessary; using multiple logs seems to give results equivalent to using the highest correlated log. Similarly, Saggaf and Nebrija (2003) found that using various input log sets to simulate DT (e.g., *GR + Neutron Porosity, GR + Density, Neutron Porosity + Density)* did not yield significantly different results in the simulated DT curves.

Using crossplots of the input and simulated data during the training time, the user can detect anomalous neural network behavior. For example, Figure 5 shows a crossplot of DT and DTN1 in the training well between 11,696 and 13,060 ft depth interval. The samples are color-coded by depth for easy identification. If samples below 11,969 ft of depth are more or less correlated, the samples colored light blue (between 11,696 and 11,969 ft of depth) show a clear lack of correlation. The user has now the opportunity to fix this problem by revising the training examples or other training and design settings (e.g., number of samples in the depth interval).

Step 2. Confirmation and validation of the model

The back-predicted input curves reflect how well the input data is used for the prediction of the target value in the training well and can be used to verify the model in confirmation and application wells. To perform these steps with high confidence, the user must ensure that all rock types, expected to be found in confirmation and application wells, are represented in the training well. If all rock types cannot be represented in a single training well, then more than one well can be used to train the neural network. A careful interpretation of the available data (well logs, cores, drilling reports, etc.) is necessary.

Confirmation and validation of the model was performed by applying the modeled solution obtained in the training well to additional sets of data that contain the same inputs (in our examples, gamma-ray GR and resistivity REID logs) and the target values (sonic log DT). During this step, the solution from the training well can be validated through back-prediction of the predictor data and the fit between the predicted DT and the recorded DT in the confirmation well. Figure 6 shows one of the confirmation wells (Whittenberg 3-29) used to confirm the trained neural network. The confirmation (match) between yellow, recorded DT curve, and the red, synthetic DT curve, is considered to be accurate and the matching error is low enough to satisfy the user.

Step 3. Application of the model

Finally, the confirmed model is used to estimate the sonic log values DT in application wells containing only the GR and REID input curves. The output is the simulated (synthetic) DT. Figures 7 and 8 show two of the application wells (Smith 1-13 and Ledbetter 1-18, respectively) in which were performed a neural network analysis to estimate the variation of sonic velocities with depth.

Predicting the presence of overpressured zones in the Anadarko Basin, Oklahoma

Determining trends in acoustic transit time on sonic logs (DT) is a conventional method of predicting abnormal pressure in shales or in sandstones interbedded with shales (e.g., Hottman and Johnson, 1965; Magara, 1976; Powley, 1982; Surdam and others, 1997; Hsu and Belaud, 1998). Because the velocity of a compressional wave in sedimentary rock is dependent on the effective rock stress, an increase in transit time is interpreted as indicating a lower effective rock stress and, consequently, overpressuring. Hermanrud and others (1998) found that sonic and resistivity log-derived porosities are significantly higher in overpressured than in normally pressured wells. Similarly, Poston and Berg (2002) stated that sonic logs show an increase in interval transit times in overpressured shales. The calculation of abnormal pressure from log data is based on the relationship between observed resistivity or acoustic values of shales and a trend line reflecting normal compaction (Heppard and others, 1998).

These considerations have led us to predict the presence of overpressured zones in the training well T&T 1-10 between ~4,200 ft and 6,400 ft (Fig. 5), in the verification well Whittenberg 3-29 between ~4,400 ft and 6,400 ft (Fig. 6), as well as in the two application wells chosen for this article: Smith 1-13 well between ~5,000 ft and 7,000 ft (Fig. 7) and Ledbetter 1-18 well between 5,800 ft and 7,200 ft (Fig. 8). These depth intervals are mostly sandy shales with intercalations of shaly sandstones (Cranganu, 2005b). The presence of such overpressured zones (compartments) within the Anadarko Basin is well documented (Al-Shaieb and others, 1990, 1994a,b; Cranganu; 2004).

Conclusions

Wireline log analysis is still one of the most effective methods available to estimate pore-fluid pressure. It is used to create models of pressure in wells during the planning of drilling programs. Many methods of pore-fluid pressure estimation, such as those using resistivity, density, or sonic logs, require, in the first instance, that the necessary logs be present for interpretation. Because the sonic log, considered to be accurate and sensitive to changes in the rock stress regime (e.g., overpressure), is rarely recorded in wireline logging operations, we used an ANN to produce synthetic sonic log curves based on mathematical relationships obtained from commonly available log curves. ANNs can use commonly available logs, such as normalized natural gamma (GR) and deep resistivity (REID) to create synthetic DT logs. The effective use of the ANN requires three steps: (1) supervised training of the neural network; (2) confirming the model validity by blind testing the solution in other wells that contain the predictor curves used in developing the model from the training well (GR and REID) and a recorded compressional acoustic log (DT); and (3) validating (through back-prediction of the input logs) and applying the model to wells containing only the input curves (GR and REID) in order to obtain the synthetic DT log.

During the training of the ANN proposed for the Anadarko Basin, we found that an accurate selection of a particular log as the network input curve was not necessary because using multiple logs seems to give equivalent results, such as when using the highest correlated log. We agree with Saggaf and Nebrija (2003) that a redundant input containing several logs may yield reasonably accurate results as long as some of the logs in the input are sufficiently correlated with the missing log.

Using existing and simulated DT values we predicted the presence of overpressured zones in the Anadarko Basin at depths starting between 4,200 and 5,000 ft and ending at depths between 6,400 and 7,200 ft. These findings are in agreement with previous similar results (Al-Shaieb and others, 1990, 1994a,b; Cranganu, 2004)

Using ANNs to predict the presence of overpressured zones in the Anadarko Basin of Oklahoma has several advantages over traditional deterministic methods. ANN do not require a precise mathematical model equation that describes the dependency between the predictor values and the target values and, unlike linear regression techniques, neural network methods do not over-predict mean values, thereby preserving original data variability. One of the most important advantages is that predictions can be validated and confirmed through back-prediction of the input data.

The method presented here may be applied in other areas of the Anadarko Basin or in similar basins experiencing abnormal pore-fluid pressures and where DT (sonic log) values are scarce or missing. The initial results described in this article are promising and encouraging for future use and refinement of the method.

Acknowledgements

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—The Agglomerate

The Position and Shape of the Earth: A Story of Luck and Misfortune

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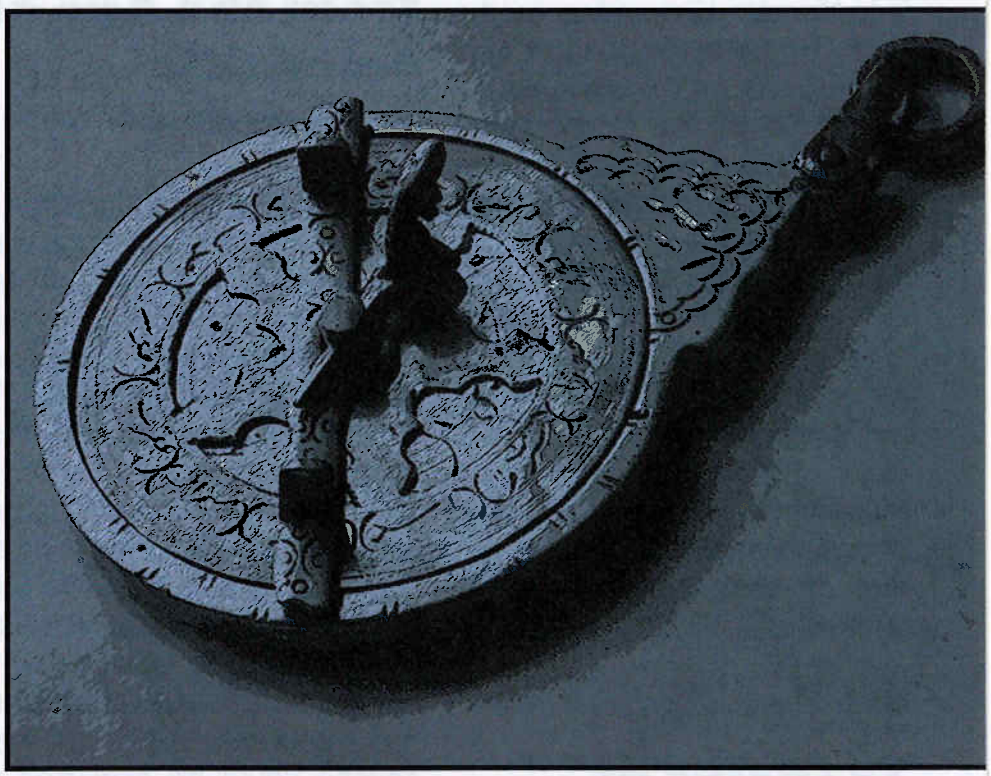


Many people and their activities gave us the picture of the shape of the Earth and its position in the Solar System. It certainly was not a straight path and we are lucky to have the view we have today.

It's Greek to Me

Our story begins with the Greeks who recognized that some stars did not remain in one place, and so the Greeks called them planets. In Greek the word *planet* loosely translates as a body that wanders or does not remain fixed. One Greek, Hipparchus (190–120 BC), was way ahead of his time. Hipparchus is believed to have developed the foundations of modern trigonometry, which is based upon the relationships of angles to the sides of triangles, and also to have invented a device called the Astrolabe (*example shown above right*) for measuring these angles. The idea for the Astrolabe is simple. It consists of a flat table with an arrow that can be turned in different directions. The table is marked in angles and measuring an angle consisted of lining up a mark on the table in one direction and pointing the arrow in another direction. The arrow was called the alidade. The Astrolabe was the instrument of choice for measuring angles until the 18th century when the sextant replaced it. (*I was surprised to find that surveyors for seismic crews still used "a plane table and alidade" when I first came to Oklahoma in 1987. The practice goes back to 120 BC!*)

About 130 BC, Hipparchus made another big contribution to our understanding of the behavior of the Earth in its orbit. He carefully compared the observations of the Babylonians and more recent Greeks to conclude that the rotational axis of the Earth changed direction by 2 degrees in the 169 years before his time. His conclusion was an incredible accomplishment because it required knowledge of the position of the Sun against the stars. It seemed an impossible task because stars are not visible during the day when the Sun is in the sky. Hipparchus used a trick. He used the shadow cast by the Earth on the Moon during an eclipse of the Moon. Lunar eclipses were observed and recorded by the early Babylonians as well as the early Greeks. Today Hipparchus is given credit for being the first to recognize "the precession of the Earth about its axis." The period for this precession is about 26,000 years. The accomplishment of Hipparchus was a combination of understanding and a long period of recorded observations (169 years).

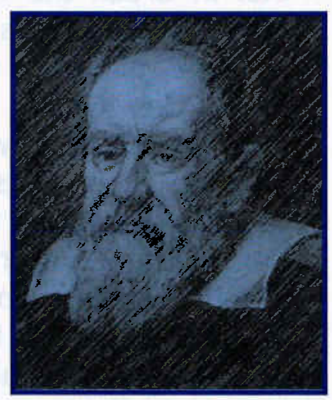
The Lucky Transfer of Greek Technology

It is surprising how lucky we are to have the knowledge of Hipparchus today. Ptolemy lived in Alexandria (in Egypt) from approximately 87-150 AD. He found in an Egyptian library, and saved for future generations, ancient Greek records that described the work of Hipparchus. Ptolemy also was awed by Aristotle and adopted his view that the Earth was the center of the Solar System. So Aristotle and Ptolemy led the course of human thinking toward an Earth-centered system consisting of the planets and the Sun.

Breaking Out from the Age of Scientific Darkness

There was a long dry spell in some scientific thought between the time of the early Greeks and the early 1500s. Luckily, mankind discovered a new way of thinking in the 1500s. The new thinking started with Nicolas Copernicus (1473-1543). He took a number of careful observations and concluded that the Sun was the center of the Solar System. It was a time when the Church took the view, based on biblical scripture, that the Earth was the center of the Universe. Anyone could be executed for heresy for believing otherwise. As he neared death Copernicus managed to publish his findings the year he actually died (1543). Following Copernicus, the Danish astronomer, Tyco Brahe (1546-1601), recorded 20 years of observations of planetary motions. The observations were made with the naked eye and measurements of angles based on the Astrolabe. Just before his death, Brahe passed these observations along to Johannes Kepler (1571–1630). Brahe wanted his observations to be used and he was apprehensive about the fate of his data. He made the right choice, however, because Kepler saw some systematic behavior in the motions of the planets. Kepler expressed all of Brahe's observations in terms of three laws that today are called Kepler's laws. These laws are considered empirical laws by modern physicists; there was no understanding of the cause(s) of these planetary observations. Kepler's laws simply described the movements of the planets. The amazing aspect of Brahe's and Kepler's works is that their observations were done without a telescope.

The first person to use a telescope to look at the heavens was Galileo Galilei (1564-1642; *shown at right*). Imagine his excitement. He observed four of Jupiter's moons



and recognized that Venus had phases like the Moon. He is often given the title "the father of modern science." Galileo concluded from his observations that the Earth rotated about the Sun in agreement with Copernicus; however, Galileo modified his first publication in this regard because the Church threatened him. Some of Galileo's original works are archived in the history of science museum here at the University of Oklahoma. One can see the corrections made in one of those works. The corrections possibly were made by Galileo himself.

The excitement of learning seemed contagious in England and throughout Europe during the 1500s. The stage was set for another big contribution to the understanding of our world. Once again, luck played a part.

The Birth of Physics

Isaac Newton (1643–1743; *shown below*) formulated the natural laws that govern the motions of objects, such as planets, in space. He was an incredible genius and developed his own ideas (quite unusual by today's standards). Newton's father died before he was born. When Newton was two years old, his mother remarried a rich man. Newton was sent to live and be raised

by his grandmother. Newton's mother had three other children with the rich man before he died. When Newton was 10 years old, his mother and her three children moved back to live with his grandmother. Newton was sent to boarding school where his talents were soon discovered.

Newton was admitted to Trinity College in Cambridge, but he did not make a big impression in the scientific community until another lucky event occurred. Newton's early scientific developments were for his eyes only. Part of his reluctance to publish came from people attempting to take credit for his work; Robert Hooke was an example. (Today seismologists use "Hooke's law" to relate stress to strain.) An example of just how secretive Newton could be involved his development of calculus. He formulated calculus 30 years before he told anyone else about it!

The new physics generated massive interest when three men became involved in a conversation of why the planets moved in elliptical motions (one of Kepler's observations). The three men were Sir Christopher Wren, Robert Hooke, and Edmond Halley (of Halley Comet fame). During their discussions, Sir Christopher Wren agreed to put up a reward of 40 schillings (approximately two weeks pay at the time) to the man, either Hooke or Halley, who could provide a solution. Hooke was known to claim credit for solving problems that others already had solved. When Wren made his offer, Hooke claimed to have known the solution, but he declined to share it so as not to rob others the satisfaction of discovering the answer for themselves.

It was during the contest between Hooke and Halley that the latter sought Newton's help. Thanks to Abraham DeMoivre, a Newton confidant, a record of what happened survives (Bill Bryson, 2003).

In 1684 D' Halley came to visit at Cambridge [and] after they had some time together the D' asked him what he thought the curve would be that be described by the Planets supposing the force of attraction toward the Sun to be the reciprocal to the square of the distance from it.

S' Isaac replied immediately that it would be an [ellipse]. The Doctor, struck with joy & amazement, asked him how he knew it. 'Why,' saith he, 'I have calculated it", whereupon D' Halley asked him for his calculation without further delay. S' Isaac looked among his papers but could not find it.

Bill Bryson (2003) likened the moment to someone who found the cure for cancer, but could not remember where he kept the formula. Newton promised to reproduce the paper. He did as promised but gave much more as a result of the contest between Halley and Hooke. He retired for two years of reflection and produced his masterwork: *Philosophiae Naturalis Principia Mathematica* (otherwise known as *Principia*). In it, Newton explained the laws of gravity and the laws of motion, which today are the foundations of engineering and physics. Newton also explained ocean tides and the shape of the Earth in *Principia* using some simplifying assumptions.

Newton Estimates the Shape of the Earth

Newton assumed the Earth was very much like a spinning drop of water. Because of its rotation, the drop gets larger at the Equator where the effect of spinning is at a maximum. Today we describe the Earth's shape as an oblate spheroid. The amount of fattening at the Earth's Equator increases more than expected with Newton's water-drop model. The bulging at the Equator may be a result of the Earth spinning faster during an earlier period, and it had not yet rebounded back to its original shape. Alternatively, the Earth may act as a dynamic system, modifying its shape because of internal motions (plate tectonics).

Confirming the Shape of the Earth

Some French scientists did not believe Newton's prediction of the shape of the Earth. They had preliminary evidence that the Earth was actually fatter at the poles than at the Equator. The distinction between the two models (Newton and the French Model) could be discerned by making a measurement of one degree of meridian (or 1/360th of the distance around the planet). The idea was to take these measurements of arc length near the pole and near the Equator. If the two arc lengths were equal, then the Earth could be treated as a sphere. If the equatorial arc length was longest, then one of the French models would have been correct. If the polar arc length was longer and the equatorial arc length was shorter, then Newton would have been right.

The French Effort to Prove Their Shape of the Earth

Two French expeditions each were sent to measure one meridian of arc. One went to northern Scandinavia to measure a degree of meridian near the pole while the other went to Peru to make a similar measurement near the Equator. Bryson (2003) says the Scandinavian expedition faced everything from squelching bogs to dangerous ice flows, but managed to finish their measurement first. Their measurement was longer than the arc length measured in France as predicted by Newton. Although the northern expedition was finished and had their results, the southern expedition faced a number of special problems.

The Southern Expedition to Peru

The southern expedition to Peru ran into a streak of bad luck. Everywhere they went, the expedition was met with suspicion from the Peruvians, who found it difficult to believe that some French scientists would travel so far just to find out the shape of the Earth. In one incident, the Frenchmen somehow provoked the locals and were chased out of town by a mob throwing stones. Later, the expedition's doctor was shot over a misunderstanding that concerned a woman. The botanist for the expedition became deranged. Others died of fevers or falls from high places. Jean Godin, the third most senior member of the party, ran off with a thirteen-year-old girl and refused to return to the expedition. To make matters worse, the group had to suspend work for eight months while one of the leaders rode off to Lima, the capital city, to sort out a problem with their government permits. Eventually the two leaders of the expedition would not talk to one another.

The French had chosen the Andes Mountains in Peru because they reasoned that the mountains would give them a good line of sight for measurements at the Equator. However, the mountains were often in the clouds and the team waited weeks for just one hour of clear sky for surveying. Beside the surveying difficulties, they had chosen one of the most difficult and accident prone terrains on Earth. Bryson claims that the Peruvians refer to this landscape as *muy accidentado*. Just getting there was an accomplishment. They crossed wild rivers, hacked through jungles, and crossed miles of high stony desert. Most of the terrain was uncharted and far from any source of supply. One could say that these men really wanted to know the shape of the Earth! Shortly before finishing their measurement, the expedition received word that the French team in Scandinavia had completed their measurement; they had found that one degree of arc really was longer near the poles just as Newton had predicted.

The Peruvian team had spent nearly a decade working toward a result contrary to what they originally had expected. They completed their survey and found that a degree of arc was shorter near the Equator as predicted by Newton. Newton never left the comfort of his work space to get the answer, while the French sent out two major surveying expeditions. Newton comprehended without having to see any of it. Imagine how much travel money he saved by visualizing everything in his mind. He traveled to places that others only dreamed of visiting. He did not have to see the tides to predict them, and similarly he did not have to see the fattening at the Earth's Equator to predict the bulge there.

Edmond Halley Strikes Again

The second portion of the story is concerned with finding a more accurate way to measure the distance from the Earth to the Sun and to the planets. Edmond Halley played an important role in this story, too. Halley had suggested years earlier that one could very accurately measure the distance to the Sun and then calibrate distances to all other bodies in the Solar System by measuring the angles between the planet Venus and different spots on Earth. He would use triangulation to solve the problem.

Transits of Venus, as they are called, represent times when Venus crosses between the Sun and the Earth. Transits occur in pairs eight years apart and then are absent for a century or more, for example, there were none in the 20th century. None occurred during Halley's lifetime. Nearly two decades later when the next transit occurred in 1761, the scientific world was ready.

It was history's first international cooperative event from a scientific point of view. Countries from all over the world participated. The idea was to make Venus transit measurements from different parts of the world and then reconstruct the distance to the Sun. It was not an easy task because the survey teams encountered difficulties almost everywhere. Many observers were stopped by war, sickness, or shipwreck. Some made their destination, but their equipment was broken or warped by tropical heat.

Unlucky French

The French provided the most memorable efforts to survey the transits of Venus. Jean Chappe spent months traveling to Siberia. He went by coach, boat, and sleigh. He had to take special care of delicate instruments during his passage. As he neared his destination, he was stopped by swollen rivers, the result of unusually heavy rains. To make matters worse, the locals blamed him for the rain when they saw him pointing his instruments at the sky. Chappe escaped with his life, but his instruments were destroyed.

Guillaume Le Gentil was even unluckier than Jean Chappe. Le Gentil set off from France a year ahead of time to observe the transit in India in 1761. Different problems caused him to be at sea when the Venus transit took place. The sea was just about the worst possible place to be during the transit because steady measurements are difficult on a pitching, rolling ship.

Le Gentil traveled to India anyway to await the next transit in 1769. He was going to wait eight years for the next transit! Le Gentil was a patient man! During his eight-year wait, he constructed a first-rate viewing station. He tested and retested his instruments and was completely prepared for the next transit in 1769.

On the morning of June 3, 1769, Le Gentil awoke to a fine day, so he was optimistic that everything would go his way. Unfortunately, just as Venus began to pass in front of the Sun a cloud slid in and remained there for almost exactly the duration of transit. For three hours, fourteen minutes, and seven seconds this happenstance cloud hid the Sun and deprived Le Gentil of the chance to make his measurements!

Le Gentil took the bad fortune in stride as he packed his gear and set off for the nearest port. En route he contracted dysentery and was laid up for nearly a year in India. While still in a weakened condition, Le Gentil made it to port and finally embarked aboard a ship for the journey home; however, the ship was nearly wrecked when a hurricane struck just off the African coast.

Le Gentil finally arrived home after an unsuccessful scientific expedition that lasted eleven and a half years. He discovered upon his arrival that his relatives had had him declared dead during his absence and that they had enjoyed plundering his estate. One can only hope that he had better luck after all that!

Conclusion

We are lucky to have the science of others before us. The notes of Hipparchus were found in a library in Egypt by Ptolemy. Sir Isaac Newton's work might not have ever been published had it not been for the contest between Halley and Hooke to understand why planets moved in elliptical orbits. However, the knowledge we have today is not always due to good luck. The French surveys near the North Pole and at the Equator were an important confirmation of Newton's model of the shape of the Earth. The Earth is fatter at the Equator; however, it was not an easy task to prove it.

The Venus transit measurements were successful even though I described some of the failures. One of the successful measurements was made by Captain James Cook who watched the 1769 transit from a nice sunny position high on a hilltop in Tahiti. A French astronomer, Joseph Lalande, used Cook's measurements and estimated the distance of the Earth to the Sun at just over 150 million kilometers. Two additional transits in the 19th century set the figure at 149.59 million kilometers where it has remained ever since. The position we know today is 149.597870691 million kilometers. Thanks to all those scientists before us who contributed to our knowledge of the shape and position of the Earth.

References and recommended reading:

Bryson, Bill, 2003, A short history of nearly everything: Broadway Books, New York, 544 p.

Gleick, James, 2003, Isaac Newton: Pantheon Books, New York, 272 p.

Coalbed Methane and Gas Shales Attract Record Crowd

By Jane Weber, OGS Staff

A record attendance at the Coalbed Methane and Gas Shales in the Southern Midcontinent Conference on March 21, 2006, indicates not only how important coalbed methane (CBM) and shale gas have become in the overall national energy picture, but also how eagerly petroleum industry personnel are seeking to better understand the exploitation and development of unconventional resources. In the next 10–12 years, unconventional reservoirs are projected to supply 1/3 of the United States domestic natural gas demand.

A diverse group of 392 geologists, engineers, other geoscientists, and energy industry representatives packed the room at the Clarion Hotel Meridian Convention Center in Oklahoma City for the one-day meeting. Co-sponsored by the Oklahoma Geological Survey (OGS) and the U.S. Department of Energy's National Energy Technology Laboratory, the conference drew attendees from 13 states and Canada. (See breakdown by state in Fig. 1.)

Following brief welcome remarks by Charles J. Mankin, Director of the OGS, and Lori Wrotenberry, Director of the Oil & Gas Conservation Division of the Oklahoma Corporation Commission (pictured below), Wrotenberry explained the role of the Corporation Commission in formulating existing regulatory issues so that they encourage, rather than hinder, development of CBM resources. Gas shales

Figure 1. Breakdown of "Coalbed Methane and Gas Shales in the Southern Midcontinent Conference" attendees.

Conference Attendance by State (and Country)	
UNITED STATES	
Arkansas	9
Colorado	8
Florida	1
Kansas	14
Louisiana	8
Minnesota	1
Mississippi	3
Missouri	1
New Mexico	1
Oklahoma	285
Pennsylvania	1
Texas	55
Wyoming	2
CANADA	3
TOTAL	392

have not yet presented any special problems. The question is how to apply existing Oklahoma rules for conventional oil and gas wells to CBM wells, with regard to hydraulic fracturing (not viewed as environmentally significant under federal guidelines); commingled production; horizontal drilling; required pressure tests (nonsensical for CBM wells); and produced water. Commission staff also spend time explaining natural events to the public, such as the recent situation in Tulsa where gas from nearby coal seams was seeping into residences.

The first four of twelve technical presentations centered on coalbed methane.

In Kansas, CBM wells are being drilled at the rate of almost 2/day, a level of activity driven largely by price. Dave Newell (pictured on previous page) reported that southeast Kansas is the State's most productive region for CBM; but its gas is not yet sufficient there to offset decreased production in conventional gas from the Hugoton area.

In eastern Kansas most CBM wells are vertical; water disposal is not a problem. A northward decrease in gas content is not a function of coal quality but probably is due to less maturation. Isotopic studies show shallow coalbed gases on the basin flanks have a microbial or mixed origin, whereas deeper conventional gas is thermogenic. A near-future investigation involves injecting a combination of landfill gas and coalbed gas into a coal seam in an attempt to both sequester the CO_2 and enhance the release of more methane.

CBM activity in Oklahoma is divided between the northeast Oklahoma shelf and the Arkoma Basin. According to data compiled through 2005 by Brian Cardott, cumulative production from 2,292 wells in the shelf area was 70 Bcf while 1,779 Arkoma Basin wells produced a cumulative 154 Bcf. Cardott (shown at left) stressed the growing importance of horizontal drilling in Oklahoma. In 2005, 96% of Arkoma Basin CBM wells were horizontal. Lateral lengths averaged about 2,000 ft, but one lateral extended 5,771 ft. He also reported the first occurrence of semi-anthracite coal in the State, in Cavanal Mountain in Le Flore County. Additional information on coal rank in the Arkoma Basin appeared on a poster by Cardott. His second poster dealt with thermal maturity of the Woodford Shale.

To illustrate the challenges of horizontal coal-seam drilling, Paul Bruce summarized the drilling plans, drilling results, and production for individual wells in three Osage County case studies. Successful completion techniques were either hydraulic fracture or horizontal lateral. The latter approach was used to counter surface limitations (e.g., housing developments, lakes) or low-permeability coal seams that could not withstand fracture stimulation. There were problems trying to stay within the thin (<3 ft) beds when drilling horizontally. Improved production rates from horizontal wells vs. vertical wells were best realized in low-permeability coal seams. Bruce's talk was followed by questions on well spacing, drilling costs, and how to decide which direction a horizontal well should go. (Answer: Updip.)

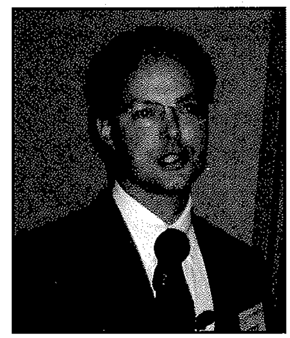
A more detailed view of horizontal drilling by David Tschopp (shown at right) focused on his experiences drilling in Arkoma Hartshorne coal. Although the technology is no longer considered unconventional, no cookbook method exists. Each company must perfect its own technique in a) drilling to the kickoff point, b) drilling the curve, c) drilling out of the casing shoe, and d) drilling the lateral. Control points may be ¼ mile away but you are aiming for a coal seam a couple of feet wide. To stay in the lateral, Tschopp believes in following the gamma-ray reading (e.g., up with a 15/20 reading, down with a 21/14 reading), even though the detector can be 20–30 ft back of the drill tools. Key considerations include orienting the well updip and perpendicular to face cleat and major fracture planes, handling small scale geologic features such as faults, and preparing a post drill summary for future reference.

The only paper specifically about Arkansas's Fayetteville Shale was presented by Ed Ratchford. Fayetteville Shale, an Upper Mississippian deposit, is exposed on the surface across Arkansas, from the edge of the Mississippi Embayment on the east to Oklahoma on the west. With approximately 2 million acres leased within the last 2 years and 80 producing wells, the Fayetteville Shale gas play is good for the economy of Arkansas. The central zone is where most activity has occurred. Forty-three wells in the pay zone of a multi-county study area were modeled using TOC (total organic carbon) and vitrinite reflectance. Ro values of 2.2–2.4% are consequences of fluids pushed out from the Ouachitas and migrated to the Arkoma Basin. Development challenges include a need for gas pipeline infrastructure proximal to the leased acreage, large volumes of fresh water for well completions, and wells to dispose of frac water. Ratchford, along with Scott Ausbrooks, offered further information on the Fayetteville shale gas play in a poster.

In a study of the Woodford Shale, Alischa Krystyniak used gamma-ray and lithofacies descriptions of 5 outcrop samples from south-central Oklahoma in an attempt to characterize the late-Devonian, organic-rich black shale in the subsurface. She concluded that outcrop-based gamma-ray profiles can be correlated with subsurface gamma-ray logs. Organic richness, as measured by TOC, tends to be higher in the fissile Woodford shales and lower in the non-fissile, phosphatic, siliceous shales. Thin-section analysis suggests that radiolarians are the main source of the silica and serve as nuclei for the development of phosphate nodules, a common occurrence in the Woodford.

The Caney Shale in southern Oklahoma is equivalent to the Fayetteville in Arkansas and Barnett Shale of north Texas. With measured TOC in the 2–8% range, the Caney has 4–10 times the minimum amount of organic material required to qualify as a gas shale. In his presentation on the Caney, Rick Andrews discussed its stratigraphy and log character; contrasted Caney with Woodford in outcrop; and showed production decline curves for both oil and (conventional) gas wells. The Caney tends to produce oil in the Ardmore Basin and gas in the Arkoma Basin.

Looking at well logs in each township throughout a 132 x 54 mile study area in southeastern Oklahoma, Scott Schad (shown above right) quantified the commercial hydrocarbon potential of the Mississippian Caney Shale. Detailed core photos documented an anoxic deposition for the shale. Organic content as high as 8% TOC and maturity levels producing a Tmax exceeding 500°C and vitrinite reflectance in the 0.67–3.0% range indicate the Caney's high potential to source hydrocarbons. Correlation of gas desorption data with mud log gas shows suggests a fairly close estimate of GIP (gas-in-place) can be obtained from mud log data alone. Of six Caney Shale members, A–F, the D zone is the most organic and holds most of the gas, perhaps as much as 150 SCF/ton GIP, making it comparable to the best Barnett Shale. Operators should establish horizontal spacings and drill multiple laterals from a single surface location to develop the play efficiently. The D zone is poised to become another rich gas source in the midcontinent.



The purpose of Tyler Maughan's investigation was to determine where gas occurs in the Caney. He utilized log analyses, drill cutting observations, and thin-section analyses of samples from 8 townships in McIntosh County in the western Arkoma Basin. For his work, Maughan broke the Caney into 3 zones: upper (probably corresponding to Schad's A, B, and C), lower (probably including Schad's D), and basal (contains no gas). Thin sections revealed bands of calcite as well as separated regions of sorbed and non-sorbed calcite. Acid is the recommended fracture treatment for the sorbed calcite.

Darwin Boardman examined the cyclic stratigraphy and conodont biostratigraphy of the Barnett Shale at its type locality in the Chappell Limestone. Other representative shale sections are hard to find, due to lack of exposure. The Barnett contains conodonts from bottom to top, with 3 faunal intervals recognizable. Some faunal types were found in both lower and upper intervals. Those found in the top interval are early Morrowan, not Mississippian. As a result of exploring whether the Barnett, Caney, and Fayetteville conodonts are the same, Boardman reported on a preliminary correlation of the Barnett to the Caney. He discovered the Caney is a different age from the Barnett and that the Caney is not uniform along the outcrop belt. The question is: *What happens when you go into the subsurface?*

Dan Jarvie (shown below) outlined many aspects to consider in prospecting for and developing shale gas, stressing the need for both a geochemical and a geological reconnaissance approach. He gave few details but presented information on topics such as differences between exploring for conventional *vs.* unconventional gas; biogenic *vs.* thermogenic shale gas systems; organic richness and its relation to generation potential; the impact of kerogen type on hydrogen content, organic matter decomposition rate, and product generated; the role of thermal maturity and how to measure it; the relation between organic carbon volume and porosity; and how to fingerprint residual hydrocarbons in the rocks, to name just a few. Jarvie also showed shale gas appraisal results for several basins, with emphasis on the Barnett Shale in the Fort Worth Basin.

Productive shales, as source rock, reservoir rock, and trap, are thought to be relatively non-reactive to acid. But in the studies reviewed by Bill Grieser, reactive fluids appear to improve shale gas production. One conceptual model of gas shales suggests the "free gas" component is stored in and produced from micro-porosity in laminae and natural fractures and the "adsorbed gas" component is stored in and produced from the bulk shale matrix. XRD analysis and SEM images showed that surface reactive fluids can enhance gas diffusion into and through micro-porosity/fractures and increase surface area for flow of gas from the shale matrix. The fluids remove acid-soluble minerals in the bulk shale as well as the calcite-filled fractures to open up additional surface area, thereby providing microchannels. The amount of gas desorbed is related to the amount of surface area exposed. Examples of Woodford, Caney, and Barnett Shales were used throughout the talk to illustrate the diverse make-up of midcontinent shales. Grieser also presented his material in poster format; co-authors were Matt Blouch and Ray Loghry.

In addition to the four posters already mentioned, the poster session included three more displays on topics not covered in the oral presentations: coal nomenclature in northeastern Oklahoma (Vance Hall and Glenn Cole), coalbed methane recoveries from U.S. basins (Troy Cook), and downhole critical gas content—without core (John Pope and Bob Lamarre). The meeting also featured seven commercial exhibitors plus the usual array of OGS publications for sale. A conference manual with printouts of the slides shown during the talks was given to each attendee; but no manuals have been made available for distribution since the conference. To obtain additional information about any of the conference topics, you are encouraged to contact the author(s) directly.

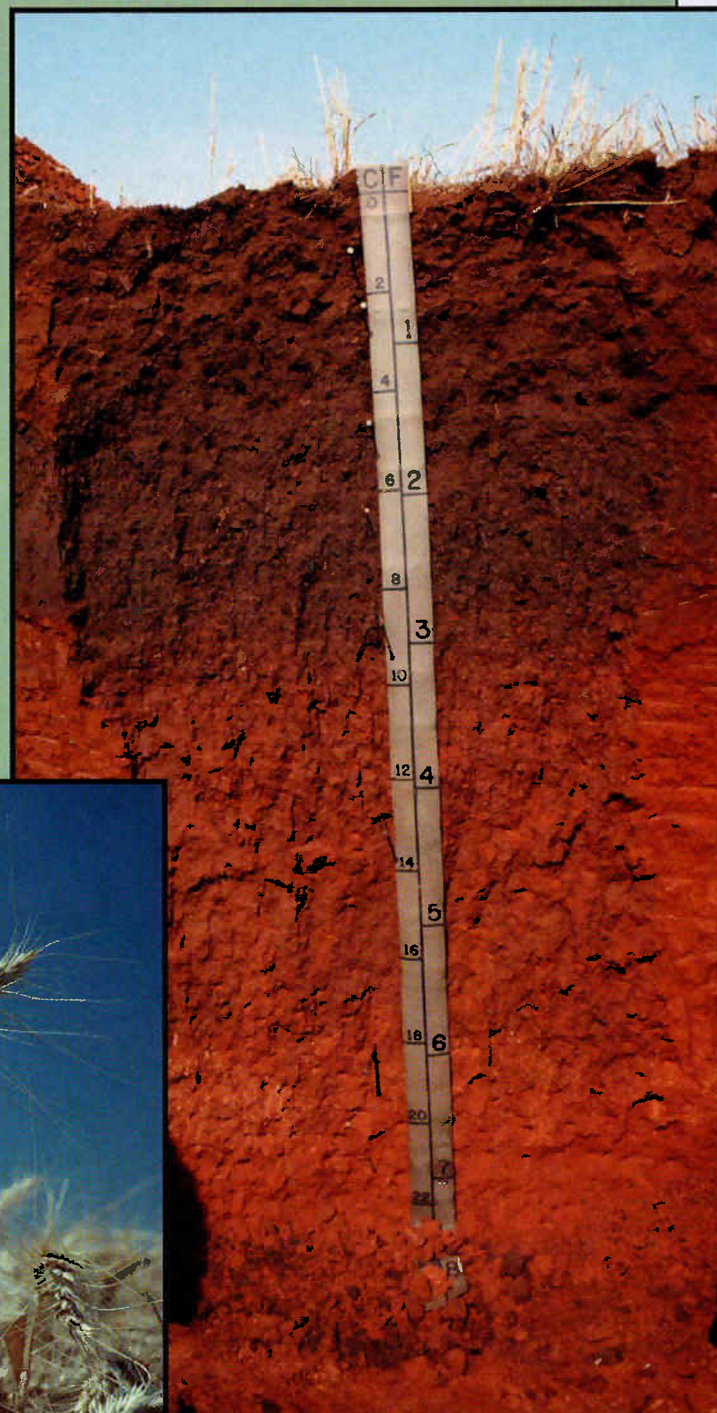
The symposium was the 19th in an annual series hosted by the OGS that is devoted to the exploration and development of oil and gas resources in the southern midcontinent. The purpose of the symposia is to provide independent operators the means to benefit from the experience of others in identifying practical techniques and technologies for finding new resources and efficiently producing more hydrocarbons. Twenty years ago the types of gas resources highlighted at this meeting would not have been proposed as program topics.

—Thanks for Asking...!

Why Does Oklahoma Have a "State Soil"?

Karla Beatty
Oklahoma Conservation Commission

Even before statehood Oklahoma's most valuable resource was its resourceful and imaginative people. Through the years they have chosen varied official state symbols to reflect their numerous interests, endeavors, and habitat. Many state symbols come with stories as colorful and unusual as the symbols themselves. One of the more unusual state symbols is our state soil, *Port Silt Loam*. The state soil was added to the list of official state symbols by the Oklahoma Legislature in 1987.

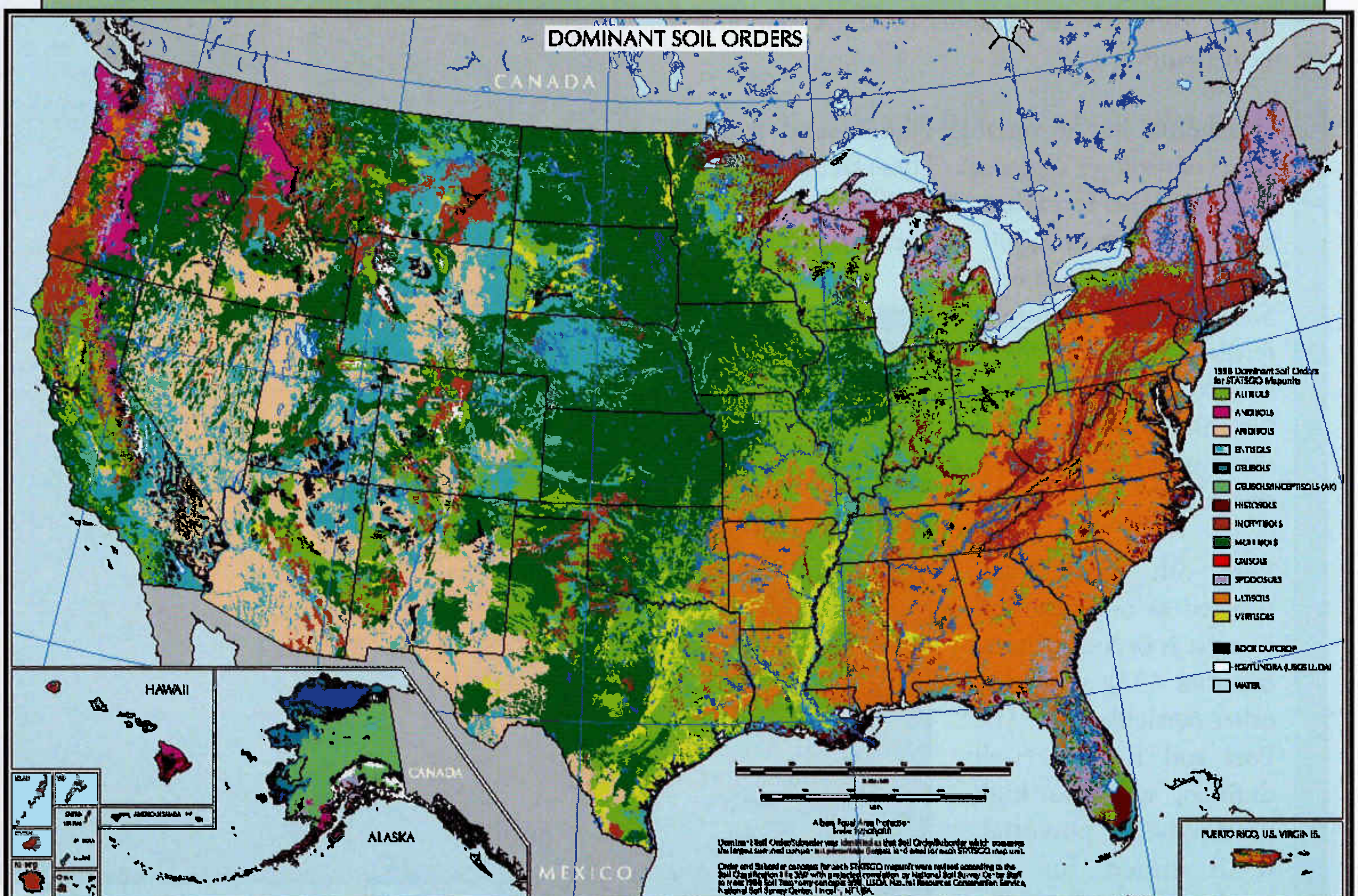


Oklahoma has a variable climate and many kinds of geologic materials. These factors greatly influence the formation of different kinds of soil. More than 2,500 different kinds of soil are found in Oklahoma. Some soils are naturally fertile, but others are very limited in productivity. No one individual soil series occurs throughout the state.

Port Silt Loam was selected as our state soil because it occurs in more counties (33) than any other particular soil. The Port soil is deep, well drained, and has high productivity potential. It is suited for the production of alfalfa,

cotton, wheat, sorghum, oats, and other crops. Port soil is dark brown to dark reddish brown, its color derived from upland soil materials that weathered from reddish sandstones, siltstones, and shales of the Permian Geologic Era. Native vegetation is tall grasses with an overstory of pecan, black walnut, bur oak, and eastern cottonwood trees. This native condition offers a very desirable habitat for most of Oklahoma's wildlife species.

Soils are often named after an early pioneer, town, county, community, or stream in the vicinity where they are found. The name "Port" comes from a small community located in Washita County. The name



"silt loam" refers to the texture of the topsoil. This texture consists mostly of silt-sized particles (.002 to .05 mm) and when the moist soil is rubbed between the thumb and forefinger, it is loamy to the feel.

Soils are classified using a system known as Soil Taxonomy. The classification system is similar to that used for plants and animals and is based on soil properties such as moisture, temperature, color, texture, and structure. Soil Taxonomy also uses unique nomenclature, or names, which indicate the major characteristics of soils. There are six categories of classification in Soil Taxonomy: (1) order (the broadest category), (2) suborder, (3) great group, (4) subgroup, (5) family, and (6) series (the most specific category). The taxonomic classification for Oklahoma's state soil is Mollisols – Ustolls – Haplustolls – Cumulic Haplustolls – fine-silty, mixed, superactive, thermic Cumulic Haplustolls – Port Silt Loam. This classification indicates that these soils developed under grassland vegetation; are intermittently dry during the summer; have minimum horizon development; have a surface horizon greater than 50 cm thick with texture finer than loamy fine sand; and have a slope less than 25%.

So why have a state soil?

Designating a state soil provides educational opportunities and helps bring attention to the importance of our soils and to the fact that it is necessary to conserve the land for the well-being of future generations. Educators and conservationists can use a specific soil on which to focus attention and to have as an example.

Soil is one of our most valuable natural resources. Society could not survive and enjoy life without soil. All food and much of the clothing and shelter that society needs comes from plants growing in soil. Soil provides a place for homes and communities. Soil cleans our water, regulates climate, and purifies waste.

Soil conservation is not an easy job. In 1982 wind and rain eroded over 113 million tons of

soil in Oklahoma. Much of that soil ended up in our streams, rivers, and lakes. In 1997 the amount of soil lost to erosion in Oklahoma was 68 million tons. The reduction in soil loss is a direct result of conservation practices implemented by many Oklahomans. Through continued conservation efforts, all Oklahomans can learn to appreciate and conserve their precious soil.

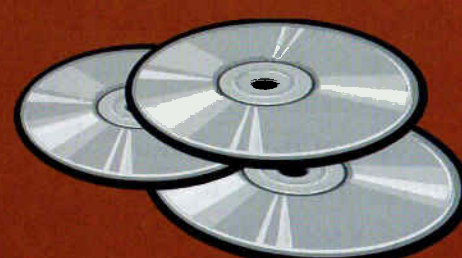
For more information on soil resources in Oklahoma, contact your local conservation district, the Oklahoma Conservation Commission (www.conservation.ok.gov), or the USDA Natural Resources Conservation Service (www.ok.nrcs.usda.gov).

OCGS Compiles Publications into Digital Format

By Jane Weber, OGS Staff

All the publications of the Oklahoma City Geological Society (OCGS), including feature articles from their journal, the *Shale Shaker*, are now available on a set of three compact discs. The digital collection is fully searchable by title, author, and keyword. The price of the set is $95.00 plus postage for non-OCGS members or $37.50 including postage for members.

To order a set of CDs, contact Michelle Hone at 405-236-8086 or ocgs@sbcglobal.net.



Upcoming Meetings

2007

JANUARY

17 Oklahoma City Geological Society (OCGS) Technical Luncheon, 11:45am – 1:00pm, Oklahoma History Center, Oklahoma City, Oklahoma. Speaker: Brian J. Cardott, Oklahoma Geological Survey, Norman, OK, *"Frontier Gas-Shale Plays of Oklahoma."* Information: OCGS, (405) 235-3648; 120 North Robinson, Ste. 900 Center, Oklahoma City, Oklahoma 73102; e-mail: tgsweb@inbox.com; website: http://www.ocgs.org.

23 Tulsa Geological Society (TGS) Luncheon Meeting, Tulsa, Oklahoma. Speaker: Charles Kerans, *"The Role of Tectonics and Glacioeustacy in Development of Permian Carbonate Reservoir Systems."* Information: TGS, PMB 602, 4306 S. Peoria, Tulsa, Oklahoma 74105-3922; website: http://www.tulsageology.org.

FEBRUARY

12–13 Gravity and Magnetics for Explorationists, taught by Michal Ruder; Courtyard Houston, I-10 West, Houston, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

12–13 Seismic Fluid Detection, Reservoir Delineation, and Recovery Monitoring: The Rock Physics Basis, taught by Gary Mavko; Courtyard Houston, I-10 West, Houston, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

12–13 Seismic Interpretation in the Exploration Domain, taught by Don Herron and Timothy Smith; Courtyard Houston, I-10 West, Houston, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

14–15 Application and Interpretation of Converted Waves, taught by James Gaiser & Robert Stewart; Courtyard Houston, I-10 West, Houston, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

14–15 Petroleum Geology for Geophysicists & Engineers, taught by Norman Hyne; Courtyard Houston, I-10 West, Houston, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

25–28 Society for Mining, Metallurgy, and Exploration (SME) Annual Meeting & Exhibit and 109th National Western Mining Conference, Denver, Colorado. Information: SME, (303)973-9550 and (800)763-3132; FAX: (303)973-3845; 8307 Shaffer Parkway, Littleton, CO 80127; website: http://www.smenet.org/meetings/annualMeeting2007/index.cfm.

27–MARCH 1 Petroleum Engineering for Non-Engineers, taught by John Farina; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

MARCH

6–8 Fundamentals of Titles, Leases & Contracts, taught by Lewis G. Mosburg, Jr.; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

12–14 Northeastern GSA Section Meeting, Durham, New Hampshire. Information: Wally Bothner, University of New Hampshire, (603)862-3143, wally.bothner@unh.edu; website: http://www.geosociety.org/sectdiv/northe/07nemtg.htm.

17–28 Appraisal of Oil & Gas Properties, taught by John Gustavson & Ed Moritz; Denver, Colorado. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

29—30 Southeastern Section GSA Meeting, Savannah, Georgia. Information: website: http://www.geosociety.org/sectdiv/southe/07semtg.htm.

APRIL

1—4 AAPG Annual Convention and Exhibition, *Understanding Earth Systems Pursuing the Checkered Flag*, Long Beach, CA. Information: AAPG Convention Department; P.O. Box 979; Tulsa, OK 74101-0979 USA; 1(888) 945-2274 ext. 617 (U.S. / Canada); 1(918) 560-2617. Website: http://www.aapg.org/.

9—10 Fundamentals of 3D Seismic Survey Design, taught by Henry Posamentier, Renaissance Pere Marquette Hotel, New Orleans, LA. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

11—12 Seismic Stratigraphy and Seismic Geomorphology into the 21st Century, taught by Gijs Vermeer, Renaissance Pere Marquette Hotel, New Orleans, LA. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

11—14 North-Central / South-Central Sections GSA Joint Meeting, Lawrence, Kansas. Information: website: http://www.geosociety.org/sectdiv/Northc/07nc-scmtg.htm.

17—19 Advanced Concepts of Titles, Leases & Contracts, taught by Lewis G. Mosburg, Jr.; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

22—24 AAPG Southwest Section Meeting, *Unconventional Challenges - Innovative Solutions*, Wichita Falls, Texas. Sponsored by North Texas Geological Society. Call for Abstracts information (due March 1): Brian Brister, Gunn Oil Company, PO Box 97508, Wichita Falls, TX 76307; (940)723-5585; bbrister@gunnoil.com.

24—26 Basic Petroleum Geology for the Non-Geologist, taught by Norman J. Hyne; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

MAY

4—6 Cordilleran Section, GSA 103rd Annual Meeting, Bellingham, Washington. Information: website: http://www.geosociety.org/sectdiv/cord/07cdmtg.htm.

7—9 Rocky Mountain Section, GSA Annual Meeting, Saint George, Utah. Information: website: http://www.geosociety.org/sectdiv/rockymtn/07rmmtg.htm.

7—11 Fluid Flow Projects: Two-Phase Flow in Pipes, taught by Cem Sarica & Jim Brill; Tulsa, Oklahoma. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

8—9 Application and Interpretation of Converted Waves, taught by Ronald Hinds & Richard Kuzmiski; International Hotel Suites, Calgary, Calgary, AB. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

8—9 Borehole Geophysics: Theory and Practice, taught by James Gaiser & Robert Stewart; International Hotel Suites, Calgary, Calgary, AB. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

8—9 Seismic Data Processing, taught by Steve Hill; International Hotel Suites, Calgary, Calgary, AB. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

8—10 Petroleum Engineering for Non-Engineers, taught by John Farina; Tulsa, Oklahoma. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

10—11 Fundamentals of 3D Seismic Survey Design, taught by Gijs Vermeer; International Hotel Suites, Calgary, Calgary, AB. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

13—18 Society for Exploration Geophysicists Summer Research Workshop 2007, Antalya, Turkey. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

15—17 Problems and Pitfalls in Joint Operating Agreements, taught by Lewis G. Mosburg, Jr.; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

20—25 43rd Forum on the Geology of Industrial Minerals, Boulder, Colorado. Information: Colorado Geological Survey, 1313 Sherman Street, Room 715, Denver, CO 80203; (303)866-2611; website: http://im-forum2007.crmca.org.

22—23 Basics of Well Log Interpretation, taught by George R. Bole; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

AUGUST

28—30 Petroleum Engineering for Non-Engineers, taught by Norman J. Hyne; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

SEPTEMBER

9—11 AAPG Mid-Continent Section Annual Meeting, *New Ideas - More Oil & Gas*, Wichita, Kansas. Sponsored by Kansas Geological Society. Information: Ernie Morrison; EMorrison@MULLDRLG.com; phone: 316-264-5368. Website: http://www.aapg.org/meetings/midcont07.pdf.

11—13 Fundamentals of Titles, Leases & Contracts, taught by Lewis G. Mosburg, Jr.; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

18—20 Petroleum Engineering for Non-Engineers, taught by Norman J. Hyne; Denver, Colorado. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

22—23 Planning and Operating a Land 3-D Seismic Survey, taught by J. Bee Bednar; San Antonio, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

22—23 Seismic Anisotropy: Basic Theory and Applications in Exploration and Reservoir Characterization, taught by Ilya Tsvankin and Vladimir Grechka; San Antonio, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

22—23 Seismic Data Processing, taught by Steve Hill; San Antonio, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

22—23 3D Seismic Attributes for Prospect Identification and Reservoir Characterization, taught by Kurt Marfurt; San Antonio, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

22—23 Migration Without Math (OK Maybe a Little Greek Math), taught by Andreas Cordsen and Peter Eick; San Antonio, TX. Information: Society for Exploration Geophysicists, (918)497-5500; PO Box 702740, Tulsa, Oklahoma 74170-2740; e-mail: web@seg.org; website: http://seg.org.

23—28 Society for Exploration Geophysicists (SEG) International Exposition & 77th Annual Meeting, San Antonio, Texas. Sponsored by Kansas Geological Society. Information: 8801 S. Yale, Tulsa, OK 74137; phone: 918-497-5538, Fax: 918-497-5557; website: http://meeting.seg.org/.

OCTOBER

3—6 2007 Precious Metals Symposium, Tucson, Arizona. Information: website: http://www.smenet.org/meetings/.

6—9 AAPG Rocky Mountain Section 56th Annual Meeting, *Exploration Discovery Success*, October, Snowbird, Utah. Information: website: http://www.aapg.org/meetings/index.cfm#sections.

11—12 Basics of Well Log Interpretation, taught by George R. Bole; Tulsa, Oklahoma. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

17—28 Appraisal of Oil & Gas Properties, taught by John Gustavson & Ed Moritz; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

23—25 Problems and Pitfalls in Joint Operating Agreements, taught by Lewis G. Mosburg, Jr.; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@utulsa.edu.

28—31 Geological Society of America, Annual Convention, *Earth Sciences for Society — Beginning of the International Year of Planet Earth,* Denver, Colorado. Information: Geological Society of America, P.O. Box 9140, Boulder, CO 80301; (303) 447-2020; fax 303-357-1071; e-mail: meetings@ geosociety.org. Website: http://www.geosociety.org/meetings/2007/.

NOVEMBER

6—9 14th Annual International Petroleum Environmental Conference, Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@ utulsa.edu.

13—15 Petroleum Engineering for Non-Engineers, taught by John Farina; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@ utulsa.edu.

DECEMBER

4—6 Petroleum Engineering for Non-Engineers, taught by Norman J. Hyne; Houston, Texas. Information: The University of Tulsa, Continuing Engineering & Science Education, 600 S. College Avenue, Tulsa, OK 74104; phone: (918)631-3088. E-mail: cese@ utulsa.edu.

—Oklahoma Abstracts

The Oklahoma Geological Survey thanks the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geoscientists.

EVALUATION OF MAGNETIC SUSCEPTIBILITY RELATIVE TO SPECTRAL GAMMA-RAY RESPONSE IN THE UPPER DEVONIAN – LOWER CARBONIFEROUS WOODFORD SHALE OF SOUTH-CENTRAL OKLAHOMA

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Economic interest in the occurrence and distribution of shale gas has heightened interest in tools and techniques available for the characterization and correlation of shale. One promising tool is magnetic susceptibility (MS). Previous researchers have measured the magnetic susceptibility (MS) of the Woodford Shale as a means to correlate marine strata and to define important geologic boundaries on a global basis. Likewise, gamma-ray (GR) response is commonly used for gross regional stratigraphic correlation in the Woodford Shale. MS literature reveals no instances of basin-specific shale studies employing outcrops with well-control data in the form of logs or core. In the present study, we quantify the correspondence between MS and GR at two Woodford Shale exposures and in select subsurface cores. Recent research concludes that MS response in rocks is controlled by input of detrital iron that varies with fluctuations in global sea level. Likewise, GR response in hot shales is strongly related to U sequestration under conditions of anoxia and starved sedimentation. Consequently, one might expect MS to vary inversely with GR. Preliminary results based on high-resolution paired MS and GR measurements suggest that lithology of the Woodford Shale (siliceous shale or dolomite versus fissile shale) exerts strong control on both MS and GR response. The data also suggest that some Woodford Shale contains an MS signal that varies directly with GR response. Although GR response and correspondence to lithology has been widely documented by the petrophysics community, the lack of documentation of physical and chemical conditions involved in the transportation and selective sequestration of magnetically susceptible mineral matter in shale is problematic. The facility and economy of MS measurements in shale could prove to be powerful prospecting tool when used in combination with GR.

SURFACE AND SUBSURFACE LITHOSTRATIGRAPHY OF DEVONIAN SUCCESSIONS, NORTHERN ARKOMA BASIN, OKLAHOMA AND ARKANSAS

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The Devonian System is represented in the northern Arkoma Basin of Arkansas and immediately adjacent Oklahoma by three unconformity-bounded units designated the Penters Chert, Clifty Formation and Chattanooga Shale in ascending order. In Arkansas, these units are assigned Lower, Middle and Upper Devonian/Lower Mississippian ages respectively, although biostratigraphic data are meager. Subsurface analysis of the units indicates that the Penters Chert is developed pervasively as a blanket deposit of penecontemporaneous chert and calcisiltites reflecting transgression of an outer shelf-lower ramp setting. Thickening-thinning relationships do not seem to reflect depositional topography but instead are related to post-Penters erosion. Chert lithology mirrors that of the lower Boone Formation suggesting a volcanic source of the silica, and deposition below the sediment-water interface while the calcisiltites were still poorly indurated. Initiation of basin formation following Penters deposition tilted what was to become the north limb of the Arkoma Basin and turncated its presumed shallow water equivalents, and devloped a karsted surface on the Penters and older strata. Thin orthoquartzitic sandstones and associated shallow water, dolomitic, carbonate mudstones of the Clifty Formation were deposited on the karsted surface at the top of the Lower Devonian section. Their distribution is unpredictable, and most knowledge of the interval is based on widely scattered outcrop exposures. The well-known Upper Devonian transgression across the southern midcontient is marked by black shale deposition of the Chattanooga Shale, and its thin, basal, phosphatic quartz sandstone Sylamore Member. Subsurface distribution of the Chattanooga also develops a predictable blanket geometry similar to the Penters, but in the outcrop belt, pronounced thickening-thinning relationships reflect the maturely karsted surface developed on the Penters and older strata across the northern Arkoma Basin.

ELECTRON MICROPROBE ANAYLSIS OF LOWER MORROW SANDSTONE, WOODWARD COUNTY, OKLAHOMA

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This project was part of a course in Electron Microprobe Analysis taught at Oklahoma State University. The goal was to analyze a core plug from the Morrow sandstone, Woodward County, Oklahoma to evaluate its potential as a reservoir rock. The research was conducted by two undergraduates collaborating with a graduate student to assist with a Master's thesis. The electron microprobe was used to examine the core plug's cement, porosity, permeability, and general composition. Identifying these characteristics helps to determine if the site is a potential reservoir. With the use of an electron microprobe, we hope to find valuable information that would help in future production processes. The Morrow Sandstone is Pennsylvanian, located in the Northern shelf of the Anadarko Basin situated above the Chester Limestone and below the Atoka Limestone. The core was taken from the Lower Morrow, which is more sandstone oriented. During the class, the core was imaged using backscattered and secondary electrons. An EDS spectrum determined that the rock consisted mainly of clay minerals and quartz, and smaller amounts of pyrite and copper. X-ray element maps of Fe and Ca were generated to identify elemental distributions within the material. Zoned calcite appeared to fill pore spaces surrounding larger quartz grains. The rock in general had 9.6% porosity, but the calcite and pyrite cement affects the permeability. It was determined that there was sufficient porosity in the sample, but the permeability was not high enough to be a potential reservoir. During field trips taken in this course and discussions with industry petroleum geologists, the electron microprobe does not appear to be a regularly used tool in hydrocarbon research. However, the instrument offers the ability for compositional analyses, relative porosity measurements, and identifying minerals that could be problematic for production.

USING BALANCED STRUCTURAL CROSS-SECTIONS TO DETERMINE STRAIN PARTITIONING FROM THE CENTRAL OUACHITAS TO THE ARKOMA FORELAND BASIN, SOUTHEASTERN OKLAHOMA

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The Arkoma basin, an arcuate structural feature located in southern Oklahoma and western Arkansas, is a foreland basin of the Ouachita fold and thrust belt. We have constructed many balanced structural cross-sections to determine the structural evolution of thrust faulting and the nature of strain partitioning from the central Ouachitas to the Arkoma basin. The cross-sections are based on the wire line logs of thousands of wells, available 2-D and 3-D reflection seismic data, and surface geologic maps.

In the Potato Hills area of the Central Ouachitas, the middle Ordovician to the Mississippian rock units are exposed at the surface. In the subsurface, however, the Choctaw detachment is the roof thrust of an antiformal stack structure which involves Pennsylvanian rock units. From the central Ouachitas to the leading edge of the frontal Ouachitas, strain partitioning is accommodated by imbricate fan thrusts on the hanging wall of the Choctaw detachment. The strain partitioning is accommodated primarily by a triangle zone and associated duplex structure in the frontal Ouachitas-Arkoma basin transition zone where the Atokan turbiditic sequence is well exposed in both hanging wall and footwall of the Choctaw detachment. The duplex structure is located between the Springer detachment (the floor thrust) and the Lower Atokan detachment (the roof thrust) in the footwall of the Choctaw detachment. The triangle zone is floored by the Lower Atokan detachment and flanked by the Choctaw detachment to the south and the Carbon fault to the north. When restored to their original position prior to early Atokan time the cross-sections indicate about 60% shortening from the central Ouachitas to the Arkoma basin. The shortening is, however, only about 20% in the Arkoma basin in the footwall of the Choctaw detachment.

APPLICATION OF PETROLEUM INDUSTRY DATA TO THE EVALUATION OF THE ARBUCKLE AND SIMPSON AQUIFERS, ARBUCKLE MOUNTAINS, OKLAHOMA

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Increasing demands for groundwater supplies in Oklahoma are focusing attention on the "Arbuckle" aquifer of southern Oklahoma as a potential source of supply. The Arbuckle aquifer outcrops and recharges in the Arbuckle Mountains, a large east-west trending anticlinal fold. The aquifer consists primarily of carbonate flow units in the Cambro-Ordovician Arbuckle Group and sandstone flow units in the overlying Ordovician Simpson Group. The thickness of the Arbuckle Group carbonates exceeds 1000 meters; the thickness of the sandstone flow units typically ranges from 30 to 50 meters. Determining aquifer characteristics is difficult, but essential for ground water flow modeling. Few water-supply wells penetrate more than 300 meters of the Arbuckle Group, whereas in the Simpson Group wells are generally <100 meters deep and restricted to areas close to the outcrop. Fortuitously, the limited aquifer data provided by water supply wells are augmented by information collected during the exploration for petroleum. These latter data, which are not part of the traditional hydrogeologic dataset, are essential to aquifer characterization and include: lithologic and wireline logs to determine interval and flow unit thicknesses, cores and bit cuttings to determine lithology, reports from cable-tool-drilled wells, drill stem test and well completions that establish fluid types in flow units, calculations of fluid properties from wireline log curves, pore morphology and rock architecture determined from core, quantified porosity measurements from core and wireline logs, and seismic sections for interpreting structural elements and stratigraphy. In some cases, only legacy 2-D seismic data are available. Generally, these data are poor quality. However, with modern processing techniques, the quality of the stacked seismic can be improved, leading to a better interpretation of the flow units. The seismic and well data acquired for petroleum exploration are essential to determining the thickness, type and spatial distribution of flow units within aquifer-bearing intervals, establishing the structural grain and predicting paths of potentiometric flow, delineating the distribution of fresh, brackish and saline waters within flow units, and quantifying flow unit porosity and thickness for numerical modeling.

MILLIPEDS (DIPLOPODA) FROM THE FORT SILL FISSURES (LOWER PERMIAN) OF SOUTHWESTERN OKLAHOMA: RARE EXAMPLES OF PERMIAN MILLIPEDS AND OF FOSSIL MILLIPEDS FROM A PALEOZOIC FISSURE FILL

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Several taxa of rare Permian millipeds have been found in a new fossil-producing pocket of the Fort Sill fissures exposed in the Dolese Quarry in southwestern Oklahoma. Permian millipeds are very rare, especially so considering their relative abundance during the preceding Carboniferous. The forms found here are elongate (helminthomorph) millipeds, with up to about twenty midbody segments preserved. Pleurotergal ornamentation varies from simple ridges and striae to exquisitely preserved, reticulate microsculpture. Probable ozopores and coxal segments are preserved on some material. The fossils were found in greenish clay cave-fill and calcite-cemented rock, and calcite crystals adhere (or did adhere before preparation) to some of the millipede material. The fissure fill with the millipedes also contained several taxa of amphibians and reptiles not previously known from this site. Interestingly, the main animal found at the site, Captorhinus aguti, is a possible predator of arthropods.

Fossil myriapods (millipeds and centipeds) have been previously described from karst deposits (caves and fissure fills) in a number of localities including Europe (Greece, Austria, Hungary, Romania), South Africa, and the Caribbean (Jamaica). These karst deposits were formed in a variety of climatic regimes ranging from the tropics (e.g., Jamaica) to cooler mountainous (e.g., Transylvania and South Africa) climes. Carbonate mineralization of and around myriapods (especially millipeds with their already carbonate-rich cuticles) is common in both lowland and highland, and tropical to cooler, environments, as is three-dimensional preservation. Most previous accounts of cave and fissure-fill myriapods (almost all millipeds) are of Pleistocene (or at least Cenozoic) occurrences of forms that are closely allied to modern taxa.

PALEOECOLOGY OF A LOWER PERMIAN LOCALITY IN NORTHERN OKLAHOMA

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The depositional environment of the Billings Channel Site of Noble County, Oklahoma has been uncertain. Though the site's sediments were deposited during the Early Permian, when the region was at or near the edge of an epicontinental sea, sedimentary evidence for the paleoenvironment of this particular locality is ambiguous. Previous studies have examined the geology and general biota of the site, its ichnofossils, and its paleobotany. In this study, the vertebrate fauna was examined. This data was then combined with paleontological and sedimentary data from the previous studies to determine the depositional environment. The combined data indicate a mostly-terrestrial environment subject to both long-period and short-period cycles of dryness and inundation. The site also appears to boast a high level of biodiversity.

CAMBRIAN (STEPTOEAN-BASAL SUNWAPTAN) TRILOBITE BIOSTRATIGRAPHY OF THE HONEY CREEK FORMATION, WICHITA MOUNTAINS, OKLAHOMA

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The sandy carbonates of the Honey Creek Formation are well exposed in a section at Ring Top Mountain on the north flank of the Wichita Mountains. Abundant trilobites offer an opportunity to revise the biostratigraphy of the Steptoean-Sunwaptan boundary interval. A succession of assemblages through the Steptoean support previous suggestions that this part of the formation can be divided into at least two distinct zones. *Camaraspis parabola* Frederickson is a short ranging species that occurs in the lower part of the formation in association with species of *Kindbladia, Apachia* and *Xenocheilos*. These species are absent from younger faunas dominated by *Camaraspis convexa* (Whitfield). The base of the Sunwaptan is marked by the appearance of species of *Comanchia, Dellea* and *Sulcocephalus*, and the extinction of most genera from the underlying fauna. This basal Sunwaptan assemblage, usually assigned to the *Irvingella* major Zone, persists through a surprisingly thick interval of about two meters of section. Well-preserved sclerites of *Irvingella* occur abundantly in a succession of bioclastic rudstones. They record the presence of several distinct morphotypes whose relationship to *I. major* Ulrich and Resser, a widely reported species based on sandstone internal molds from the Upper Mississippi Valley, is unclear. The data do cast doubt on the notion of a single, geographically-widespread species of *Irvingella* at the base of the Sunwaptan. Rather, "*Irvingella major*" likely represents a plexus of closely related species with a far more complex geographic and environmental distribution pattern.

CORRELATION OF CARBON ISOTOPE (δ13C) STRATIGRAPHY WITH SHIFTS IN LITHOFACIES AND TRILOBITE BIOFACIES, LATE ORDOVICIAN VIOLA GROUP, SOUTHERN OKLAHOMA

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The Ordovician Viola Group of south-central Oklahoma is a thick, shallowing-upward succession of carbonate rocks that records infilling of the Southern Oklahoma aulacogen. Five sedimentary facies occupy a depth gradient along a carbonate ramp sloping into the aulacogen. The facies of the deep ramp consists of laminated to weakly bioturbated carbonate mudstone that was deposited below wave base under anaerobic to dysaerobic conditions. Increased bioturbation and the appearance of thin, storm-winnowed horizons characterizes the transition to middle ramp. In the shallow ramp, interlayed wackestone and bioclastic packstone to rudstone record periodic storm winnowing between storm and fair-weather wave base. Bryozoan-rich bioclastic intervals represent shoals that formed near fair-weather wave base. The Viola Group contains at least 52 trilobite species and 36 genera. Cluster analysis identifies four discrete trilobite biofacies, each of which occupied a distinct habitat along the carbonate ramp. Species diversity declines from shallow to deep ramp settings. On the margins of the aulacogen, near Fittstown, an initial abrupt deepening is recorded by the appearance of a thin interval of deep ramp litho- and biofacies above peritidal carbonates of the Bromide Formation. The change is expressed by a shift towards negative carbon isotope (δ13C) values. Upward shallowing is marked by progradation of shallow ramp litho- and biofacies, and a return to increasingly positive δ13C values. At the top of the local succession, deepening and replacement of a diverse trilobite fauna with graptolite-rich assemblage is marked by a return to more negative values. Thus, variation in isotopic values within the Viola correspond well to sedimentological and faunal trends that were driven by relative sea level changes.

UNUSUAL CIRCULAR STRUCTURES IN SOUTHERN OKLAHOMA

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Near Tishomingo, OK, at least one, and maybe several, small circular depressions have recently been discovered. These features occur in an otherwise flat, wooded area with thin regolith overlying Tishomingo Granite. The largest of these depressions is approximately 6 m in diameter and 2 m deep. It is surrounded by a horseshoe-pattern of angular granitic blocks which seem to have come from the excavated region. Thus far, the most likely explanation of this circular depression is that it is a crater produced by meteoritic impact. In support of this hypothesis, two large meteorites were discovered within two miles of the depression in the 1970s.

In order to confirm that it is an impact structure, evidence of mineral shock (strain lamellae in quartz; presence of stishovite or coesite, although these are unlikely for such a small impact; shatter cones, also unlikely, because the impacted rock is granite) or meteoritic material must be found. If thus confirmed, the impact structure will be the smallest, and quite possibly the youngest, of the 174 currently-confirmed meteoritic impact craters (Earth Impact Database, http://www.unb.ca/passc/ImpactDatabase).

The crater site is currently being investigated. We are doing detailed mapping of the crater, its surroundings, and the distribution of strewn rock fragments to look for consistency with what we think was the angle of impact, based on the horseshoe-pattern of boulders on the periphery of the depression. Geophysical sensing of the main crater area, primarily magnetic profiling and electromagnetic sounding, will soon be carried out. Samples have been collected from within the structure and are being investigated petrographically for any kind of mineral shock effects.

EVALUATION OF A RECENT MINE COLLAPSE, PICHER MINING DISTRICT, OTTAWA COUNTY, OKLAHOMA

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A recent underground lead/zinc mine collapse in March, 2005 adjacent to U.S. Highway 69 in Ottawa County, Oklahoma, resulted in an evaluation by the U.S. Geological Survey, U.S. Army Corps of Engineers, Oklahoma Conservation Commission, and Oklahoma State University to assess the possible damage that could occur if an additional mine collapse occurs. The collapse feature is a plug-type, approximately 3 meters in diameter, 2 meters deep, and located approximately 30 meters east from the edge of the highway. An older collapse feature, located between the recent collapse and the highway, is in the same general vicinity and is as close as 5 meters from the edge of the highway. The only current information available on the extent and location of the shallow mine excavations are subsurface maps and exploration boreholes. Since the subsurface maps were last updated, other subsurface mining excavations may have occurred that could pose an additional hazard to the highway. Surveys utilizing InSAR and tripod-mounted LIDAR were utilized to determine if subsidence prior to collapse could be observed and to monitor changes in the collapse feature. Shallow boreholes were drilled and SONAR data collected to determine the location, extent, and area of the subsurface mining excavations. This approach provided useful information and allowed the creation of subsurface profiles that delineated the mines subsurface extent and its structural integrity in the proximity of the highway.

CHARACTERIZATION OF CHAT LEACHATE AND MINE DISCHARGE INTO TAR CREEK, OTTAWA COUNTY, OKLAHOMA

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The Tar Creek Superfund site is an abandoned lead and zinc mining area located in Ottawa County, northeastern Oklahoma. Large accumulations of milled mine tailings, locally referred to as chat, and byproducts of the gravity separation process, referred to as mill pond wastes, are prevalent in the area. Chat and mill pond wastes produce leachate containing cadmium, iron, lead, and zinc that enter drainages within the mining area. Mine discharge also emanates from several locations in the mining area including unplugged shafts, vent holes, seeps, and abandoned mine dewatering wells. A segment of Tar Creek was selected to characterize and quantify metal loadings by leachate from chat piles adjacent to the study segment. Four surface-water sampling sites along the study segment were sampled seven times over 14 days following a rainfall event. Instantaneous loads of cadmium, iron, lead, and zinc were determined for each sample. A mass-balance approach was used to determine the loading due to leachate within the studied segment and compare it to loading attributable to mine discharge. Iron and zinc loadings were much greater than cadmium and lead loadings in both leachate and mine discharge. Iron loading from mine discharge was greater than iron loading from chat leachate within the study segment. Cadmium loading from chat leachate was greater than cadmium loading from mine discharge within the study segment. Zinc and lead loadings from mine discharge were comparable to zinc and lead loadings from chat leachate at the study segment except the loadings mine discharge were greater than the chat leachate on the first day following the rainfall event.