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On The Cover —

Giant Ammonite Crowns Youngblood Energy Library's Superb Geological Collection

The University of Oklahoma's Laurence S. Youngblood Energy Library, which houses an extensive collection of books, journals, and maps, also boasts a magnificent collection of building stones, minerals, and fossils from around the world (see feature article, this issue, p. 236). Perhaps the most eye-catching fossil in the collection is the large coiled ammonite located by the card catalog. An interesting and unique aspect of this specimen, which is ~3 ft in diameter, is its occurrence with a nautiloid. The nautiloid is the small, coiled shell that is partly inside the aperture, or opening, of the ammonite, in the upper left.

The specimen was collected from the San Felipe Formation (Upper Cretaceous, ~75 million years old) northeast of Monclova, Coahuila, Mexico. Professor Emeritus Keith Young, University of Texas at Austin, identified the ammonite as probably *Parapuzosia boesei.*

Fossil ammonites and nautiloids were cephalopods with external shells divided into chambers by transverse plates called septa. The animal lived in the outermost chamber. Most fossil cephalopods have well-developed shells that may be coiled in various ways. Modern cephalopods are highly developed marine mollusks and are represented by the pearly nautilus, octopus, and squid.

Ammonites are characterized by thick, strongly ornamented shells that are symmetrical and coiled in a plane. The shells have intricate sutures with finely divided lobes and saddles. In contrast, the shells of nautiloids may be

continued on p. 247

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Notes

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THE LAURENCE S. YOUNGBLOOD ENERGY LIBRARY

Cory Beck[1]

Introduction

The Laurence S. Youngblood Energy Library is located on the second floor of the Sarkeys Energy Center (Fig. 1). Named in memory of prominent Oklahoma oil man Laurence S. Youngblood by his wife, Loyce L. Youngblood, who donated the funds for the library's furnishings and decor, the library holds the combined geological collections of the Oklahoma Geological Survey and the University of Oklahoma (OU). Through the generous support of Mrs. Youngblood, the library is also home to some of the most impressive geologic attractions on OU's Norman campus. Spectacular building stones, minerals, and fossils—including beautiful fossiliferous limestone, swordlike selenite crystals, and a giant ammonite—are on display.

Building Stones

Cedar Park Limestone

The first geologic feature you may notice as you approach the Youngblood Library is the veneer of cream-colored fossiliferous Cedar Park Limestone on the walls of the gallery outside the library, in the entrance, and on the circulation counter (Fig. 2). The Cedar Park Limestone, known throughout the world for its texture and aesthetic qualities, is used for interior and exterior decoration. In addition to the Youngblood Library, it also can be seen in the San Jacinto Monument in Houston, Texas; in the Central Methodist Episcopal Church in Brooklyn, New York; on some oceangoing luxury liners; and even in buildings as far away as Osaka, Japan (Barnes, 1958; Texas Quarries Inc., unpublished company literature, 1998).

The Cedar Park Limestone has been quarried in Williamson and Travis Counties, in central Texas north of Austin, since 1929, and it is estimated that more than 10 million cubic feet of the stone had been quarried through the late 1950s (Barnes, 1958). The Cedar Park Limestone is sold under one of two names, based on the number and size of the fossil-shell casts it contains: (1) Cordova Cream, primarily an oolitic limestone that is largely free of shell markings and voids; and (2) Cordova Shell (the stone featured in the library), a shelly limestone with numerous fossil casts. The Cordova Shell is quarried from a 4-ft-thick layer within the Cedar Park Limestone (Walnut Formation, Fredericksburg Group) (Barnes, 1958).

The Cedar Park Limestone was deposited about 105 million years ago, during the Early Cretaceous Period of the Mesozoic Era; at that time, a shallow inland sea covered much of what is now the southern United States, including Texas and the

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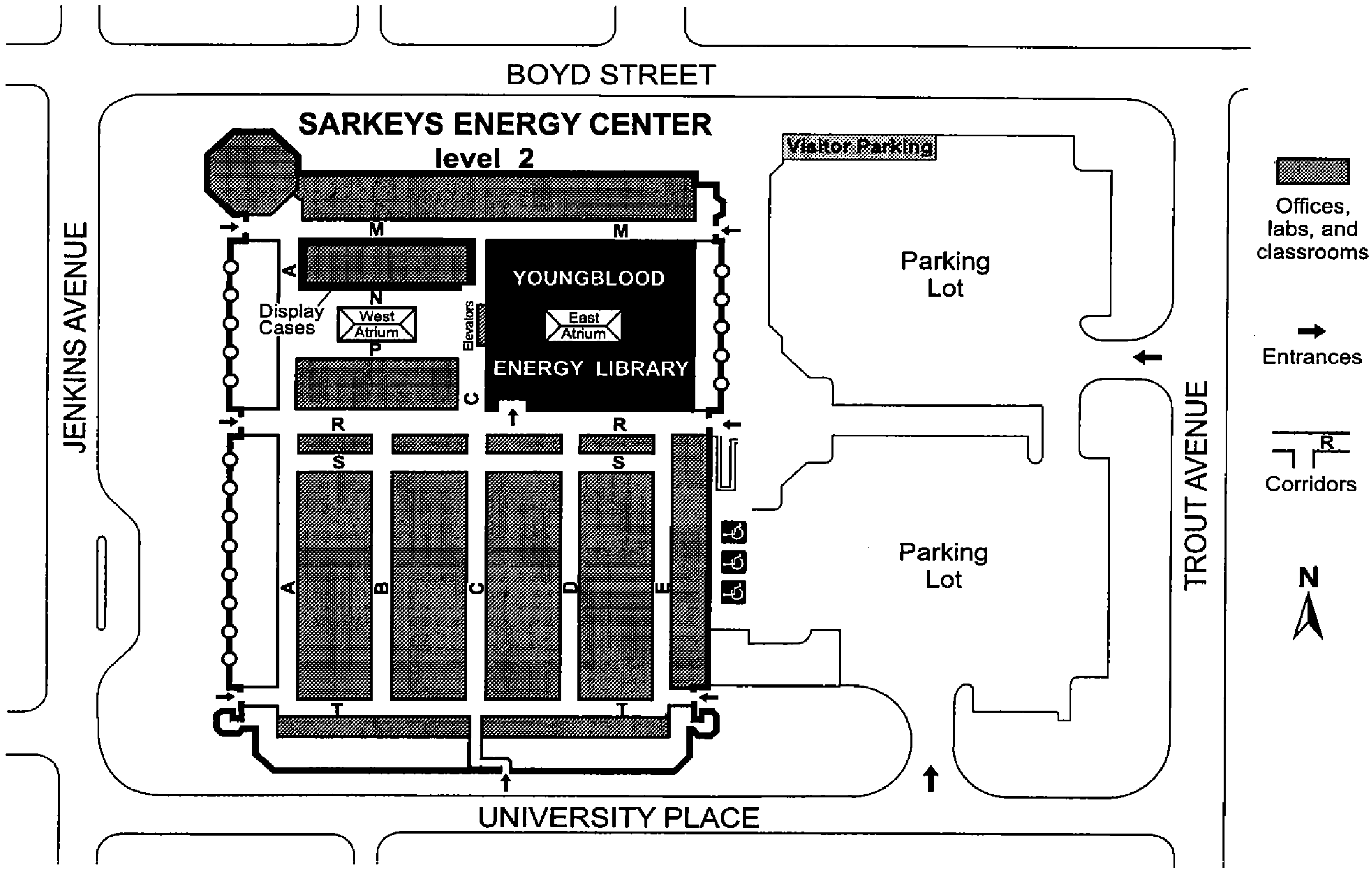


Figure 1. Map of the Laurence S. Youngblood Energy Library on the second floor of the Energy Center. For information about library hours and parking, call (405) 325-6451.

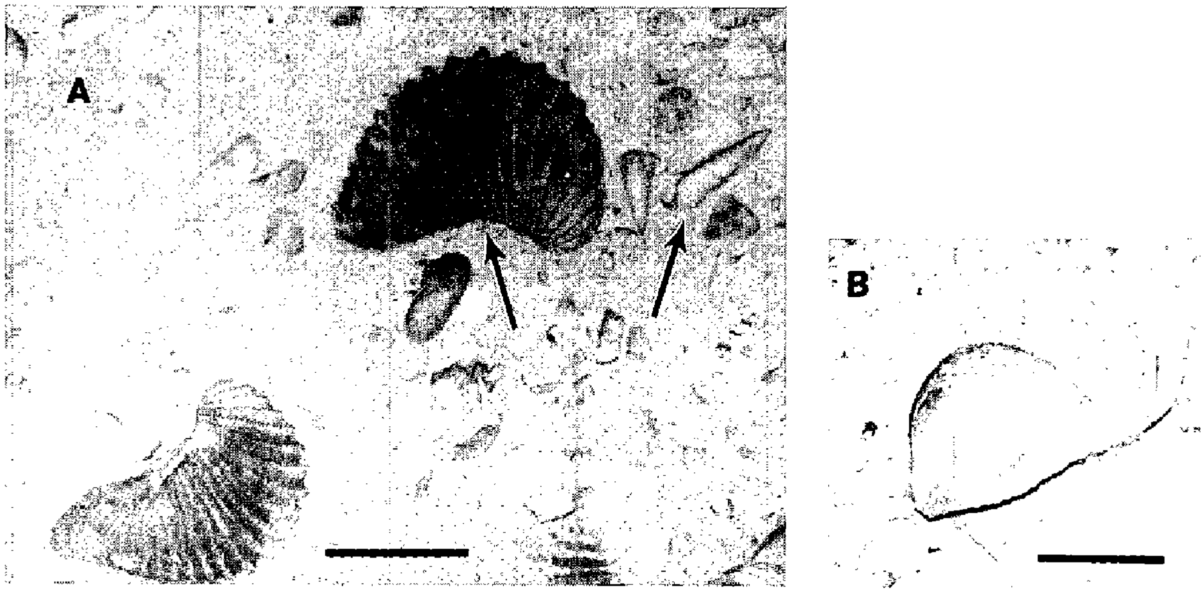


Figure 2. The Cedar Park Limestone contains many fossils, such as (A) *Trigonia clavigera* (left arrow), and *Turritella* (right arrow); (B) *Protocardia texana;* and (C) *Exogyra.* Scale = approximately 1 in.

Photos by Richard Bedard

southeastern part of Oklahoma (Worrall and Snelson, 1989). This shallow sea was inhabited by organisms that extracted dissolved calcium carbonate from the water to form shells and other hard parts. When the animals died, their shells were incorporated in the sediment on the bottom of the sea that eventually formed the limestone.

Perhaps the most obvious fossil in the Cedar Park Limestone is the relatively large *Trigonia clavigera* (Sellards and others, 1932, p. 331), a bivalve with bumpy, ribbed shells shaped like orange sections (Fig. 2A). More abundant, but smaller, is *Turritella,* a corkscrew-shaped gastropod. Appearing less commonly are two bivalves, *Protocardia texana* (Fig. 2B) and *Protocardia securiformis. P. texana* has fine ribs that are concentric over most of the shell, but are radial on one end; *P. securiformis* is similar in appearance, but is smaller and more triangular (Tom Stanley, personal communication, 1998). An uncommon fossil in the Cedar Park is *Exogyra,* a Cretaceous oyster (Fig. 2C).

Quartz Monzonite

Another distinctive building stone in the Youngblood Library is the reddish-brown quartz monzonite that creates the floor and the countertop. Quartz monzonite has been quarried from the Saint Didace Massif in the Grenville tectonic province near Saint Alexis des Monts, Quebec, Canada, since the late 1960s (Nantel, 1983). Commonly, it is used as a dimension or facing stone (as in the Youngblood Library), but it is also used as a structural or monument stone.

The stone was formed during the Grenville mountain-building episode that took place between 1.2 and 1.0 billion years ago in the Proterozoic Eon (Hoffman, 1989). The rock formed deep below the earth's surface as high-temperature magma cooled slowly to form large crystals called phenocrysts. The phenocrysts are surrounded by a fine-grained crystalline matrix (groundmass), thus forming what geologists call a porphyritic texture. The mineral composition is approximately 15% quartz (clear, gray mineral), 55% alkali feldspar (large, tabular, pink to brownish-red, well-formed crystals), 20% plagioclase feldspar (light to medium gray, granular mineral that is difficult to distinguish from quartz), and 10% hornblende and biotite (black crystals, most of which are small and granular, but some of which are as long as 0.5 in.). Although this rock is called "quartz monzonite" commercially, many geologists actually would classify it as a quartz syenite because 10–35% of the feldspar is plagioclase, whereas quartz monzonite contains 35–65% plagioclase (e.g., Barker, 1983, p. 92).

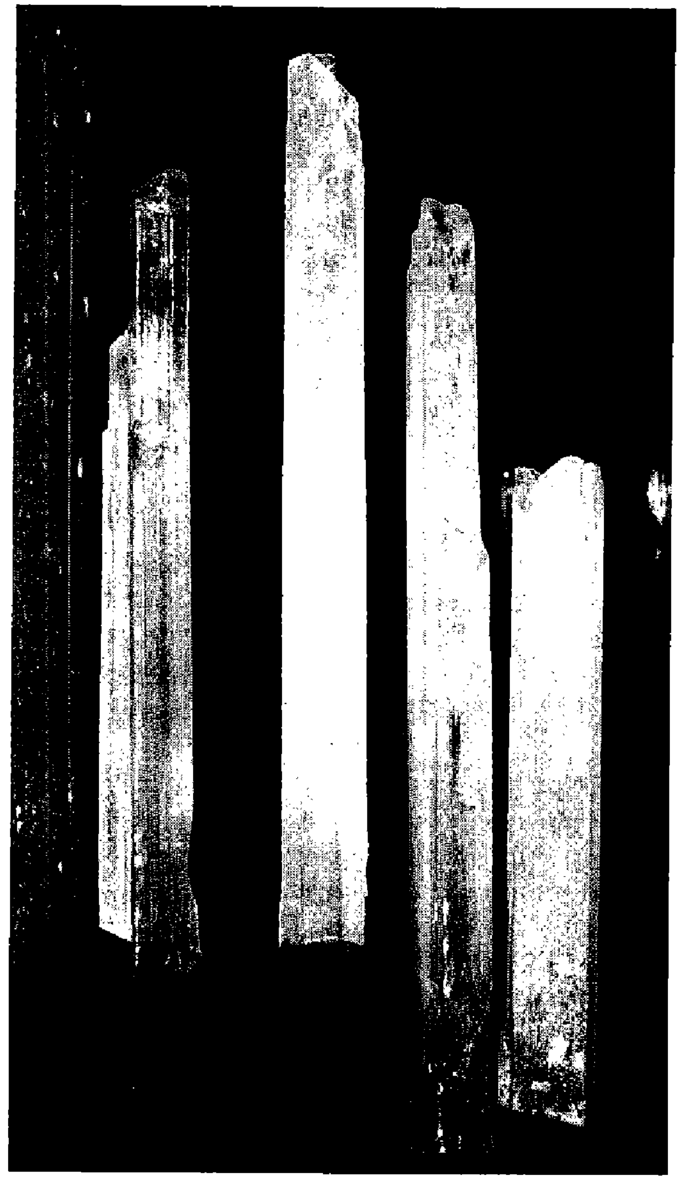
An interesting point is that the Youngblood Library actually contains quartz monzonite from a second location in addition to that from Quebec (Dave Stapleton, personal communication, 1997). Because of unforeseen problems during construction, builders ran out of the Canadian quartz monzonite. However, they found a nearly identical substitute from Milbank, South Dakota, marketed as Dakota Mahogany. (Dakota Mahogany was used to build the Franklin Delano Roosevelt Memorial in Washington, D.C.) This rock is about 2.6 billion years old (Sims, 1990). Look closely at the Canadian stone on the floor as you enter the library. Next, look at the stone from South Dakota on the floor below the southwest window of the atrium. Can you see a difference? The two stones are such a close match that even most experts cannot tell the difference. If you look closely, however, you may be able to note that the South Dakota stone has a few more dark veinlets throughout. Such veinlets are uncommon in the Canadian stone (Dave Stapleton, personal communication, 1997).

Selenite Crystals

Next, note the large, clear-to-translucent, swordlike crystals that are on display in the alcove in the southwest corner of the library entrance (Fig. 3). These crystals are selenite, a crystalline form of the mineral gypsum (hydrated calcium sulfate, $CaSO_4 \cdot 2H_2O$). They are 4–5 ft long and were collected from one of the "rooms" of the Caverna de Santo Domingo near Santa Eulalia, Chihuahua, Mexico (Panczner, 1996). Originally, the crystals were thought to have come from the Cave of Swords of the Gibraltar Mine near Naica, Chihuahua, probably because the library's selenite crystals are very similar to those described from the Cave (Panczner, 1987, p. 221). The Caverna de Santo Domingo, like the Cave of Swords, is in limestone and is associated with an active mine that is extracting sulfide-ore minerals.

The geological age of these crystals is not known, but they must be younger than the Cretaceous limestone in which they occur. The crystals at the Caverna de Santo Domingo probably formed in about the same way as those at the Cave of Swords. As water migrated through the ore-rich rocks in the area, it dissolved the sulfide ores to produce sulfuric acid, which reacted with limestone (calcium carbonate). As the water became saturated with calcium and sulfate, gypsum precipitated out of solution in the form of large selenite crystals (Johnson, 1963). These crystals turn a cave into a geological wonderland. Panczner (1996, p. 74) described his first trip into the Caverna de Santo Domingo, where selenite, other kinds of gypsum, and fluorite crystals covered floors, ceilings, and walls:

> My mining light reflected off countless thousands of crystals. I felt like I was crawling into a giant geode!...The crystals ranged from small, finger-sized specimens to crystals as large as our arms and legs, and *bigger!*
>
> The cave is made up of three galleries, or rooms. The main room is just over 350 feet long, 30 feet wide and 45 feet from the floor to the ceiling. There are two smaller side rooms which are about 30 to 40 feet long, 30 feet wide and 10 to 15 feet tall. All the rooms contained water-clear selenite crystals, but the largest crystals are found in the main gallery. The longer crystal[s] were formed in cluster sprays which were over 20 feet in diameter. In the far end of the gallery was a cluster of opaque milky-white crystals about 18 inches in diameter and up to 9 feet long! The longer crystal I could physically measure was 12 feet 10 inches long! but there were three crystals which appeared to be longer, but could not be reached to be measured.



Richard Bedard

Figure 3. Clear sword-shaped selenite crystals are about 3.0–4.5 ft long and were once probably part of a much larger cluster of crystals.

Fossils

Fossils are naturally preserved remains (or, more commonly, traces of remains) of organisms that lived in the past. Like living organisms, fossils are classified by kingdom, phylum (also division), class, order, family, genus, and species. Kingdom is the most general category, and species is the most specific. Most of the fossils in the Youngblood Library are in the kingdom Animalia and in the phyla Mollusca or Echinodermata. There is one display of fossils in the kingdom Plantae.

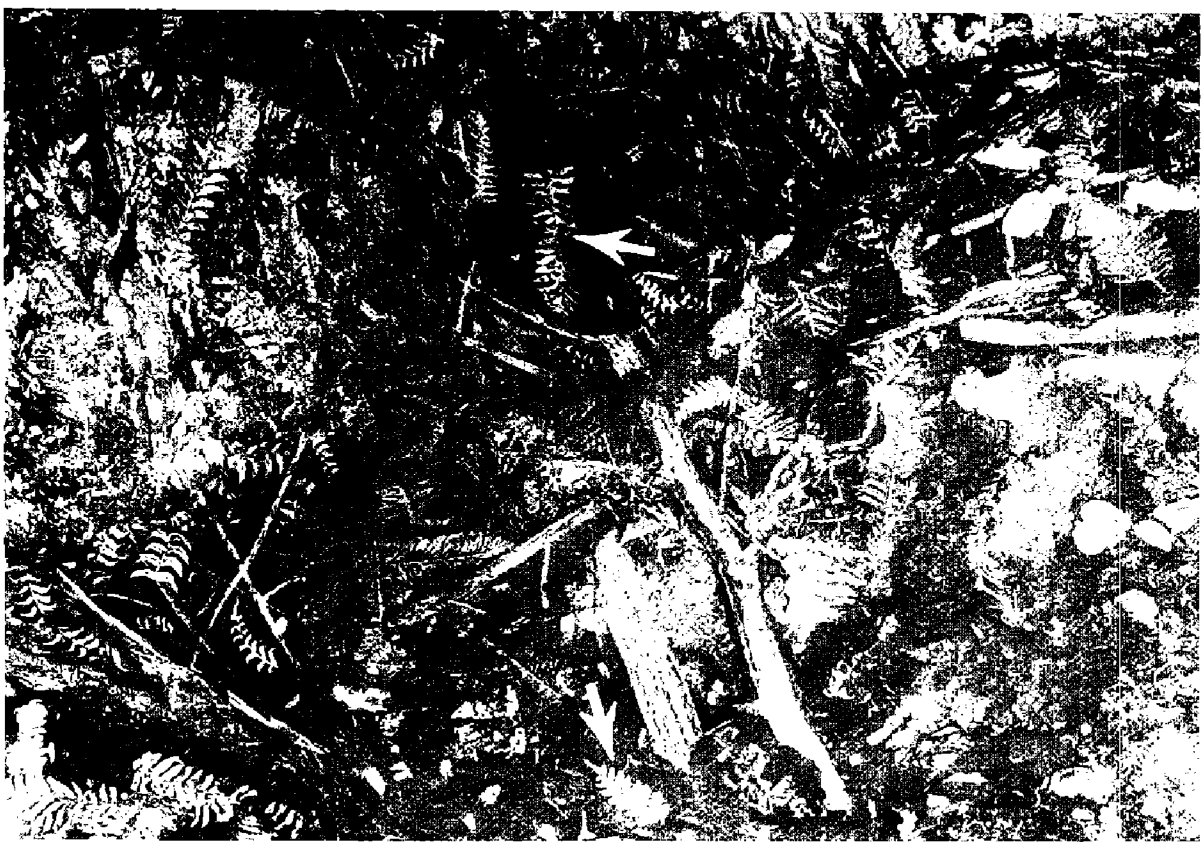
Plant Slab

The large slab containing well-preserved plant fossils (on the wall opposite the selenite crystals, to the left of the check-out counter) is about 300 million years old (Middle Pennsylvanian) (Fig. 4). It comes from the Llewellyn Formation in the southern anthracite coal fields of eastern Pennsylvanian. The slab is composed mostly of organic-rich shale formed by the compaction of clay, silt, and plant remains. The plants contained in the slab are an extinct division of gymnosperm known as Pteridospermophyta, or seed ferns. (A living order of gymnosperms are the conifers.) Small insects also are scattered throughout the slab.

The abundant plants in the Llewellyn Formation indicate that this part of the North American continent had a swampy environment during the Pennsylvanian Period. The swampy regions periodically were covered by an inland sea and then were reexposed. No fewer than 50 of these cycles occurred during the Pennsylvanian (C. W. Harper, personal communication to Claren Kidd, 1997).

The slab contains several distinctly different plant types. Look closely at the slab and see if you can identify some of the plants. Two of the more common plant fossils, *Neuropteris* and *Alethopteris*, can be distinguished by the shape of their leaves: *Neuropteris* has oval leaflets that alternate on either side of the stem; *Alethopteris* has long bladelike leaflets that are wider at their bases.

Why are all the plants white? The white color seems unusual, given that the plants were green when alive and were covered later by black sediments. They are white because, after burial, the plant tissue was replaced by minerals. During the early stages of the consolidation of the sediment, pyrite (an iron sulfide mineral—FeS_2) replaced the plant material; later, the pyrite was replaced by a white talclike mineral called pyrophyllite (Association of American State Geologists, 1982).



James H. Anderson

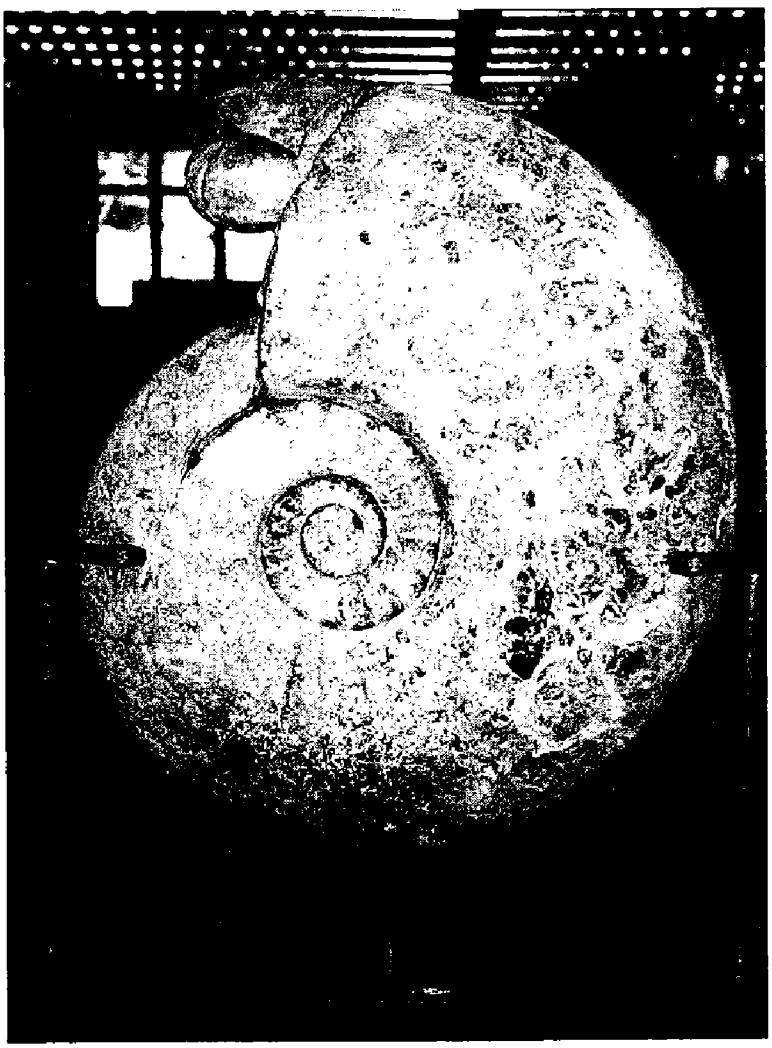
Figure 4. Well-preserved fossils of extinct seed ferns (gymnosperms), including *Alethopteris* (top arrow) and *Neuropteris* (bottom arrow), are present in this slab (approximately 4 ft × 6 ft) of fossiliferous shale from the Llewellyn Formation in Schuylkill County, Pennsylvania. The formation is Middle Pennsylvanian in age.

Cephalopods

Large Ammonite

One specimen in the Youngblood Library may be the most spectacular geological attraction on the OU campus. It is the giant snail-like creature, called an ammonite, under the arch in the entrance, adjacent to the large reading area (Fig. 5). An interesting feature of this specimen is the nautiloid nestled within the aperture. (See the discussion of the Cephalopod Slab, below, for more about nautiloids.)

This very large ammonite specimen, which was collected from the San Felipe Formation near Monclova, Coahuila, Mexico, is a member of the phylum Mollusca, class Cephalopoda, subclass Ammonoidea. Genus and species probably are *Parapuzosia boesei*, which lived in the Late Cretaceous, about 75 million years ago (Keith Young, personal communication to Claren Kidd, 1990). Although ammonites may look like snails superficially, they actually were ancient relatives of modern-day cephalopods such as the squid and the nautilus (Stearn and Carroll, 1989). Ammonoids (subclass Ammonoidea) first appeared about 400 million years ago, during the Devonian Period, and became extinct at the end of the Cretaceous, about 65 million years ago; ammonites (order Ammonitida) first appeared in the Early Jurassic (about 200 million years ago) and became extinct at the end of the Cretaceous (Stearn and Carroll, 1989). The Early Jurassic to Late Cretaceous is sometimes referred to as the "Era of Ammonites" because of the large number of species that flourished at that time.



Richard Bedard

Figure 5 *(and cover photo)*. This Late Cretaceous giant ammonite (probably *Parapuzosia boesei*) was collected in Mexico. It is about 3 ft in diameter. A nautiloid is nestled into the last remaining chamber (upper left). (Note: Conventionally, fossil coiled cephalopods are displayed with the aperture at the top, as in this specimen. In the living animal, the shell was oriented so that the aperture was at the bottom.)

The morphology of the shell that protects its soft body is an ammonite's most distinctive feature. The shell is divided into chambers by partitions called septa, which represent "growth rings" of the animal. An ammonite began its life at what would become the very center of its shell; as it grew, it secreted a series of increasingly larger living chambers for its body and abandoned and sealed off each earlier chamber with a septum. Through a tube called a siphuncle, which extends through the empty chambers, the ammonite filled the vacated chambers with gas and controlled buoyancy, so that the animal could rise or sink in the sea (Stearn and Carroll, 1989).

The body of the ammonite, much like that of the octopus or squid of today, was composed of a continuous soft muscle, and is rarely preserved. A large part of the body resided in the shell, and its long tentacles extended outside the shell so that the animal could grasp food to feed itself. Modern cephalopods (as were, presumably, the extinct ammonites) are carnivores and scavengers that feed on small animals that live near the bottom of the ocean (Stearn and Carroll, 1989). Some paleontologists think that many varieties of ammonites lived in "schools," much like modern squids.

As you look at this specimen, notice the shape of the septal sutures, which form where the septa meet the inner surface of the shell wall. The sutures are the intricately curved lines most readily visible on the outermost curved shell near the base of the specimen. The sutures on this ammonite are highly curved and jagged; small, secondary crinkles appear to have formed on larger folds. The reason for this is relatively simple—strength. It is thought that the curved and folded sutures increased the strength of a shell and allowed an ammonite to withstand increased hydrostatic pressure and to survive at great depths. Relatively straight sutures are typical of more primitive (older) ammonoids, whereas complex sutures characterize more evolved ammonoids such as the ammonites (Lane, 1986).

Small Ammonite

There is another ammonite specimen on the table just below the photographic portrait of Laurence S. Youngblood at the entrance to the reception area (Fig. 6). Although this specimen is much smaller, it is no less impressive. This species of ammonite (*Pachydiscus catarinae*) (Marc Momberger, personal communication, 1998), also Late Cretaceous in age, was one of the last to exist; it, and all other species of ammonites, became extinct about 65 million years ago, at about the same time that the dinosaurs died out.

Specimens of *Pachydiscus catarinae* (which literally means "thick disc of Catarina") are found in the Rosario Formation (Beal, 1948) of La Mision, Baja California, Mexico, in large boulders. Only 10% of the boulders contain ammonites, and only a small percentage of those contain ammonites approaching the quality of this specimen (J. R. Chaplin, personal communication to Claren Kidd, 1990).

The sutures on this specimen are better preserved than those of the large ammonite. Both, however, are curved and jagged and could indicate that the animal lived (or at least had the capacity to live) relatively deep in the ocean.

Cephalopod Slab

Next, examine the rare and well-preserved assemblage of fossil cephalopods hanging on the gallery wall outside the library (Fig. 7). The ammonoids (*Manticoceras*) (R. E. Crick, personal communication to Claren Kidd, 1991) displayed here are much older than those described above. These specimens are Late Devonian in

Figure 6. This smaller ammonite (*Pachydiscus catarinae*), also Late Cretaceous in age, is ~15 in. in diameter. The species became extinct about 65 million years ago.

age (about 365–385 million years old); they lived long before the Cretaceous ammonites described above.

The straight, conical fossils *(Michelinoceras)* (R. E. Crick, personal communication to Claren Kidd, 1991) on the slab are nautiloids, members of the subclass Nautiloidea, which appeared in the Cambrian (about 600 million years ago) and still have living representatives (modern-day nautilus). Nautiloids also produced septa as they grew and lived much like ammonites; most of them probably were free-swimming, but others may have lived on the bottom of the ocean (Fortey, 1991).

You might also notice, in the middle of the slab, a fossil that looks like a cross between a nautiloid and an ammonite. Actually, it is a coiled nautiloid that belongs to the genus *Nephriticeras* (Tom Stanley, personal communication, 1998). One of the most interesting features of this fossil slab from northern Africa is the very rare occurrence of an ammonite and two nautiloids in the same specimen.

Crinoid

Now, turn your attention to the fossilized "sea lily" that hangs on the southwest wall of the gallery outside the library (Fig. 8). Calling this fossil a sea lily is a bit deceiving, for it actually is an animal in the class Crinoidea and phylum Echinodermata (the same phylum that contains the starfish and the sand dollar). However, it is easy to understand why a crinoid would be compared to a flower, because it appears to have roots, a stem, and petals. The main part of a crinoid, the cup (or, calyx), is attached at the bottom to a slender, stalklike column, which is composed of a single stack of calcite plates (columnals); long arms stretch from the top of the calyx. The arms and calyx of a crinoid are also composed of calcite plates (Fortey, 1991; Stearn and Carroll, 1989).

Crinoids, which survive to the present, have existed since the Middle Cambrian Period (about 550 million years ago) (Stearn and Carroll, 1989). This particular fossil is *Seirocrinus subangularis* (family Pentacrinitidae) and is believed to have come from Holzmaden, Baden-Württemberg, Germany (southeast of Stuttgart). It is estimated to be about 180 million years old (Early Jurassic). It is encased in fine claystone and siltstone that form the Posidonia Shale, some of which has been partially removed to better expose the specimen.

Richard Bedard

Figure 7. This slab (approximately 3.5 ft × 6.5 ft) of former marine sediments from Morocco contains well-preserved cephalopod fossils. It is rare to find this combination of the ammonite *Manticoceras* and both straight (*Michelinoceras*) and coiled (*Nephriticeras*) nautiloids together.

In this specimen the rootlike structure by which it was attached to the sea bottom (or to some object on the bottom) is missing, but a segment of the long, thin, flexible stem and the lilylike crown of its food-gathering arms are remarkably well preserved. On the arms, you may be able to see the featherlike pinnules, which assisted in filtering minute organisms from the sea water. The small calyx, which encloses the body in this species, is not easy to see in the specimen.

If you look very closely at the matrix containing the crinoid, you might see several examples of the pelecypod *Posidonia bronni*.

Conclusion

Spectacular building stones, minerals, and fossils are on display in the Laurence S. Youngblood Energy Library, where students and visitors to the OU campus can examine the specimens closely. In addition, Claren Kidd, head librarian, is happy to answer questions about the Youngblood Library.

Acknowledgments

Claren Kidd, head librarian at the Laurence S. Youngblood Energy Library, provided me with a great deal of the information presented here on the library's collection. In turn, she received help from Jim Chaplin and Ken Johnson (Oklahoma Geological Survey [OGS]) and Dave London and Pat Sutherland (OU School of Geology and Geophysics) on identifying some of the specimens and obtaining information on where they were collected. The manuscript was greatly improved by the comments of Frances Young (OGS technical editor) and Neil Suneson (OGS reviewer).

Figure 8. The 8-in. crown of the Jurassic crinoid, *Seirocrinus subangularis*, clearly shows the well-preserved arms, as well as a portion of its slender column.

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Giant Ammonite *(continued from p. 234)*

straight, curved, or coiled, and they have simple sutures. Nautiloids survived the great extinction at the end of the Cretaceous, but ammonites, like the dinosaurs, did not.

Large ammonites—though not as large as the library specimen—are common in the lower part of the Duck Creek Member of the Caddo Formation (Washita Group) in south-central Oklahoma. The Duck Creek Member is Early Cretaceous in age (~100 million years old) and contains the ammonite *Eopachydiscus brazoensis* (Shumard), which is commonly about 1 ft in diameter. The genus name is derived from Greek and Latin: *eo* = early (Gk.); *pachy* = thick, fat (Lat.); *discus* = disk (Lat.); the species name is derived from the Brazos River area of Texas, where the species was first described.

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Claren M. Kidd and Neil H. Suneson

Photograph by Richard Bedard
Fayetteville, Arkansas

MINERAL INDUSTRY OF OKLAHOMA, 1997[1]

Oklahoma climbed to 32nd from 34th in rank among the 50 States in total nonfuel mineral production value[2] in 1997, according to the U.S. Geological Survey (USGS). The estimated value for 1997 was $411 million, an increase of more than 11% over that of 1996. This increase followed a 3.4% increase from 1995 to 1996 (based on final 1996 data). The State accounted for 1% of the U.S. total nonfuel mineral production value.

In 1997, crushed stone and portland cement continued as Oklahoma's top two nonfuel mineral commodities, accounting for about 33% and 30%, respectively, of the State's total nonfuel mineral value. The combined values of construction materials—crushed stone, portland and masonry cements, construction sand and gravel, and gypsum, in descending order of value—accounted for 77% of the total value. Oklahoma's increase in value in 1997 mostly resulted from the higher values of crushed stone, iodine, salt, construction sand and gravel, and portland cement, in descending order of increase (Table 1). Only common and fire clays and crude helium showed relatively small value decreases, while industrial sand and gravel and feldspar remained at the same levels. In 1996, an increase in portland cement was balanced out by an equal decrease in crushed stone. Most other nonfuel minerals had relatively small increases in value, resulting in the State's net increase. Tables 2–4 show, respectively, the quantity and value of crushed stone sold or used in Oklahoma by kind, use, and district; Tables 5 and 6 show, respectively, the quan-

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[1]From U.S. Geological Survey Minerals Yearbook, 1997, v. 2—Area reports: domestic, Oklahoma chapter. Prepared under a Memorandum of Understanding between the U.S. Bureau of Mines, U.S. Department of the Interior, and the Oklahoma Geological Survey for collecting information on all nonfuel minerals. Kenneth S. Johnson, Oklahoma Geological Survey associate director, wrote the text of state mineral information submitted by the OGS. The text, tables, and map of Oklahoma (Fig. 1) were retrieved from the USGS World Wide Web site at http://minerals.er.usgs.gov/minerals/pubs/state/ok.html#myb. The text and tables are the PDF file labeled "The Mineral Industry of Oklahoma, 1997"; the map is PDF file "Map of Principal Mineral-Producing Localities"; both files can viewed with the free Adobe Acrobat Reader that can be downloaded from the same site.

[2]The terms "nonfuel-mineral production" and related "values" encompass variations in meaning, depending on the minerals or mineral products. Production may be measured by mine shipments, mineral-commodity sales, or marketable production (including consumption by producers) as is applicable to the individual mineral commodity.

Note: All 1996 USGS mineral-production data published in this article are estimates as of February 1997. For some commodities (e.g., construction sand and gravel, crushed stone, and portland cement), estimates are updated periodically. To obtain the most current information, please contact the appropriate USGS mineral commodity specialist. Call MINES FaxBack at (703) 648-4999 from a fax machine with a touch-tone handset, and request document no. 1000 for a telephone listing of all mineral commodity specialists, or call USGS information at (703) 648-4000 for the specialist's name and number. This telephone listing may also be retrieved over the Internet at http://minerals.er.usgs.gov/minerals/contacts/comdir.html. All mineral industry surveys—mineral commodity, state, and country—also may be retrieved by way of MINES FaxBack or over the Internet at http://minerals.er.usgs.gov/minerals/.

TABLE 1.—NONFUEL RAW MINERAL PRODUCTION IN OKLAHOMA[a,b]
(thousand metric tons and thousand dollars unless otherwise specified)

	1995		1996		1997	
Mineral	Quantity	Value	Quantity	Value	Quantity	Value
Cement:						
Masonry	95	$7,248	101	$8,849[c]	89	$6,499[c]
Portland	1,740	110,096	1,745	117,591[c]	1,898	131,530[c]
Clays						
Common	674	3,579	799	4,090	653	4,426
Fire	—	—	23	W	—	—
Gemstones	NA	W	NA	603	NA	354
Gypsum, crude	2,831	17,003	2,694	16,549	3,099	17,484
Iodine, crude (metric tons)	1,207	12,466	1,274	14,617	1,321	19,640
Sand and gravel:						
Construction	7,800	25,107	7,905	27,686	8,254	28,999
Industrial	1,249	25,363	1,349	27,189	1,379	28,231
Stone:						
Crushed[d]	31,053	124,784	28,330	117,366	31,871	112,056
Dimension (metric tons)	9,172[d]	2,354[d]	9,710	2,220	5,773	995
Combined value of feldspar, helium (crude, Grade-A [1996–97]), lime, salt, stone (crushed shell and traprock [1995–96], crushed shell, traprock, and misc. [1997], dimension quartzite and sandstone [1995]), tripoli, and values indicated by symbol W	XX	28,676	XX	32,339	XX	35,817
Total	XX	**$356,676**	XX	**$369,099**	XX	**$386,031**

Dashes (—) indicate that no production was reported.
NA = Not available.
W = Withheld to avoid disclosing company proprietary data; value included with "Combined value" data.
XX = Not applicable.
[a]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[b]Data are rounded to three significant digits; may not add to totals shown.
[c]Estimated.
[d]Excludes certain stones; kind and value included with "Combined value" figure.

tity and value of construction sand and gravel sold or used in Oklahoma by major use category and district. The general distribution of Oklahoma's nonfuel mines is shown in Figure 1.

Oklahoma's mines exclusively produced industrial minerals; no metals were mined in the State. Based on USGS estimates of the quantities produced in the 50 states during 1997, Oklahoma remained the only state that produced iodine; first in crude gypsum; second of four states producing tripoli; third of three crude helium-producing states; fifth in feldspar; and eighth in industrial sand and gravel. Additionally, significant quantities of crushed stone, portland and masonry cements, and common clays were produced in the State.

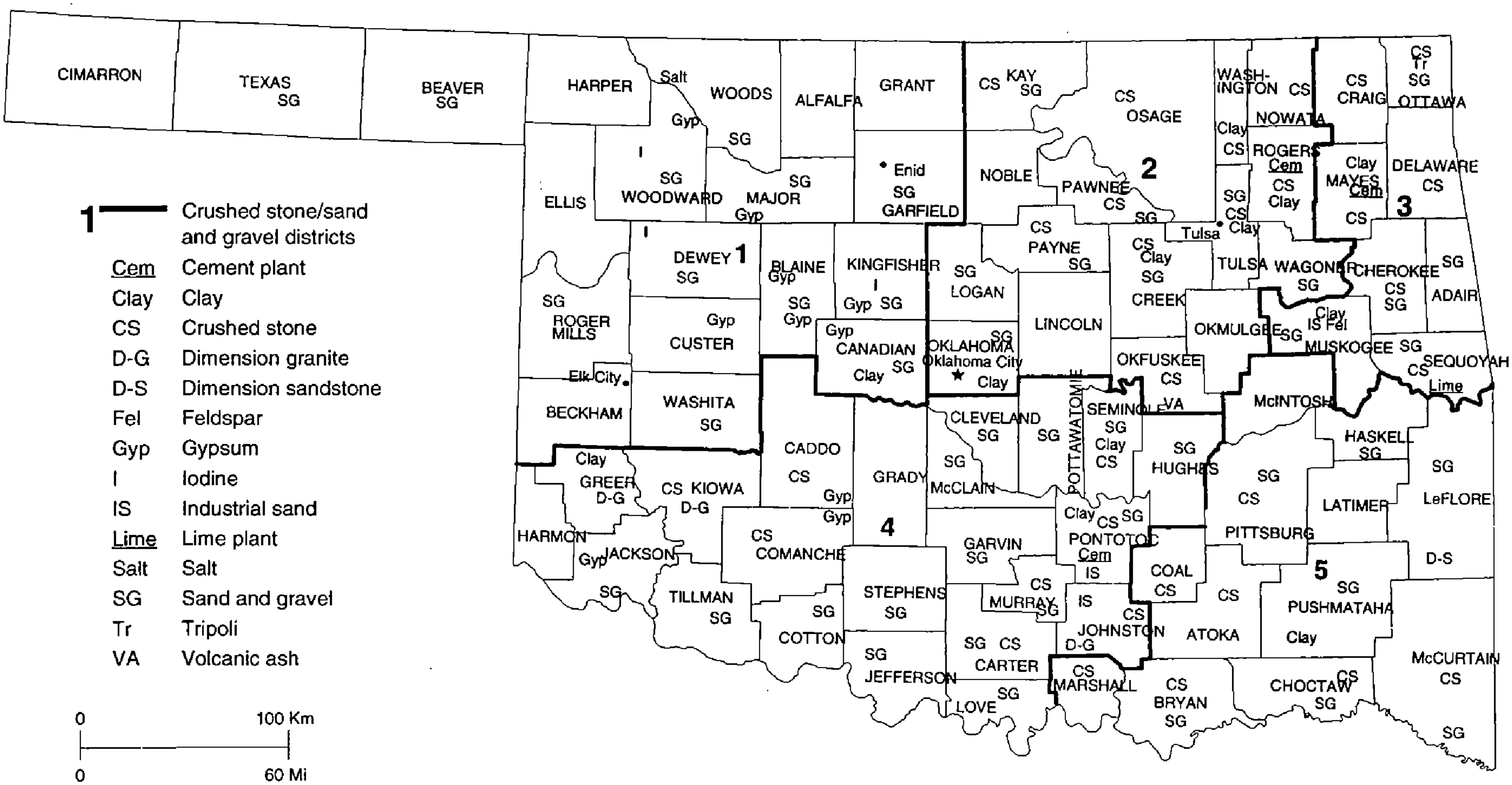

Figure 1. Principal mineral-producing localities in Oklahoma.

TABLE 2.—OKLAHOMA: CRUSHED STONE SOLD OR USED, BY KIND[a]

Kind	1995 Number of quarries	1995 Quantity (thousand metric tons)	1995 Value (thousands)	1995 Unit value	1996 Number of quarries	1996 Quantity (thousand metric tons)	1996 Value (thousands)	1996 Unit value
Limestone	46[b]	21,700[b]	$88,500[b]	$4.07	45	21,000	$82,800	$3.95
Dolomite	5[b]	3,830[b]	16,100[b]	4.20	5	2,990	12,600	4.20
Granite	3	W	W	5.21	3	W	W	5.15
Traprock	1	1,490	(c)	(c)	(c)	(c)	(c)	(c)
Sandstone	5	W	W	4.93	6	W	W	4.96
Shell	(c)	(c)	(c)	(c)	(c)	(c)	(c)	(c)
Slate	1	12	66	5.50	1	15	84	5.60
Miscellaneous stone	1	27	118	4.37	1	91	402	4.42
Total or average	**XX**	**31,100**	**$125,000**	**$4.01**	**XX**	**28,300**	**$117,000**	**$4.14**

W = Withheld to avoid disclosing company proprietary data; included in "Total."
XX = Not applicable.
[a]Data are rounded to three significant digits; may not add to totals shown.
[b]Revised.
[c]Excludes shell and traprock (1995 value only) from State total to avoid disclosing company proprietary data.

The following narrative information was provided by the Oklahoma Geological Survey (OGS), which reported that industrial-mineral activity in the State continued to increase during 1997. Production has been level or has been rising steadily over the past several years for several of the major commodities, including gypsum for wallboard and plasters; crushed stone for aggregate, railroad ballast, and fill; cement for highways, housing, and commercial buildings; iodine for pharmaceuticals, disinfectants, and animal feed; dimension stone for houses and commercial buildings; and sand and gravel for various construction projects. Construction activities that held steady or increased somewhat in 1997 included highway construction and residential and commercial building.

In 1997, gypsum production dropped slightly, but the price underwent a moderate increase. Most Oklahoma wallboard plants operated at near-capacity during the year, and there was little room to expand to meet the rising national and regional demand. Republic Gypsum Co. is now adding a second board line at its plant in Duke, Jackson County (southwest Oklahoma); this will significantly increase the company's capacity by the end of 1998.

Crushed-stone demand rose in 1997, due largely to highway construction, the need for granite and rhyolite as railroad ballast, and the need for aggregate on roads and drilling pads in the oil and gas drilling business. Most Oklahoma highways are now being built with a concrete surface, which increases the demand for aggregate and cement.

Iodine production increased slightly during 1997, but the value rose significantly above that of 1996. The price of iodine held steady at about $18 per kilogram during most of the year, which was a significant increase over the $11 to $15 per kilo-

TABLE 3. — OKLAHOMA: CRUSHED STONE SOLD OR USED BY PRODUCERS IN 1996, BY USE[a,b]

Use	Quantity (thousand metric tons)	Value (thousands)	Unit value
Coarse aggregate (+1½ in.):			
Riprap and jetty stone	140	$987	$7.05
Filter stone	81	433	5.35
Other coarse aggregate	W	W	5.00
Coarse aggregate, graded:			
Concrete aggregate, coarse	2,550	13,000	5.10
Bituminous aggregate, coarse	997	5,860	5.87
Bituminous surface-treatment aggregate	367	2,390	6.52
Railroad ballast	697	3,820	3.34
Other graded coarse aggregate	W	W	4.81
Fine aggregate (–⅜ in.):			
Screening, undesignated	966	2,320	2.40
Other fine aggregate[c]	356	1,450	4.08
Coarse and fine aggregates:			
Graded road base or subbase	2,170	7,890	3.64
Unpaved road surfacing	W	W	4.88
Terrazzo and exposed aggregate	W	W	4.83
Crusher run or fill or waste	1,650	6,450	3.90
Other coarse and fine aggregates	W	W	3.92
Other construction materials[d]	348	1,500	4.32
Agricultural limestone	([e])	([e])	3.82
Chemical and metallurgical:			
Cement manufacture	([e])	([e])	2.81
Flux stone	([e])	([e])	4.54
Special, other fillers or extenders	([e])	([e])	6.62
Unspecified:[f]			
Actual	13,700	55,500	4.05
Estimated	1,910	7,530	3.95
Total or average	**28,300**	**$117,000**	**$4.14**

W = Withheld to avoid disclosing company proprietary data; included with "Other construction materials."

[a]Includes dolomite, granite, limestone, miscellaneous stone, sandstone, and slate; excludes shell and traprock from State total to avoid disclosing company proprietary data.

[b]Data are rounded to three significant digits; may not add to totals shown.

[c]Includes stone sand (concrete) and stone sand (bituminous mix or seal).

[d]Includes lightweight aggregate (slate).

[e]Withheld to avoid disclosing company proprietary data; included in "Total."

[f]Includes production reported without a breakdown by end use and with estimates for nonrespondents.

TABLE 4.—OKLAHOMA: CRUSHED STONE SOLD OR USED BY PRODUCERS IN 1996, BY USE AND DISTRICT[a,b,c]

(thousand metric tons and thousand dollars)

Use	District 2		District 3		District 4		District 5	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Construction aggregates:								
Coarse aggregate (+1½ in.)[d]	86	$515	W	W	W	W	W	W
Coarse aggregate, graded[e]	1,250	7,050	W	W	W	W	W	W
Fine aggregate (–⅜ in.)[f]	767	1,890	W	W	W	W	W	W
Coarse and fine aggregate[g]	1,780	6,470	W	W	W	W	1,050	4,160
Other construction materials[h]	—	—	1,450	6,130	1,780	8,630	2,160	11,200
Agricultural[i]	([j])	([j])	([j])	([j])	—	—	([j])	([j])
Chemical and metallurgical[k]	([j])	([j])	—	—	([j])	([j])	([j])	([j])
Special[l]	—	—	—	—	([j])	([j])	—	—
Unspecified[m]:								
Actual	2,690	13,000	([j])	([j])	8,890	35,800	658	2,840
Estimated	108	250	195	788	816	3,300	788	3,190
Total	**7,700**	**$31,400**	**3,130**	**$10,800**	**12,500**	**$52,200**	**4,990**	**$22,900**

Dashes (—) indicate that no production was reported.

W = Withheld to avoid disclosing company proprietary data; included with "Other construction materials."

[a]No crushed stone was produced in District 1.

[b]Excludes shell and traprock from State total to avoid disclosing company proprietary data.

[c]Data are rounded to three significant digits; may not add to totals shown.

[d]Includes filter stone, riprap and jetty stone, and other coarse aggregate.

[e]Includes concrete aggregate (coarse), bituminous aggregate (coarse), bituminous surface-treatment aggregate, railroad ballast, and other graded coarse aggregate.

[f]Includes stone sand (concrete), stone sand (bituminous mix or seal), screening (undesignated), and other fine aggregate.

[g]Includes graded road base or subbase, unpaved road surfacing, terrazzo and exposed aggregate, crusher run (select material or fill), and other coarse and fine aggregate.

[h]Includes lightweight aggregate (slate).

[i]Includes agricultural limestone, poultry grit and mineral food, and other agricultural uses.

[j]Withheld to avoid disclosing company proprietary data; included in "Total."

[k]Includes cement manufacture and flux stone.

[l]Includes other fillers or extenders.

[m]Includes production reported without a breakdown by end use and estimates for nonrespondents.

gram price in 1996. Three companies are operating four facilities in northwest Oklahoma, and the companies have drilled several new producing wells during the year.

The number of mining permits in Oklahoma dropped slightly in 1997, but the acreage under permit has risen. The Oklahoma Department of Mines (ODM) issued a total of 435 permits in 1997, covering a total of about 17,000 hectares (42,500 acres). According to ODM, many more companies are opting to obtain a Life-Expectancy Permit, as allowed under the State's 1994 law. Under this law, a company may submit a mining plan only once to cover the mine's life expectancy, instead of undergoing a permit review every 5 years. Of permits on file for 1997, ODM reports that 174 (40%) have been secured under the life-expectancy provision.

TABLE 5.— OKLAHOMA: CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN 1996, BY MAJOR USE CATEGORY[a]

Use	Quantity (thousand metric tons)	Value (thousands)	Value per ton
Concrete aggregate (including concrete sand)	3,210	$13,200	$4.11
Plaster and gunite sands	1	5	5.00
Concrete products (blocks, bricks, pipe, decorative, etc.)	152	530	3.49
Asphaltic concrete aggregates and other bituminous mixtures	308	745	2.42
Road base and coverings[b]	407	1,170	2.88
Fill	990	1,680	1.69
Other miscellaneous uses	2	27	13.50
Unspecified[c]:			
Actual	1,490	6,100	4.09
Estimated	1,340	4,240	3.16
Total or average	7,910	$27,700	$3.50

[a]Data are rounded to three significant digits; may not add to totals shown.
[b]Includes road and other stabilization (cement) and snow and ice control.
[c]Includes production reported without a breakdown by end use and estimates for nonrespondents.

TABLE 6.— OKLAHOMA: CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN 1996, BY USE AND DISTRICT[a,b]

(thousand metric tons and thousand dollars)

Use	District 1		District 2		District 4	
	Quantity	Value	Quantity	Value	Quantity	Value
Concrete aggregate and concrete products[c]	235	$896	1,560	$4,640	1,570	$8,190
Asphaltic concrete aggregates and road base materials[d]	348	804	847	1,620	510	1,170
Other miscellaneous uses	2	27	—	—	—	—
Unspecified[e]:						
Actual	739	2,530	—	—	752	3,570
Estimated	53	328	569	1,920	720	1,990
Total	1,380	$4,580	2,980	$8,190	3,550	$14,900

Dashes (—) indicate that no production was reported.
[a]Production reported in District 3 and 5 was included with "District 4" to avoid disclosing company proprietary data.
[b]Data are rounded to three significant digits; may not add to totals shown.
[c]Includes plaster and gunite sands.
[d]Includes fill, and snow and ice control.
[e]Includes production reported without a breakdown by end use and with estimates for nonrespondents.

Oklahoma hosted the 34th Forum on the Geology of Industrial Minerals on May 2–6, 1998, in Norman. This prestigious annual meeting was attended by about 175 specialists in the geology, production, and marketing of a wide range of industrial minerals throughout the United States and elsewhere in the world.

NEW OGS *Publications*

BULLETIN 146. *First Occurrence of* Deinonychus antirrhopus *(Dinosauria: Theropoda) from the Antlers Formation (Lower Cretaceous: Aptian-Albian) of Oklahoma,* by Daniel L. Brinkman, Richard L. Cifelli, and Nicholas J. Czaplewski. 27 pages. Price: $3.

The first unambiguous occurrence of *Deinonychus antirrhopus* outside of the Cloverly Formation (Aptian-Albian) of Montana and Wyoming is documented in this OGS bulletin.

Deinonychus ("terrible claw") is an Early Cretaceous dromaeosaurid, a "raptor" dinosaur closely related to the velociraptors featured in the movie *Jurassic Park.* It appears to have been a lightly built, agile predator, and may have hunted in packs.

The specimen described consists of the partial skeleton of a subadult animal. It was found in the Antlers Formation in Atoka County, Oklahoma. The specimen includes bones from every major area of the skeleton, and includes skeletal elements not preserved in any of the described specimens from the Cloverly Formation. An additional block of material that still needs to be prepared and studied probably contains additional skeletal elements. Moreover, the Oklahoma specimen, along with several presumably shed *Deinonychus* teeth, was found in association with several partial skeletons of the ornithopod dinosaur *Tenontosaurus,* which helps confirm the hypothesis that *Deinonychus* preyed upon tenontosaurs. The occurrence of these two dinosaur species together in both the Antlers and Cloverly Formations provides the most compelling biostratigraphic link yet between these two units, and indicates broad geographic distributions for at least some groups of terrestrial vertebrates in the Early Cretaceous of North America.

Author Daniel Brinkman is a Ph.D. candidate at Yale University in New Haven, Connecticut, and a research associate at the Oklahoma Museum of Natural History (OMNH) at the University of Oklahoma in Norman. Richard Cifelli is associate curator for vertebrate paleontology at the OMNH and Nicholas Czaplewski is staff curator at the OMNH.

SPECIAL PUBLICATION 98-6. *Coal Geology of McIntosh County, Oklahoma,* by LeRoy A. Hemish. 74 pages, 2 color plates. Price: $16.

Author's abstract:

McIntosh County is located in the east-central part of the coal belt of eastern Oklahoma, and almost the entire county is underlain by coal-bearing strata of Desmoinesian (Middle Pennsylvanian) age. For lack of data about coal depth and thickness, resource potential is unknown for ~75% of the county—mostly in its western and southern parts. Structural complexity further inhibits evaluation of resources.

Remaining resources of coal in the county total 36,319,000 short tons, and reserves total 5,437,000 tons. Eight coal beds have commercial potential: Stigler coal with reserves of 457,000 tons; Rowe coal—144,000 tons; Lower Witteville coal—368,000 tons; Secor coal—2,119,000 tons; Peters Chapel coal—1,003,000 tons; Wainwright coal—95,000 tons; Mineral coal—42,000 tons; and Croweburg coal—1,209,000 tons.

The coals rank predominantly as high-volatile A bituminous (hvAb). The Secor coal has the least sulfur, averaging ~2.5%. However, its sulfur varies areally, and is as high as 7.8%. The combined average sulfur content of all the other coals is 4.5%.

In the late 1980s and early 1990s, one operator was producing coal from the Secor bed, using surface methods. At the time of this publication (1998), no coal was being produced in McIntosh County.

OPEN-FILE REPORT 2-98, ***Geologic Map of the Piedmont and Bethany NE Quadrangles, Kingfisher, Logan, Canadian, and Oklahoma Counties, Oklahoma,*** and **OPEN-FILE REPORT 3-98,** ***Geologic Map of the Edmond and Arcadia Quadrangles, Logan and Oklahoma Counties, Oklahoma.*** Scale 1:24,000. Xerox copies. Price: $4.80 each, rolled in tube.

The Oklahoma STATEMAP project, which began in 1993, is a joint effort of the OGS and the U.S. Geological Survey to prepare new 1:24,000 geologic maps of Oklahoma. STATEMAP is part of the National Cooperative Geologic Mapping Program and replaces the successful COGEOMAP program, which began in 1984. Under COGEOMAP and STATEMAP, the OGS completed and published 22 7.5′ geologic quadrangle maps of the northern part of the Ouachita Mountains frontal belt and the southern part of the Arkoma basin in southeastern Oklahoma.

In 1996, the Oklahoma Geologic Mapping Advisory Committee (OGMAC), chaired by OGS Associate Director Kenneth S. Johnson, determined that new maps of the Oklahoma City metropolitan area (OCMA) were the State's highest priority for continued STATEMAP efforts. This assessment was based on the following factors: (1) the OCMA is the most populous area in the State and is undergoing rapid development; (2) it has major waste-disposal problems; (3) there are increasing demands to develop local geological resources; (4) there are hazardous-waste cleanup problems at Tinker Air Force Base; and (5) city and eastern suburbs overlie a major aquifer that provides municipal drinking water.

The Piedmont–Bethany NE Quadrangles, by Neil H. Suneson and LeRoy A. Hemish, and the Edmond–Arcadia Quadrangles, by Hemish and Suneson, were mapped in fall 1997 and spring 1998 and are the first two in a series of STATEMAP geologic maps of the OCMA. These northern OCMA quadrangles were selected because outcrops are extensive and because much of the bedrock geology to the south is covered by Pleistocene terrace deposits and Recent alluvium. Maps are one sheet each and are black-and-white, author-prepared photocopies; they consist of a geologic map, cross section, and description and correlation of units.

Planners for new highway construction, commercial and residential construction, city facilities such as waste-disposal sites, and those interested in the Garber–Wellington aquifer will find the maps useful in addressing engineering and environmental concerns.

USGS Water Resources Division Now Releasing Digital Data Sets on the Web

The USGS Water Resources Division is making its spatial data sets available on the World Wide Web for use with geographic information systems (GIS) software. Three new digital data sets recently released are:

- *Digital Base of Aquifer Map of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming* (Open-File Report 98-393).
- *Digital Map of Hydraulic Conductivity for the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming* (Open-File Report 98-548), and
- *Digital Map of Specific Yield for the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming* (Open-File Report 98-414),

Look for these digital data sets at http://water.usgs.gov/lookup/get?OFR98-414; http:/water.usgs.gov/lookup/get?OFR98-548; and http://water. usgs.gov/lookup/get?OFR98-393. Links to other digital data sets for Oklahoma aquifer characteristics are also available at the USGS web site http://wwwok.cr.usgs. gov/gis/aquifers/index.html#Aquifers.

For spatial data from the Water Resources Division's Oklahoma office, also check http://wwwok.cr.usgs.gov/public/gis.html. The downloadable files available from this Web page include simple maps; the GCIP reference data set; watershed boundaries and a digital elevation model of Oklahoma; digital surficial geology maps of Oklahoma; information about the *Digital Atlas of Oklahoma* CD–ROM; the aquifer characteristics data sets mentioned above; and mean-annual precipitation and peak-flow skew coefficients grids for Oklahoma. The home page (http://wwwok. cr.usgs.gov) also lists links to water usage data and to information on the publications prepared by the Oklahoma district office.

USGS data sets are also available on diskette. A limited number of those pertaining to Oklahoma resources are available at no charge from the USGS, Water Resources Division, 202 N.W. 66, Building 7, Oklahoma City, OK 73116, telephone (405) 810-4400, fax (405) 843-7712.

Annual Yield and Selected Hydrologic Data for the Arkansas River Basin Compact, Arkansas–Oklahoma, 1996 Water Year

J. E. Porter prepared this 62-page USGS open-file report, in cooperation with the Arkansas River Compact Commission, Arkansas–Oklahoma.

Order OF 97-0399 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $10 for a paper copy or $4 for microfiche, plus $3.50 per order for handling.

Silurian, Devonian, and Mississippian Geology and Petroleum in the Southern Midcontinent

Workshop to be held in ***Norman, Oklahoma, March 23–24, 1999***

A two-day program cosponsored by the OGS and the National Petroleum Technology Office of the U.S. Department of Energy will focus on the rocks, reservoirs, and geologic events of the Silurian, Devonian, and Mississippian Periods. The workshop is the 12th in a series designed to aid in the search for, and production of, our oil and gas resources. It will be held at the Postal Service National Center for Employee Development in southeast Norman.

Silurian, Devonian, and Mississippian rocks in the region include sandstones, limestones, and dolomites that are major petroleum reservoirs. They already have yielded large volumes of oil and gas, and they have great potential for yielding additional hydrocarbons with improved exploration and development techniques. These geologic periods were times of tectonic stability; shallow-marine carbonates and clastics dominate in most of the region, although thick shales, sandstones, and cherts were deposited in the Ouachita basin. Rock units of special interest are the Hunton, Bois d'Arc, Misener, Woodford, Chat, Osage, Mississippi lime, Chester, Manning, Stanley, Goddard, and Springer.

The workshop will consist of 17 papers presented orally and 13 informal poster presentations. It will cover the geologic setting, depositional environments, and structural and diagenetic history of these strata and/or reservoirs, as well as reservoir characterization, engineering factors that influence hydrocarbon accumulation or production, and specific field studies. The workshop will have about 200–300 participants.

The program for talks and posters is listed below:

Oral Presentations

Geology and Petroleum Reservoirs in Silurian, Devonian, and Mississippian Rocks in Oklahoma—Robert A. Northcutt, Independent Geologist; Kenneth S. Johnson, OGS; and G. Carlyle Hinshaw, Independent Geologist

Depositional Environment and Sequence Stratigraphy of Silurian to Mississippian Reservoirs in the Midcontinent—Richard D. Fritz and Ted Beaumont, Masera Corp.

Overview of the Hunton Group—Zuhair Al-Shaieb and Jim Puckette, Oklahoma State University

Utilization of Dipmeter Techniques in the Exploration for Lower Paleozoic Reservoirs in Southern Oklahoma—Robert F. Ehinger, RAM Energy, Inc.

Conodont Biofacies and Biostratigraphy in Subdividing the Upper Silurian Henryhouse Formation, South-Central Oklahoma—James E. Barrick, Texas Tech University

Geologic Setting Provides Keys to Locating the Elusive Devonian Misener Sandstone in North-Central Oklahoma—William F. Ripley, The Environment Co.

Geomorphology of the Pre-Woodford Unconformity in Northeastern Oklahoma—George W. Krumme, Krumme Oil Co.

Discovering Economic Fractured Source-Rock Reservoirs in the Devonian and Mississippian of Oklahoma—Thomas L. Thompson, Thompson's Geo-Discovery, Inc.; and James R. Howe

Facies and Petrophysical Characteristics of the Chattanooga Shale and Misener Sandstone in the McPherson Paleovalley in Central Kansas—K. David Newell and John H. Doveton, Kansas Geological Survey

High-Resolution Correlation within the Woodford Shale (Upper Devonian) Using Magnetosusceptibility Event and Cyclostratigraphy (MSEC)—Rex E. Crick and Brooks B. Ellwood, University of Texas at Arlington

Mississippian Springer Sands May Have Been Conduit for Emplacing Prolific Ordovician Reserves in Southern Oklahoma—Harry W. Todd, Certified Petroleum Geologist

Significance of Accurate Carbonate-Reservoir Definition and Delineation: Chester and Springer Carbonates—Paul W. Smith, Walter J. Hendrickson, and Ronald J. Woods, IHS Energy Group

Exploration Potential of the Sycamore Limestone—Richard D. Fritz and Larry Gerken, Masera Corp.

Mississippian 3-D Case History: Porosity Prediction Using Seismic Trace Inversion—A Prospector's Perspective—Jasha Cultreri, Independent Geophysicist

Sequence Stratigraphy of Chesterian Sandstones of the Black Warrior Basin, Northeastern Mississippi—Arthur W. Cleaves, Oklahoma State University

Geochemical Characteristics of Mississippian Lime and Chester Formation Rocks—R. Paul Philp and D. Kim, University of Oklahoma

3-D Seismic and Hydrocarbon Microseepage: Exploration Adventures in Osage County, Oklahoma—Daniel C. Hitzman, Geo-Microbial Technologies

Poster Presentations

Thermal Maturation of the Woodford Shale in South-Central Oklahoma—Brian Cardott, OGS

Field Study of the Sycamore Limestone on I-35 in the Arbuckle Mountains—R. Nowell Donovan, Texas Christian University

Depositional Environment and Sequence Stratigraphy of Silurian to Mississippian Reservoirs in the Midcontinent—Richard D. Fritz, Ted Beaumont, and Larry Gerken

Borehole-Image Applications in Silurian, Devonian, and Mississippian Midcontinent Reservoirs—Matthew G. Garber, Schlumberger Oilfield Services

The Resource-Full Mississippian of Kansas—Paul Gerlach and D. F. Merriam, Kansas Geological Survey

An Example of a Carbonate Platform and Slope System and Its Stratigraphically Equivalent Basinal Clastic System—Springeran/Chesterian Relationship within the Anadarko Basin of Northwestern Oklahoma and the Texas Panhandle—Walter J. Hendrickson, John Hogan, Paul W. Smith, Charlie E. Willey, and Ronald J. Woods, IHS Energy Group

Advanced Reservoir Characterization of a Hunton Field, Kingfisher County, Oklahoma—Daniel C. Hitzman and Brooks Rountree, Geo-Microbial Technologies; and Charles O'Donnel, Bristol Resources

Geology and Petroleum Reservoirs in Silurian, Devonian, and Mississippian Rocks in Oklahoma—Robert A. Northcutt, Kenneth S. Johnson, and G. Carlyle Hinshaw

Mississippian Overview of Southwestern Kansas—Bob Slamal, Consultant, Canyon Energy

Significance of Accurate Carbonate-Reservoir Definition and Delineation: Chester and Springer Carbonates—Paul W. Smith, Walter J. Hendrickson, and Ronald J. Woods

Discovering Economic Fractured Source-Rock Reservoirs in the Devonian and Mississippian of Oklahoma—Thomas L. Thompson and James R. Howe

Mississippi Lime: Chert Occurrence Related to Productive Reservoirs, Blaine County, Oklahoma—Dan Towns, Louis Dreyfus Natural Gas

Reservoir Characterization and Comparison of the Hunton in the Texas/Oklahoma Anadarko Basin to the Equivalent Devonian, Silurian, and Fusselman Rocks of the Texas Permian Basin—Ronald J. Woods and Charlie E. Willey

Registration Information

The fee for advance registration (by March 5) is $50, and includes two lunches and a copy of the proceedings; late and on-site registration is $70. For more information, contact Kenneth S. Johnson, general chair, or LeRoy Hemish, poster chair, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 or (800) 330-3996; fax 405-325-7069. For registration forms, contact Tammie Creel or Jan Coleman at the same location and numbers.

GSA South-Central Section Annual Meeting
Lubbock, Texas March 15–16, 1999

The Department of Geosciences of Texas Tech University, in conjuction with the Departments of Economics and Geography, Civil Engineering, and Plant and Soil Science, will host the 1999 annual meeting of the South-Central Section of the Geological Society of America.

The following agenda is planned:

Symposia

Paleontology and Stratigraphy of Cretaceous and Tertiary Strata in West Texas and Northern Mexico
Proterozoic and Early Paleozoic Magmatism and Tectonics in Southern Laurentia
Aeolian Processes and Geomorphology
Environmental Applications of Geology in the Southern High Plains
Calcium Carbonate-Enriched (Caliche) Horizons in the Soils of the Southwest
Applications in Geophysics
Environmental Applications of Stable Isotopes

Student Workshop

Basic Well Log Analysis, *March 14*

Field Trips

Premeeting

Stratigraphy of the Caprock Escarpment, *March 14*
Quaternary Stratigraphy of the Southern High Plains, *March 14*
Geology of Palo Duro Canyon, *March 14*

Postmeeting

Nuclear Waste Storage at the WIPP Site, New Mexico, *March 17*

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For more information about the meeting:

Contact GSA, Meetings Dept., P. O. Box 9140, Boulder, CO 80301, (800) 472-1988 or (303) 447-2020; e-mail: meetings@geosociety.org; World Wide Web: http://www.geosociety.org.

Preregistration deadline is February 19.

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

Conocardioid Molluscs from the Buckhorn Asphalt Quarry of South-Central Oklahoma: Rostroconchs or Rostroconch Homeomorphic Bivalves

M. J. HEANEY III and *T. E. YANCEY*, Dept. of Geology and Geophysics, Texas A&M University, College Station, TX 77843

Specimens of a bivalved mollusc recovered from the Buckhom Asphalt Quarry represent material with prodissoconch and early dissoconch growth stages of *Pseudoconocardium* cf. *P. laterna* (Branson, 1965), a taxon assigned to the conocardioid rostroconchs. The Buckhorn specimens bear a distinct prodissoconch on each valve, stout peg-like teeth on the hingeline, a simple planar ligament that connects the two valves, and a nacreous middle shell layer. This taxon is clearly bivalved during its early ontogeny and not fused across the dorsal margin during the early and intermediate dissoconch growth stage. These features are clearly part of the character suite of the class Bivalvia. The ontogenetic development of the Buckhorn specimens contrasts with the Pojeta & Runnegar (1976) rostroconch development paradigm, whereby ontogeny initiates with a single protoconch from which two valve-like flaps develop.

These characters imply that *Pseudoconocardium* is a bivalve homeomorphic to the rostroconchs, and that conocardiods develop in a manner different from the Pojeta & Runnegar (1976) development paradigm. Because *Pseudoconocardium* shares many characters in common with other taxa of conocardioids, it is reasonable to conclude that other taxa assigned to the Order Conocardioida (which lacks the pegma characteristic of riheroid and ischyrinoid rostroconchs) are actually true bivalves. Structures (beak-like or pyramid-like projections) previously interpreted as a protoconch on the dorsal margin of some adult conocardioids, including species assigned to *Pseudoconocardium,* are too large to be considered true protoconchs. The much better preserved Buckhorn material unequivocally shows that *Pseudoconocardium* possesses a prodissoconch, not a protoconch. This character state and other bivalve features of the Buckhorn specimens indicate that the memhers of the superfamily Conocardioidea (and perhaps all of the order Conocardioida) should be removed from the Rostroconchia and reunited with the Bivalvia.

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Ontogenetic Development of Pseudoconocardium

T. E. YANCEY and *M. J. HEANEY III*, Dept. of Geology and Geophysics, Texas A&M University, College Station, TX 77843

Superbly preserved specimens of *Pseudoconocardium* cf. *P. laterna* (Branson, 1965) from the Buckhorn Asphalt Quarry in south-central Oklahoma provide the first oppor-

tunity to document the ontogeny of this taxon. There is an ontogenetic series of individuals with well preserved prodissoconch, early dissoconch and intermediate dissoconch growth stages, most of which preserve hinge characters. These individuals lack the thickened shell typical of fully grown adults of *P. lanterna*, but possess the trigonal anterior form, carinae, great medial inflation, hood, ornamentation, and marginal denticulation typical of *Pseudoconocardium*.

The earliest shell consists of a smooth bivalved prodissoconch of 100 um diameter. These grow into small (1 mm) ovoid valves with low inflation, anterior-pointing apex, and fine, regularly-spaced commarginal growth ridges. At this growth stage the shell resembles a tiny veneroid clam. During ensuing growth, a major transformation occurs with the shell acquiring pronounced radial ribbing, including two carinae, a 45° rotation of hinge orientation and a reduction of growth on the new posterior margin. The posterior carina becomes a sharp angulation and the new posterior shell forms a flat, narrow hood surface, nearly perpendicular to the hinge axis. This is the growth stage at which the shell acquires conocarioid shell features. However, the shell retains a functional hinge and ligament and is truly bivalved. The ligament is large and simple, occupying a large interarea above the dissoconch beaks. There are several stout peg-like teeth on a straight hingeline. At this growth stage the shells have not secreted secondary shell layers to fuse the hingeline. The middle shell microstructure consists of thin nacreous tablets.

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Conodont Biostratigraphy of Late Carboniferous–Early Permian Depositional Sequences

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In contrast to other geological systems where conodonts are present, no widely applicable conodont zonation has been established for Late Carboniferous–Early Permian strata. This is attributed to two things: (1) widespread occurrence of cyclothems in rocks of these systems with attendant environmental control on conodont distributions and (2) the prevailing view that evolution within the numerically dominant genera *Idiognathodus, Neognathodus*, and *Streptognathodus* was essentially stagnant during this time, resulting in long ranging species that recurred over and over in successive cycles. Recent study of conodont faunas from maximum trangressive deposits of Desmoinesian through Wolfcampian (Moscovian-Asselian) cyclothems in the midcontinent USA and Paradox Basin, however, indicates that speciation within the *Idiognathodus* and *Streptognathodus* lineages was not stagnant, and that several cyclothems (or cyclothem bundles) contain diagnostic conodont faunas. Desmoinesian through lower Wolfcampian (Moscovian through Asselian) sediments are subdivided into 19 zones based upon the first occurrences of *Idiognathodus* and *Streptognathodus* species. These zones, each of which comprises from one to several cyclothems, permit a greatly enhanced level of regional cycle correlation. Typically, the recognition of sequences and parasequences permits a potential level of correlation of greater precision than can be obtained by biostratigraphy alone, on the order of a few hundreds of thousands of years. Highest biostratigraphic resolution is attained when each successive cycle contains a unique biotic fingerprint.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 2, p. 68.

Conodont Biostratigraphy of the Verdigris Limestone (Pennsylvanian, Desmoinesian) from Oklahoma and Missouri

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The purposes of this study are to describe the conodonts from the Verdigris Limestone Member of the Senora Formation of Oklahoma and from the Ardmore Member of the Verdigris Formation of Missouri and to use the conodonts for correlation and biofacies analysis. The Verdigris is a medium to dark gray fossiliferous limestone and the Ardmore a light to medium gray limestone commonly interbedded with shale. Both are underlain by black shale and overlain by gray shale.

Idiognathodus dominates the Verdigris/Ardmore fauna. *Hindeodus, Neognathodus,* and *Adetognathus* are common in some samples. *Idioprioniodus, Aethotaxis, Gondolella,* and *Diplognathodus* are minor constituents. The shallow-water black shale underlying the Verdigris contains elevated numbers of *Idiognathodus, Gondolella,* and *Idioprioniodus.*

Assignment of the Verdigris to the *Neognathodus medexultimus–N. medadultimus* zone indicates an early Desmoinesian age. On the basis of *Neognathodus,* the Verdigris of Oklahoma and the Ardmore of Missouri are about the same average age. In Oklahoma the Verdigris appears to be about a zone and a half older to the northeast than to the southwest. We attribute this possible diachronism to asymmetric forced regression caused by encroachment of a clastic wedge shed from the Ouachita uplift. The Verdigris correlates with the Seahorne Limestone Member of Illinois. It is one-half zone younger than the Holland Limestone Member and about two zones older than the Velpen Limestone Member, both of Indiana.

Conodont biofacies associations of the Verdigris/Ardmore reflect a shallow-shelf, marine environment of generally low to moderately elevated energy with elevated numbers of *Adetognathus* at some localities representing localized euryhaline, perhaps lagoonal, conditions.

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The Apparatus Architecture of *Phragmodus*

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The multielement composition of species of the Middle-Upper Ordovician genus *Phragmodus* is noncontroversial; since the mid-1960s observations of recurrent element associations and similarities in secondary element characteristics have provided reliable evidence for apparatus reconstruction. However, the number of these elements and their spatial arrangement in three dimensions is more problematic. Apparatus architecture can be determined directly only from analysis of natural assemblages. Without such material, hypotheses of the architecture of *Phragmodus* are necessarily based solely on inferred element homologies with much younger taxa, most of which are assigned to the Order Ozarkodinida. The reliability of this approach is open to question,

as it is unclear whether architectural and skeletal templates based on ozarkodinid natural assemblages are applicable to prioniodontids such as *Phragmodus*. Similarly, although the architecture of the giant Late Ordovician prioniodontid conodont *Promissum pulchrum* Kovács-Endrödy is well understood, the degree to which its apparatus reflects the architecture of other prioniodontids remains untested.

A Middle Ordovician black shale deposited in a meteorite crater near Ames, Oklahoma, USA, preserves numerous well-preserved natural assemblages of species of *Phragmodus*. The species from the Ames structure belong to either *Phragmodus flexuosus* Moskalenko or *P. inflexus* Stauffer. However, the distinctive Pa element of the latter, having a small denticle on the anterior edge of its cusp, has not been found at the collected horizons, so *P. inflexus* has yet to be confirmed. The elements in these assemblages are unusually small, but they provide the first direct evidence for the apparatus architecture of *Phragmodus*. The apparatus contains nine subparallel S elements. Above (apically to) the S elements, and near to their anterior ends, lies a pair of dolabrate M elements. Posterior to the S elements are opposed pairs of Pb and Pa elements, arranged with their long axes almost perpendicular to the long axes of the S elements. This has important implications for the reconstruction of other prioniodontid taxa, and the recognition of homologies both with prioniodontids and between conodont higher taxa. The similarities between the apparatuses of *Phragmodus* and taxa assigned to other orders lends further support to the hypothesis that the Conodonta was more conservative architecturally than has been thought.

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Conodonts from the Chattanooga Shale and the Devonian-Mississippian Boundary, Southern Ozark Region

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Age of the Chattanooga Shale and placement of the Devonian-Mississippian boundary have been long standing problems in the southern midcontinent. The problem has been exacerbated by the lack of reliable faunal/floral data and the practice of including unrelated shale and sandstones units within the Chattanooga. Conodonts have been recovered from bedding planes and as discrete elements from unequivocal black Chattanooga Shale in northeastern Oklahoma and northwestern Arkansas. These occurrences demonstrate that the Devonian-Mississippian boundary is at a significant erosional unconformity, where green-gray, calcareous shales referable to the Middle-Upper Kinderhookian Bachelor Member, St. Joe Limestone overlie black shales of the Chattanooga that yield middle Famennian conodonts dominated by species of *Palmatolepis*. Along the southern margin of the Ozark outcrop belt, black shales, becoming interbedded with crinozoan packstones, comprise the upper half meter of the Chattanooga Shale below its contact with the cliff-forming St. Joe Limestone. At these localities, there is no Bachelor Member present, and the Chattanooga spans the Devonian-Mississippian boundary. Bedding plane concentrates of conodonts in these sections are dominated by ramiform elements, but contain advanced species of Middle-Upper Kinderhookian *Siphonodelia* that cannot be attributed to stratigraphic leak. Precise location of the Devonian-Mississippian boundary and assessment of its physical relations in these localities remains obscure, but the possibility exists that an intraformational unconformity occurs within the Chattanooga Shale.

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Dimorphism and Maturity in Middle Carboniferous Ammonoids, Southern Midcontinent, United States

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Middle Carboniferous ammonoid assemblages from the southern midcontinent (Oklahoma, Arkansas, Texas) number hundreds to thousands of individuals from horizons isolated both stratigraphically and geographically, developed in both basinal and high-energy, near-shore facies. In all settings, individuals within a species are of strikingly similar size, although presence of large and small taxa precludes post-mortem sorting. These occurrences seem to represent mass mortality perhaps related to reproduction (semelparity). In most taxa, no difference in conch morphology exists among individuals comprising populations assumed to represent both sexes. Where conch morphology is variable, particularly among reticuloceratid and schistoceratid species, antidimorphs typically exhibit either widely umbilicate, cadiconic conchs or narrowly umbilicate, pachyconic conchs. These antidimorphs occur in approximately equal numbers. Ribbing and other ornament may be more pronounced on cadiconic conchs, but all individuals are typical of the species. Conch dimorphism is consistent between populations from different horizons and localities. Mature modifications, including septal crowding and change in aperture profile, are widely cited evidence of sexual maturity in ammonoids. Most individuals represented in the Middle Carboniferous populations from the southern midcontinent exhibit septal crowding, but apertural modifications are unknown. Septal crowding begins at a predictable ontogenetic stage but is not consistently developed in those taxa exhibiting conch dimorphism. In particular, individuals with cadiconic conchs do not exhibit septal crowding even at the largest diameters available. In contrast, dimorphism recognized in Mesozoic ammonoids, attributed to onset of sexual maturity, emphasizes significant differences in size, conch morphology, and antidimorph ratios.

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Stable Isotope Ecology of Proboscideans from Port of Entry Pit, OK (Late Miocene): Diet, Climate and Diagenesis

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A marked decrease in North American mammalian diversity during the late Miocene has been attributed to an increase in seasonality and consequent habitat changes. The stable isotope composition of mammalian apatite (e.g., enamel, dentin) is a valuable source of paleoecological data. In mammalian herbivores, the $\delta^{13}C$ of mineralized tissues is related to the proportion of trees, shrubs and herbs (C_3 plants) vs. warm climate grasses (C_4 plants) in the diet. In large bodied mammals such as proboscideans, apatite $\delta^{18}O$ is sensitive to the composition of ingested water, which ultimately reflects meteoric water, and hence ambient temperature. I measured $\delta^{13}C$ of structural carbonate and $\delta^{18}O$ of phosphate ($\delta^{18}O_p$) and structural carbonate ($\delta^{18}O_c$) in serial samples of tusks (modified upper incisors) of *Gomphotherium* from Port of Entry Pit, OK, a late Miocene locality in the Ogallala Group. Proboscideans at Port of Entry Pit provide a reasonable population sample for examining within-population variability. Proboscidean tusks are ideally suited to reconstructing seasonal variation in climate and diet because tusk

growth is geometrically simple and continuous throughout life and large size affords high sample resolution. Approximately one year of enamel growth was sampled from each of six tusks; $\delta^{18}O_p$ was also measured for approximately 3 years of dentin growth from one of these. The results indicate little or no seasonal variation in either diet or temperature. $\delta^{13}C$ ranges from ca. –11 to –9.5‰. The $\delta^{18}O_p$ values range from ca. 19 to 22‰ and $\delta^{18}O_c$ ranges from ca. 27 to 29‰. The $\delta^{18}O_p$ and $\delta^{18}O_c$ values from some specimens are not in equilibrium, suggesting exchange by one or both phases. However. simultaneous solution of the phosphate and calcite paleotemperature equations, constrained by the $\delta^{18}O$ of Southern Great Plains ground waters (–4 to –9‰) and reasonable diagenetic temperatures (0–40°C), indicate that a relatively smail percentage of carbonate exchange or recrystallization, without significant alteration of $\delta^{18}O_p$, can explain the discrepancy between $\delta^{18}O_p$ and $\delta^{18}O_c$. The carbon isotope data are consistent with a primarily C_3 diet. The oxygen isotope data are compatible with several interpretations: the annual range of temperature may not have been high in the Southern Great Plains during the late Miocene; seasonality may have only increased in the latest Miocene or with a complex geographic pattern; or the proboscideans may not have been drinking waters that reflect seasonal variations in meteoric waters and temperature.

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Carboniferous-Permian Boundary Foraminifers of the Mid-Continent USA and the Ural

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The Carboniferous-Permian boundary, according to fusulinacean evidence, is taken at the first occurrence of *Sphaeroschwagerina aktjubensis*. On the basis of conodonts, this boundary has recently been established in bed 19 of the Aidaralash Creek stratotype section at the first occurrence of the conodont *Streptognathodus isolatus* in the evolutionary morphocline of *S. wabaunnsensis*.

Based on conodonts, C/P boundary in the Kansas stratigraphic succession is placed in the top of the Glenrock Limestone Member of the Red Eagle Depositional Sequence. From this limestone, Thompson described the fusulinacean species *Triticites rockensis*, *Schwagerina campa*, and *Leptotriticites glenensis* in 1954. These species have been found in other typical Glenrock Limestone exposures in its outcrop belt from northern Oklahoma to southeastern Nebraska. Unfortunately, none of these species occur in the Aidaralash section. On the other hand, the fusulinacean genus Sphaeroschwagerina does not occur in the mid-continent Permian succession. An examination of small foraminifers in collections from the Aidaralash section reveals abundant *Tetrataxis*, and representatives of the Paleotextulariidae, *Glyphostomella*, and rare *Globivalvulina*. In Kansas, boundary sections have *Tetrataxis*, *Globivalvulina*, endothyrids, and encrusting foraminifers. In Central Kansas, south of Elmdale at the type Grenola section at Elmdale Hill, the Glenrock Limestone/Bennett Shale/Howe Limestone succession (upper part of the Red Eagle Depositional Sequence) exhibits a thin, conodont rich condensed shaley-limestone at the base. It is followed by a shallowing upward limestone/shale interval with an encrusting foraminifer limestone at the top. In Kansas, the boundary foraminifer succession is complicated by the varied facies of the Bennett Shale, which ranges from calcareous to an indurated black shale. Based on the fusulinacean/small foraminifer succession, the Carboniferous-Permian boundary in the mid-continent USA will be difficult to recognize.

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Preliminary Report on the Stratigraphic Distribution of Smaller Foraminifers from the Lower Permian Council Grove and Chase Groups of Northern Oklahoma and Southern Kansas

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Smaller foraminifers have been recovered from limestones within the upper Council Grove and Chase groups of Kay County, Oklahoma, and Cowley County, Kansas. Sampled units include the Cottonwood Ls., Florena Sh. and Morrill Ls. members of the Beattie Limestone; the Eiss Ls., Hooser Sh. and Middleburg Ls. members of the Bader Limestone; the Crouse Limestone; the Barneston limestone; the Winfield Limestone; and the Herington Ls. Member of the Nolans Limestone. The most commonly occurring taxa are *Geinitzina, Nodosinelloides, Syzrania, Tezaquina, Hemigordius, Globivalvulina, Tetrataxis, Pseudopalaeospiroplectammina* and a number of irregularly coiled and(or) encrusting types. Indeterminate discoidal forms (?*Pseudoammodicus*, ?*Hemidiscus*) are fairly abundant in some samples. All of these taxa range throughout the sampled interval. Pseudovidalinids, which are generally common in Lower Permian strata, are exceedingly rare in the present material.

All of the sampled horizons overlie the recently revised international base of the Permian System, identified on the appearance of the conodont *Streptognathodus isolatus*, and placed locally at the top of the Glenrock Limestone Member of the Red Eagle Limestone (lower Council Grove Group). Future sampling will target the Red Eagle Limestone and underlying units in an attempt to recognize foraminiferal biostratigraphic events useful for interregional correlation of the base of the Permian System. For example, *Geinitzina* is considered a strictly Permian taxon, but the appearance of this genus has not been established relative to that of *S. isolatus*.

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