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# J. Glenn Cole: A Stratigraphic Legacy Preserved

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**Introduction:**

The State of Oklahoma and its geological community had the very good fortune of being home to J. Glenn Cole, a petroleum geologist, stratigrapher and mentor. Shortly after he died suddenly in March of 2008, Glenn's family offered all of his geologic files and background data to the Tulsa Geological Society. He had always been recognized as an expert stratigrapher, having studied the geology of northeastern Oklahoma nearly his entire career. However, what was discovered when Glenn's office contents were reviewed was that in the course of his career he had amassed a monumental collection of over 500 meticulously correlated stratigraphic cross sections. These cover the entire northeastern quadrant of Oklahoma, extending from Kansas through the northern Arkoma Basin and from the Nemaha fault zone almost to Arkansas.

The Tulsa Geological Society, specifically Glenn's friends on the TGS Stratigraphic Committee, in collaboration with the Oklahoma Geological Survey, have made his crosss section and stratigraphic work accessible to all interested geologists. These are now available at no charge from the Energy Libraries Online (ELO) website at http://energylibrariesonline.com/.

**Biography:**

Joseph Glenn Cole was born August 2, 1929 in Sapulpa, Oklahoma. He was fascinated by the stories of his father's wildcatting days and after graduating from high school he attended the University of Tulsa, graduating in 1955 with a Bachelor's degree in geology. Glenn also attended Navy Reserve Officer Candidate School during his college summers and after graduation was commissioned as an Ensign and assigned to Ft. Mason in San Francisco. He retired from the reserves after rising to the rank of Commander.

Glenn worked as a petroleum geologist for various companies, mostly outside of the State, from 1957 through 1962. It was at this time he decided to return to Oklahoma to attend graduate school at the University of Oklahoma. At OU Glenn earned his Master's degree in 1965 and his PhD in geology in 1968. Glenn's thesis and dissertation both centered on the subsurface stratigraphy of northeastern Oklahoma, and these laid the foundation for what would become his lifelong career interest (Cole, 1965; Cole 1968) (Figure 1).

Glenn studied all aspects of both the surface and subsurface geology of this part of the State for over 40 years, giving him an encyclopedic knowledge of the stratigraphy from grass roots through the Precambrian. He was the consummate applied scientist, forever seeking his colleagues' input regardless of years of experience. One of his gifts, and why he was so greatly respected and admired, was his desire for input, even from relatively inexperienced geologists. Many of these, who are now gray-hairs themselves, were inspired by such an experienced geologist asking "What do you think?" and really meaning it (Figure 2).

In addition to being a consummate professional, Glenn was an active volunteer in numerous organizations. He was

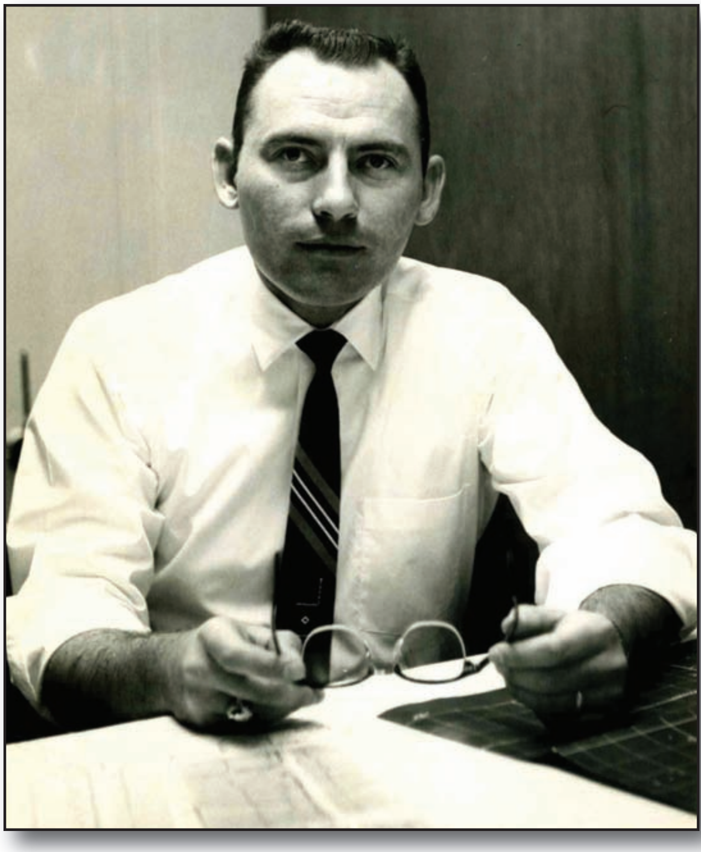


Figure 1: J. Glenn Cole as a young petroleum geologist ca. 1970.

Figure 2: Glenn standing on an outcrop of the Doneley Limestone (Brown lime equivalent) near Bluejacket, Oklahoma ca. 2005. His interest in the stratigraphy of northeastern Oklahoma extended to the outcrop.

a member of the Alumni Advisory Council for the School of Geology and Geophysics at the University of Oklahoma for many years. His participation helped keep important, fundamental geology courses in the curriculum. He was also a past president of the Tulsa Geological Society, but he was probably most visible to members of the TGS as an organizer of the annual “Shrimp Boil and Rib Feast”, where he and a few dedicated colleagues turned this into the single largest society event.

**Collection Description:**

In all, there are 506 individual cross sections in the collection including 21,177 log images, 14,823 of which, due to the number of common ‘tie’ wells, are unique. Most of these cross sections are tied to a common stratigraphic datum: the Verdigris Limestone. Deeper wells were clearly preferred, with many including most of the lower Paleozoic section and usually at least one in each cross section penetrating the top of the Arbuckle. The formation cropping out at the surface was also noted for each well, with subsurface correlation points usually beginning just below surface casing. In most areas the stratigraphic markers correlated number in the dozens, with many zones color-coded for lithology. The drilling dates for the wells and their corresponding log types vary, but most are small-scale SP/GR resistivity logs that date from the 1960s through the 1980s (Figure 3).

Knowing how rapidly facies changes can occur, Glenn was always distressed by regional cross sections with well-spacings measured in miles. To address this problem he spared no paper (or tape) and constructed his cross sections with average inter-well distances of about one mile, and in critical places much less than that. One of the remarkable qualities of these cross sections is that through a period of over 40 years he was able to maintain a consistency in his work, usually correlating the same formation tops and the same coloring scheme for basic lithologies. Glenn’s unmatched stratigraphic expertise, combined with this collection’s aerial extent, well density, and consistency is what makes these cross sections so useful.

Unfortunately, log headers were never included, and in most cases the wells are only identified with an elevation and QQQ section, township and range (numbers only, with no directions). In some cases locations were not noted, were difficult to read, or were later determined to have been marked incorrectly on the paper section. Where the location marked on a section placed a well out of alignment with adjacent wells in the cross section, the offending well was given a ‘pseudo-location.’ In almost every instance this involved only moving the well to the same QQQ section in a different township. Well(s) for which Glenn had no location noted on the paper section were placed midway between the last wells with known locations. Although not scientific, using ‘pseudo-locations’ quickly corrected obvious ‘busts’ and allowed for the plotting of all wells on all cross sections. Those wells with edited locations are noted on the map.

To improve its usefulness the collection was divided into three subsets. The largest of these, comprising most of the collection, are those contained within the regional grid of cross sections (R-series). These are oriented northwest–southeast and southwest–northeast and encompass the entire Cherokee Platform and northern Arkoma Basin in Oklahoma. They also extend almost 20 miles into Kansas, offering a rare tie between the stratigraphy of the two States. Individual cross sections in the regional series often extend 100 to 150 miles. With an average well-spacing of about one well per mile, these contain about the same number of individual wells. The regional grid itself has an average spacing between parallel cross sections of about two miles. These are connected to the perpendicular set with numerous ‘tie-wells’, insuring consistency in correlation. In some cases shorter cross sections, when they were oriented in the same direction and located near the end or beginning of the regional sections, have been linked in order to extend the regional lines (Figure 4).

A second series of cross sections are those in which porosity logs were used (P-series). These 60 sections include about 700 wells, and are located in the far northeastern part of the Oklahoma Cherokee Platform. These extend south into western Wagoner County but are concentrated in Nowata, Craig and Rogers Counties. Because the density/neutron logs that were used are displayed on a larger

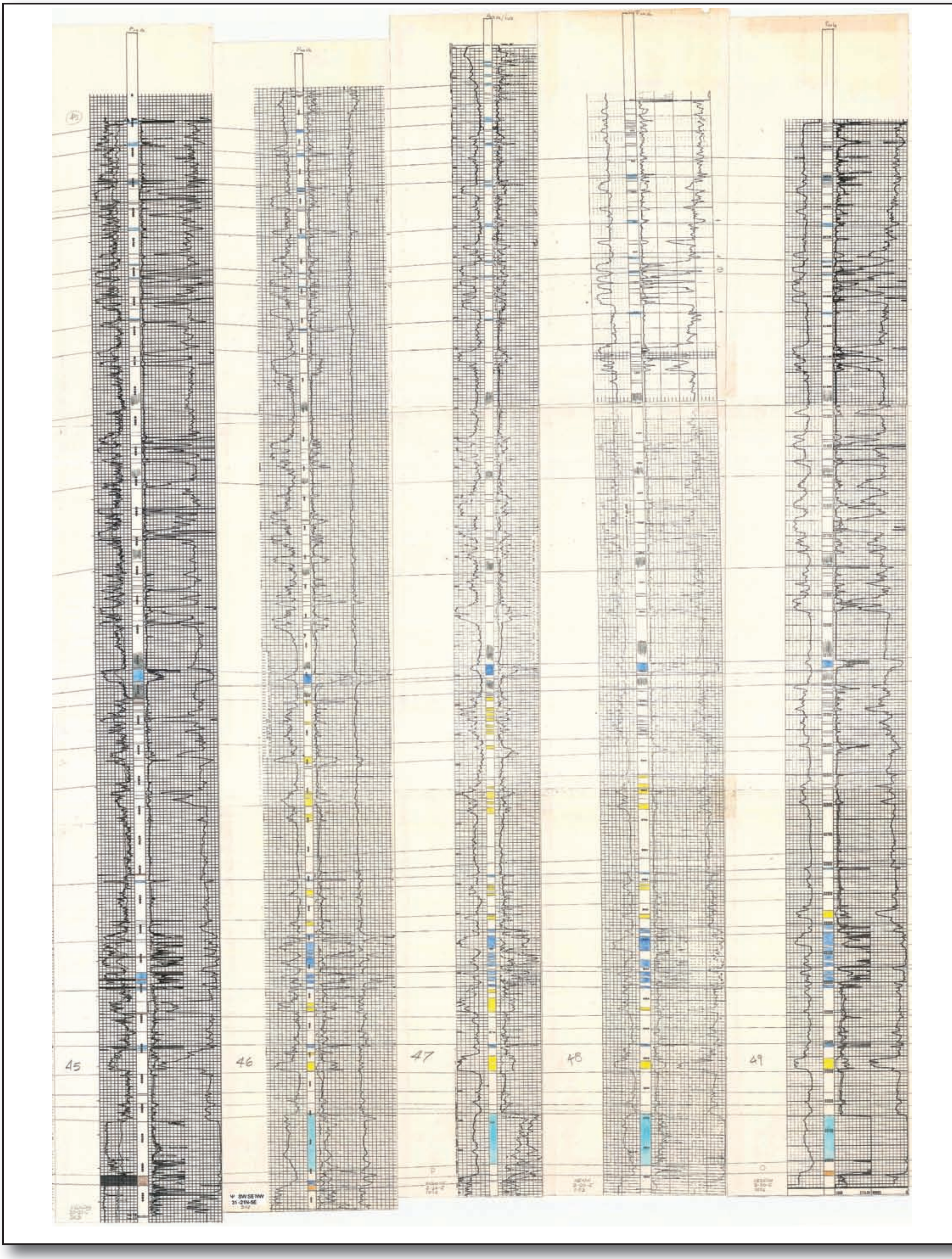



Figure 3: Example of part of one of the cross sections from the Cole collection. Well #46 has been assigned a ‘pseudo-location’ because of an error on the original.

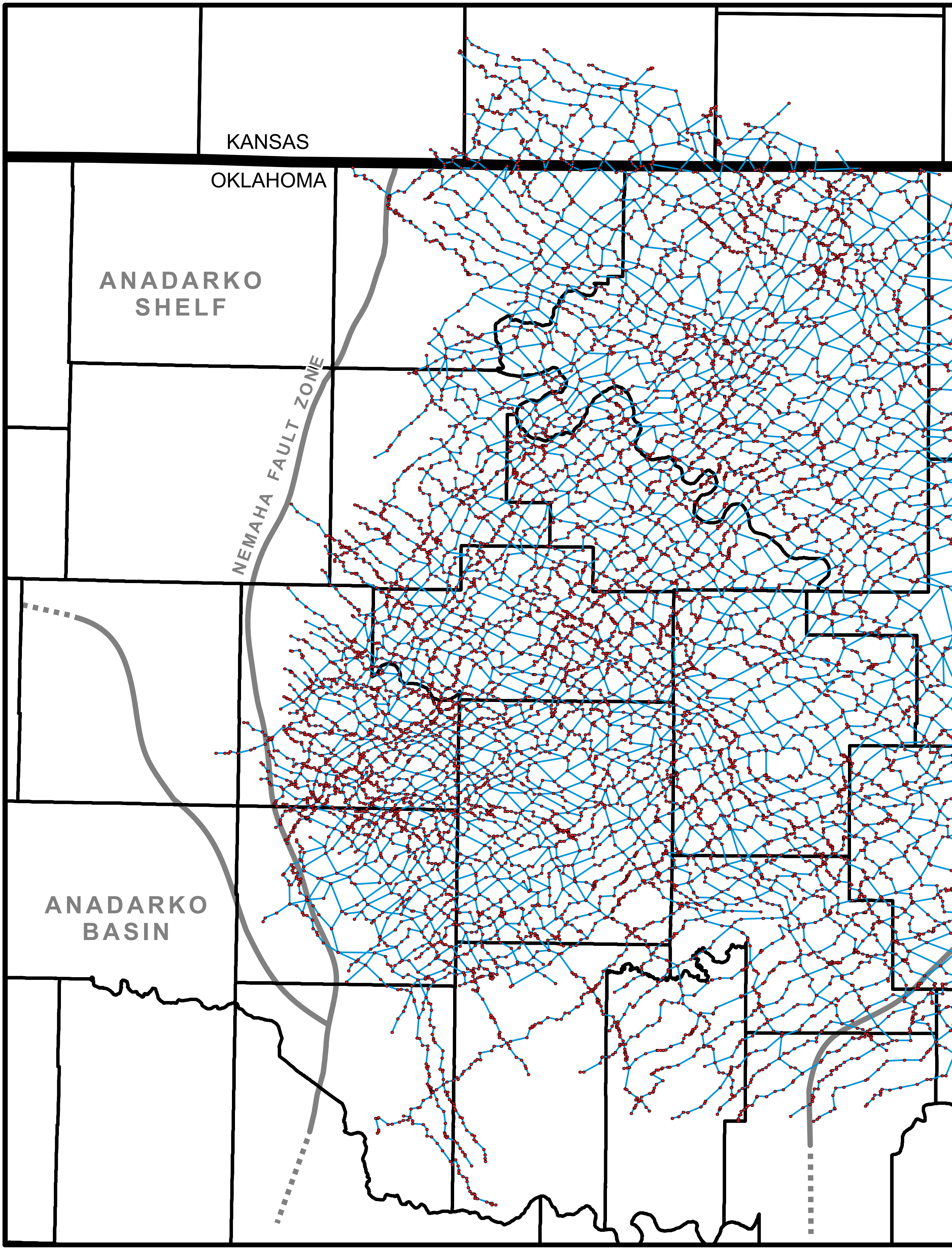
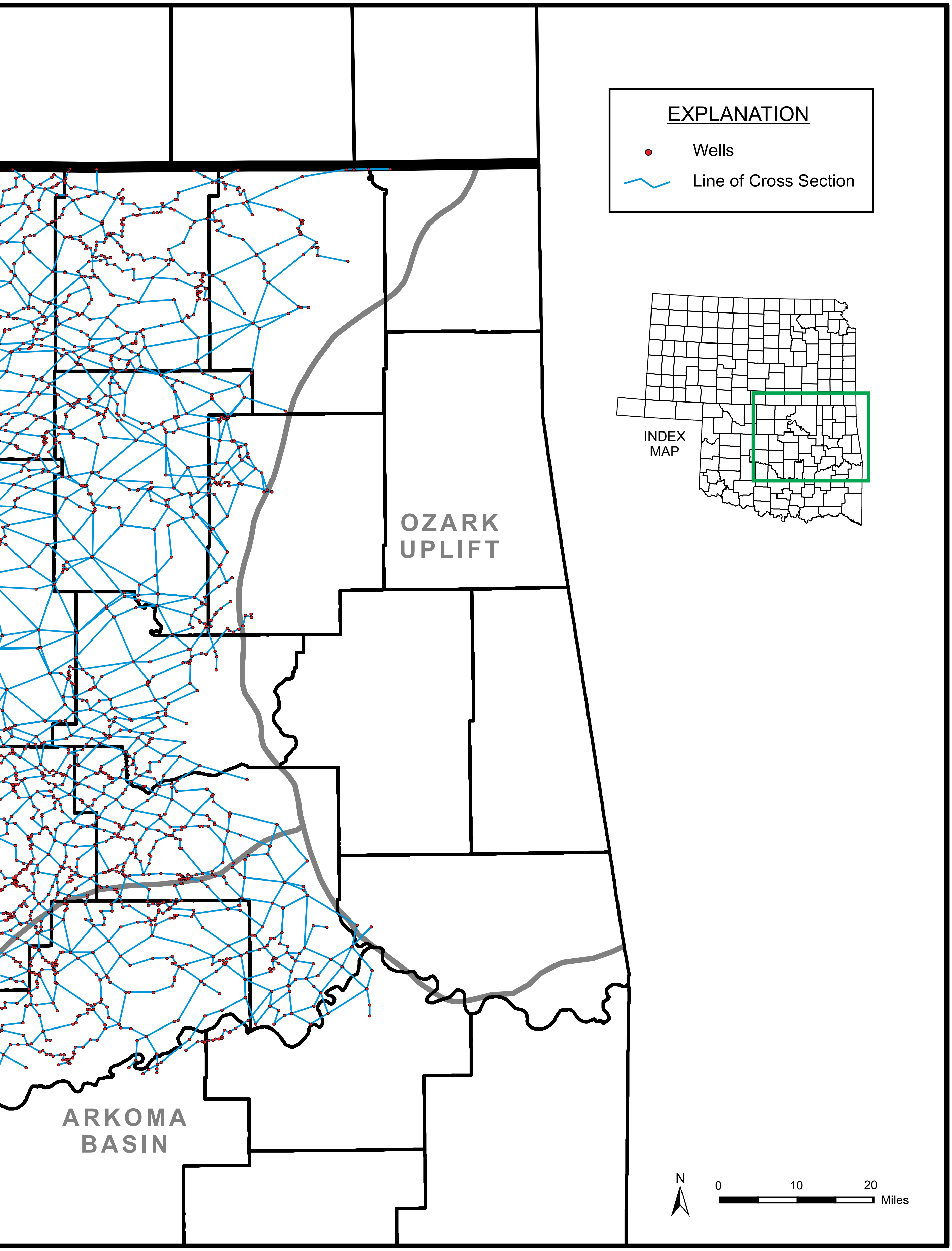



Figure 4: Base map showing the location of the Regional Grid (R-series) of the Cole cross sections.


EXPLANATION
Wells
Line of Cross Section
INDEX
MAP
OZARK
UPLIFT
ARKOMA
BASIN
N
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scale, wells in these cross sections cover a proportionately narrower stratigraphic interval. However, the thinness of the sedimentary section in this area still appears to have allowed the entire log to be displayed from total depth to surface casing (Figure 5).

The remaining cross sections, like the regional set, utilize small-scale SP-GR resistivity logs. Designated the M-series (for miscellaneous) these are comprised mostly of a second, more widely spaced regional grid in a north-south and west-east orientation. There are also many shorter cross sections that appear to have been constructed for specific projects. These also tend to fall within the area covered by the regional grid. A particularly dense concentration of these occurs in the southern Tulsa, eastern Creek, and northern Okmulgee County area where Glenn was studying the detailed stratigraphy of, coincidentally, the Glenn Pool Field. There is also an isolated group of five cross sections in the northern Caddo County area (Figure 5).

The Cole cross sections were not designed to be published but were a personal reference collection designed to help him in his work. His intimate knowledge of the entire stratigraphic section of northeastern Oklahoma famously allowed him to accurately locate wells based only on their logs. Thus, although dozens of stratigraphic markers are typically carried in these cross sections, these are almost never annotated with formation names. Work is ongoing to digitally add six to eight colored lines identifying formation tops in each of the cross sections. However, this will take time to accomplish, and is dependent on outside funding and student availability.

The collection is offered as a reference for those interested in or working on the subsurface geology of northeastern Oklahoma. Although the lack of annotation means that formation tops shown cannot be applied to a specific well, this work allows one to quickly review the stratigraphic section and extend known markers across a wide area. In addition to allowing one to become quickly oriented stratigraphically to any area in northeastern Oklahoma, the tight well spacing also graphically demonstrates the reservoir variability which makes working this area so challenging. To be used to their full potential some experience with Cherokee Platform stratigraphy is required, and geologists

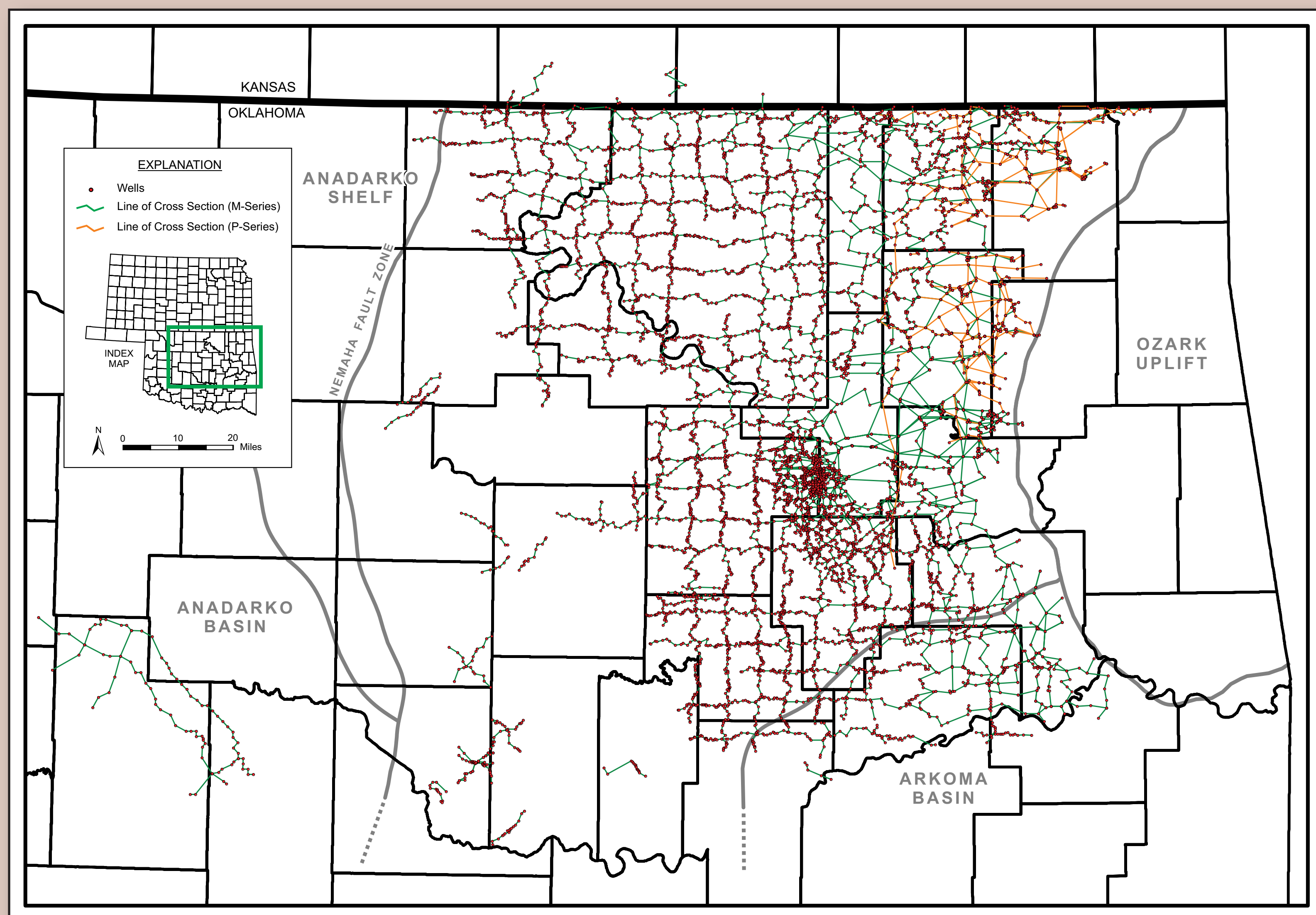


Figure 5: Base map showing the miscellaneous (M-series) cross sections and the cross sections in which porosity logs were used (P-series). Like the Regional Grid, the M-series, shown in red, uses small-scale (1" = 100') GR-SP resistivity logs, while the P-series (2.5" = 100') is shown in green.

with this experience are in for a treat. His stratigraphic ideas are now preserved and you are free to either agree or disagree, exactly as Glenn would have wanted.

**The Scanning Process:**

Glenn kept his cross sections organized and meticulously filed in his office/ work space so that he could easily find them. However, after his death his friends in the Tulsa Geological Society's Stratigraphic Committee (Rod Tillman, Vance Hall, and Bob Von Rhee) were confronted with the need to quickly package these for transport to the Tulsa offices of the AAPG. This was accomplished by dropping them into large yard bags which were each assigned a number series (100s, 200s, etc). Bags were then divided between these three volunteers, who assigned numbers to each of the cross sections based on the series number of the bag in which they were stored. Individual wells on each cross section were then consecutively numbered from left to right.

After this process the bags of cross sections were ferried by Rod Tillman, the overall leader of the entire effort, to the offices of the Oklahoma Geological Survey on the campus of the University of Oklahoma in Norman. Here, the well/cross section data were entered into an Excel spreadsheet by Nelson Osorio, a petroleum engineering doctoral student (and computer guru) employed by the Oklahoma Geological Survey. Data entered included cross section number, well number, T-R-S location, elevation and any notations that were made on the cross section. Wells for which 'pseudo-locations' were assigned, which represent 1-2% of the total, were also identified on the datasheet.

The hand-entered locations from the paper sections were then digitally converted to latitude and longitude by Russell Standridge, GIS Specialist at the Oklahoma Geological Survey. These digital locations permitted the construction of a detailed base map from which it was possible to identify potential entry errors and location problems. This made it possible to see the entire collection without trying to decipher numerous hard-copy base maps that Glenn created in which his symbology and organization were unclear. Most location issues were a result of either entry error or not being able to read Glenn's writing. It was only with the completion of this composite digital base map that it was finally possible to grasp the enormity of the collection and be able to subdivide it into useful subsets.

The physical scanning of the cross sections occurred at two locations. Those less than 42 inches wide (over 95% of the total) were scanned by Osorio at Sarkeys Energy Center on the OU campus. Cross sections that were wider than this were taken to the offices of the Bureau of Land Management (BLM) in Oklahoma City, where Doug Cook, a BLM geologist, kindly scanned these on their 60-inch scanner. Optimal parameters for the scanning process were worked out by Rod Tillman and Jingyao Gong, IT specialist at the AAPG. From their work it was determined that in the trade-off between file size and image quality 125 dpi (dots per inch) resolution was the most efficient. The cross sections were initially scanned in 24-bit color and then converted to 8-bit in order to further reduce file size. In addition, a 'Gaussian blur' was applied in order to smooth images which at first appeared angular. All cross sections were scanned in tif format and then converted to pdf.

This process was still not enough on its own to keep file sizes manageable. Most of the regional cross sections were 60 to 80 feet long, with the longest measuring over 100 feet. In addition to the difficulty in physically scanning this much paper, the file sizes of these cross sections were huge. A single scan of a regional cross section generated a tif file larger than a gigabyte. For this reason the longer cross sections were cut into segments of about 30 wells each. This nearly doubled the number of scanned images to 957, but created file sizes that were much more manageable. The average tif image size is now less than 250 megabytes. The pdf files range in size from 0.5 to 20 megabytes with an average size of about five megabytes. The file size for the entire cross-section collection in tif format is 251 gigabytes.

His leaving off the headers gave more room for the logs, but when wells still extended beyond the limits of the 42-inch paper, Glenn would simply tape more to the bottom so that the entire well log was included. The 'tails' that he added to many of his cross sections required the taping of paper 'leaders' to edges of these logs so that the bottoms would not be torn away during the scanning process.

Another significant issue that arose during the scanning process was the presence of tape gum on the cross sections. This gum would often become stuck on the scanner glass as the paper slid through and refracted the machine's incoming light. This created lovely rainbow-colored lines that extended horizontally across the entire cross section, often parallel with the correlation lines. This problem was originally addressed by a time-consuming glass-cleaning session after each scan. However, it was eventually discovered that sandwiching the cross sections between two sheets of Mylar prevented the smearing and produced much better images overall (Figure 6).

**Take a Look:**

The J. Glenn Cole cross section collection is now available at no charge from the Energy Libraries Online website http://energylibrariesonline.com/. Each cross section, and the individual wells therein, can be identified utilizing one of the series base maps described. The pdf images can be viewed online and any of these or the larger tif images are available for download.

Much of the life's work of one of Oklahoma's most outstanding stratigraphers is now available for your perusal. So please, join the Tulsa Geological Society's Stratigraphic Committee, the Oklahoma Geological Survey, and Energy Libraries Online in celebrating this man's monumental work.

Figure 6: Nelson Osorio scanning one of the Cole cross sections. After much trial and error it was found that sandwiching the paper sections in Mylar prevented tape gum from smearing across the scanner glass and ruining the image.


**References:**

Cole, 1965 M.S. Thesis, University of Oklahoma, Regional Stratigraphy and Subsurface Study of the Marmaton Group, Pennsylvanian (Desmoinesian) of Northeastern Oklahoma.

Cole, 1968 Ph.D. Dissertation, University of Oklahoma, Stratigraphic Study of the Cherokee and Marmaton Sequences, Pennsylvanian (Desmoinesian), East Flank of the Nemaha Ridge, North-Central Oklahoma.


**ABOUT THE AUTHOR**

Dan Boyd is a petroleum geologist with the Oklahoma Geological Survey, where he has been employed since 2001. Dan received his Master of Science degree in geology from the University of Arizona in 1978. He spent the first 22 years of his career as an exploration and development geologist in the petroleum industry. From 1978 through 1991 he worked on a variety of areas in the United States from Houston, Dallas, and Oklahoma City for Mobil Oil and Union Texas Petroleum. In 1991 he moved overseas, working in Karachi, Pakistan for four years and Jakarta, Indonesia for the following four. He returned with his family to the U.S. in 1999 with Arco (the successor to Union Texas) where, until Arco's sale to BP, he worked the offshore Philippines from Plano, Texas.

Since joining the OGS staff Dan has presented and published several reports on the history, status, and future outlook of the oil and gas industry in Oklahoma. He chaired the 2002 Symposium on Cherokee Reservoirs in the Southern Midcontinent (OGS Circular 108), and prepared and presented a workshop on the Booch gas play in southeastern Oklahoma (Special Publication 2005-1). His most recent study of oil reservoirs and recovery efficiencies (Shale Shaker May/June, 2008) demonstrates that large volumes of producible oil remain in the ground and that a major barrier to finding and producing this oil is shortcomings in State oil and gas data. Dan serves on the board of Energy Libraries Online (ELO) from a conviction that the long term success of the Oklahoma industry depends on improving both the completeness and accessibility of State oil and gas data.