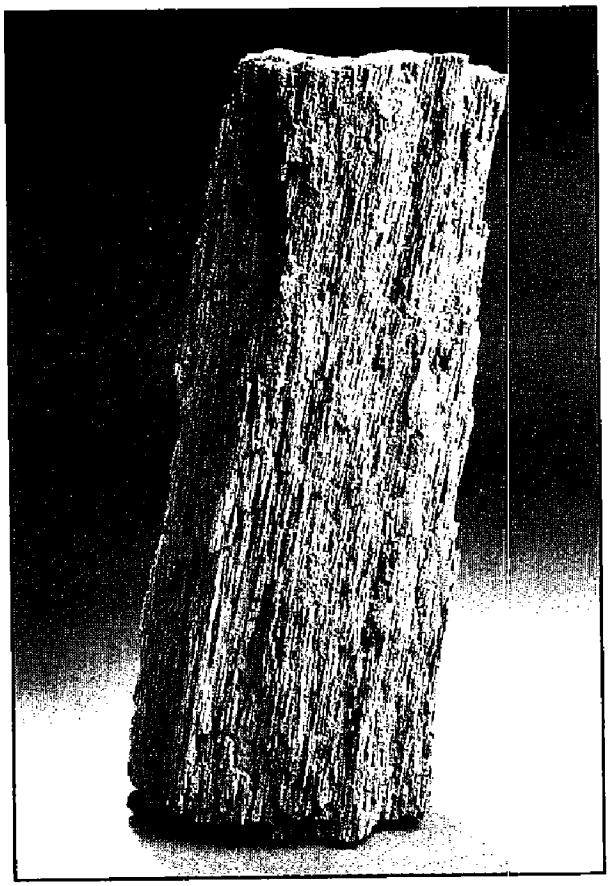
LAHOMA GEOLOGY Notes



December 1999
Vol. 59 No. 6

On The Cover —

Linoproductus oklahomae and *Dadoxylon adaense*, Wewoka Formation, Pennsylvanian (Desmoinesian, 310 Ma)

The two fossils shown on the cover are on display at the headquarters of the Oklahoma Geological Survey on the Norman campus of the University of Oklahoma. Both were collected near the Kerr Laboratory in Ada, Oklahoma, from the Pennsylvanian Wewoka Formation (Desmoinesian, 310 Ma).

The fossil molds (cover, left) are of a productid-type brachiopod known as *Linoproductus oklahomae* (Dunbar and Condra, 1932), which was a common invertebrate during the Desmoinesian of Oklahoma. All specimens of *L. oklahomae* are preserved on large slabs as external molds of the brachial and pedicle valves within fine-grained sandstones (see inset, p. 225). External molds are formed when solutions dissolve the original calcite shells of the brachiopods, leaving only impressions of the shells in the rock. (For scale: the slab on the cover measures 14 in. at its maximum width.)

All brachiopods, modern and ancient, are (or were) marine invertebrate animals. Note that the slab contains many specimens of *Linoproductus oklahomae*, almost to the exclusion of other animals. Such an occurrence is indicative of an opportunistic species (Dodd and Stanton, 1990), an organism that rapidly increases in number when ecological conditions are favorable (usually when there is abundant food). (Some present-day opportunistic species are mice and rats, locusts, cockroaches, and most weeds.) The population of an opportunistic species can grow so rapidly that other organisms appear to become excluded from the community. Consequently, op-

(continued on p. 225)

OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

Notes

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INDUSTRIAL-MINERAL RESOURCES OF OKLAHOMA[1]

Kenneth S. Johnson[2]

Introduction

Oklahoma is a region of complex geology where many fundamental concepts of sedimentation, stratigraphy, structural geology, historical geology, mineral investigation, and petroleum exploration have been formulated through the years. In the southern Oklahoma mountain belts, there are exposed a great variety of igneous and sedimentary rock units seen at few other places in the Midcontinent area. As a result of this complex and fascinating geologic history, Oklahoma has a unique and valuable array of nonfuel-mineral resources that contribute greatly to the wealth and economy of the State.

Our knowledge of Oklahoma geology has come about largely through intensive investigations of the State's petroleum and nonpetroleum mineral resources, and through the cooperative exchange of information by all agencies and companies interested in construction and earth materials. The drilling of more than 500,000 wells in search of oil and gas (a statewide average of seven wells per mi^2!) has provided basic data in all geologic provinces. Although Oklahoma is well known as an oil state, its nonpetroleum mineral resources (limestone, clay, coal, gypsum, salt, etc.) represent a vast mineral reserve needed for future industrial development and construction.

Geologic Setting

Major geologic provinces of Oklahoma (Fig. 1) include: (1) the cratonic and relatively stable northern shelf areas, including the Ozark uplift; (2) the Ouachita geosyncline (now the Ouachita Mountain belt) and associated Arkoma basin in the southeast; and (3) the southern Oklahoma aulacogen (geosyncline), comprising the area of Anadarko, Ardmore, Marietta, and Hollis basins, as well as the Arbuckle and Wichita Mountain uplifts. The three principal fold belts—the Ouachita, Arbuckle, and Wichita Mountains—all originated from a series of Pennsylvanian orogenies (about 300 million years ago) in the two Paleozoic geosynclines.

Most of the outcropping rocks in Oklahoma are of sedimentary origin, and most of these units are of Paleozoic age (Fig. 2, map). The thickness of Paleozoic strata ranges from 2,000 to 10,000 ft in cratonic shelf areas of the north, and is 30,000–40,000 ft in deep basins of the south (Fig. 2, cross sections). Sedimentary rocks overlie a basement of Precambrian to Middle Cambrian igneous rocks, Precambrian metamorphic rocks, and mildly metamorphosed Precambrian sedimentary rocks. Limestone and dolomite make up most of the Upper Cambrian to Lower Mississippian strata and attest the early and middle Paleozoic crustal stability in most of Oklahoma prior to the Pennsylvanian episodes of mountain building. Thick units of shale and sandstone predominate in the Upper Mississippian and Pennsylvanian sequence. Permian sediments are characterized by red-bed shale and sandstone, with interbedded gypsum and salt. Triassic, Jurassic, and Tertiary

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[1]Modified from Johnson (1999b).

[2]Oklahoma Geological Survey.

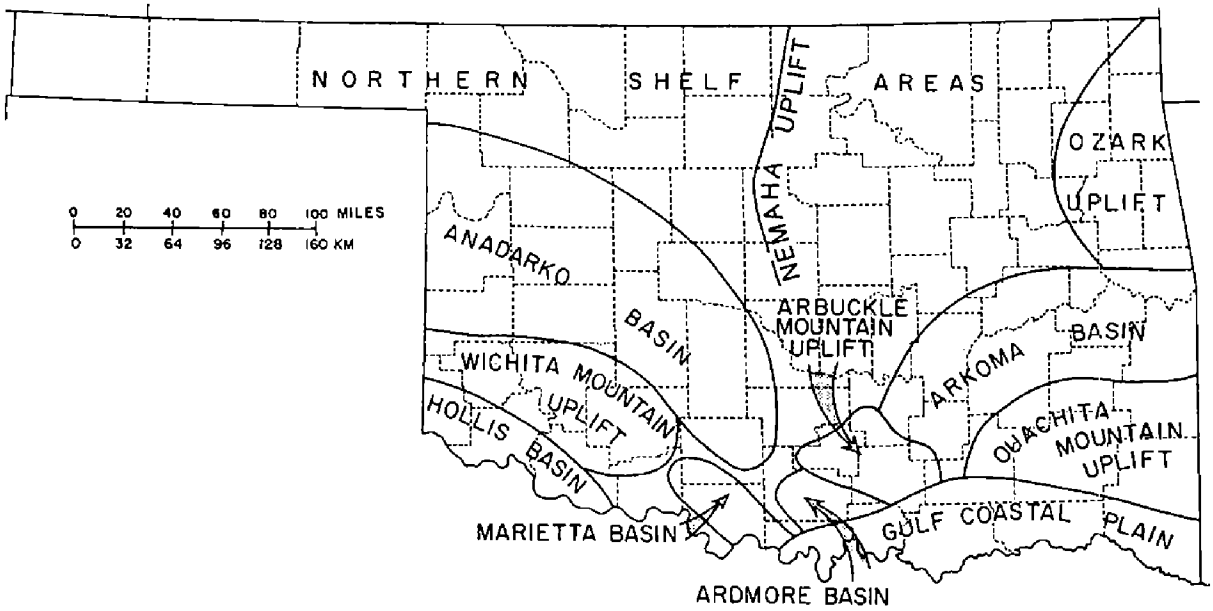

Figure 1. Major geologic provinces of Oklahoma.

deposits are mostly thin units of conglomerate, sandstone, and shale; Cretaceous deposits are similar but also include limestone units.

Oklahoma's three mountain regions have been the subject of much study and contain many of the State's major mineral deposits. The Arbuckle Mountains in south-central Oklahoma contain the most diverse suite of mineral resources in Oklahoma—limestone, dolomite, glass sand, granite, sand and gravel, shale, cement, iron ore, lead, zinc, tar sands, and oil and gas. All of these minerals are or have been produced commercially. The Wichita Mountains of southwestern Oklahoma have been mined for granite, rhyolite, gabbro, limestone, and sand and gravel. They also have been prospected (with only limited success) for kaolin, montmorillonite, gold, silver, copper, lead, zinc, aluminum, titanium, and iron ores. Oil and gas have been produced from sedimentary rocks that surround the Wichitas. Mineral resources that are, or have been, produced in the Ouachita Mountains of southeastern Oklahoma and western Arkansas include limestone, quartzite, sand and gravel, asphaltite, copper, lead, and oil and gas.

Nonfuel Minerals of Oklahoma

Nonfuel minerals (nonfuel, nonmetallic minerals that have potential for economic use, also commonly referred to as "industrial" minerals) are widely distributed in Oklahoma (Fig. 3), and many of them are being mined for local, regional, and national markets. Numerous and varied industrial-mineral industries are active in 69 of Oklahoma's 77 counties. Although such activity is widespread in the State, some of the most important regions are the Wichita, Arbuckle, and Ouachita Mountain uplifts in the south, and the Ozark uplift in the northeast (Figs. 1–3); it is in these areas that some of the State's unique rock and mineral deposits have been uplifted and are now exposed at the land surface.

Crushed-stone and building-stone resources include limestone, dolomite, granite, and rhyolite; other major construction resources are cement (made from limestone and shale) and the extensive sand and gravel deposits along modern and

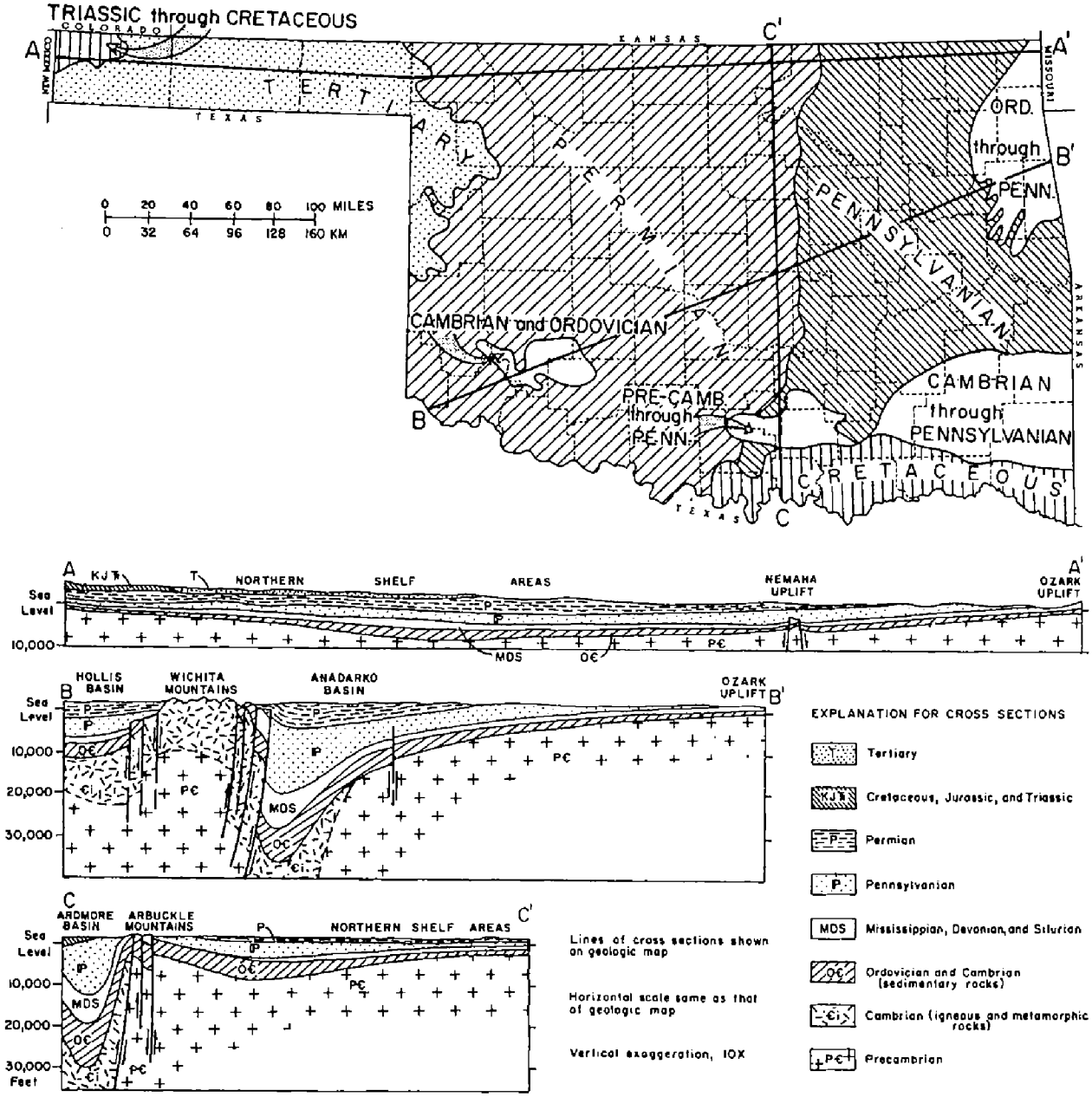

Figure 2. Generalized geologic map and cross sections of Oklahoma.

ancient river ways. Glass sand (a high-purity silica sand) is used for glass making, foundry sands, ceramics, and abrasives. Enormous resources of gypsum in the western part of the State are mined for wallboard, for plaster, as a retarder in portland cement, and as soil conditioner. Thick layers of rock salt underlie most of western Oklahoma, and natural springs emit high-salinity brine to the several salt plains. Oklahoma iodine, produced from deep-subsurface brines in the northwest, is the nation's sole domestic supply. Other important industrial minerals in Oklahoma include clays and shales (to make brick and tile), and tripoli and volcanic ash (abrasive and/or absorbent materials). Gemstone production includes freshwater mussel shells and freshwater pearls.

The total value of industrial-mineral production in Oklahoma during 1998 (the last year for which data are available) was $408 million. Leading nonfuel commodities during 1998 were portland and masonry cement ($146 million), crushed stone

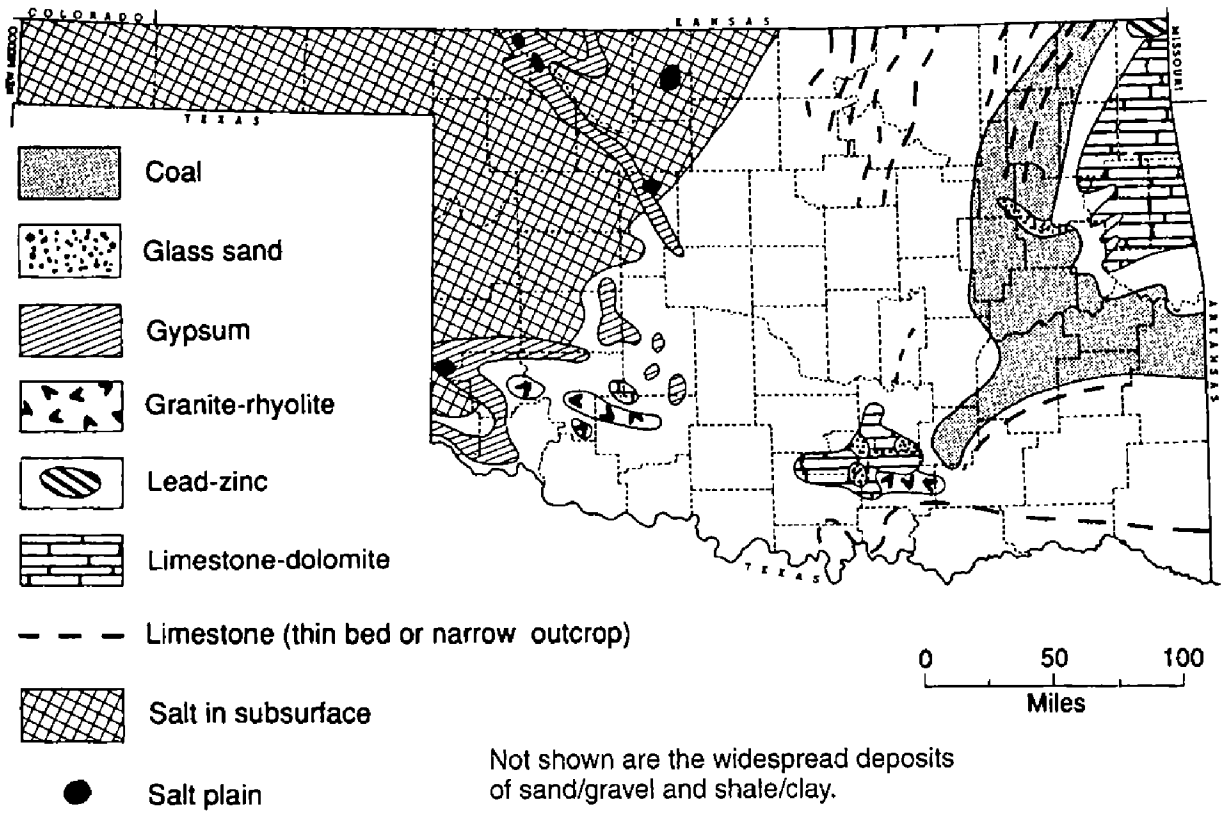

Figure 3. Selected nonpetroleum-mineral resources of Oklahoma.

($117 million), construction sand and gravel ($32 million), glass sand ($28 million), iodine ($25 million), and gypsum ($22 million). For further information about recent industrial-mineral production, see "Nonfuel-Mineral Industry of Oklahoma, 1998," p. 217, this issue.

As an aid to present and future mining operators in Oklahoma, the Oklahoma Geological Survey (OGS) held a symposium in 1992 to document the resource base, rules, regulations, and environmental issues related to wise development of the State's nonfuel minerals. The resulting publication (Johnson, 1993a) presented the major factors involved in starting up and operating an industrial-mineral mine; these factors include exploration, leasing, permits, quality control, transportation, marketing, inspections, water quality, wetlands, air quality, reclamation, and future developments.

In 1998, the OGS hosted the 34th Annual Forum on the Geology of Industrial Minerals. About 175 representatives from industry, government, and universities met to discuss the problems of geology, exploration, evaluation, and production of important nonfuel minerals, with a special emphasis on the resources of Oklahoma. The OGS published the proceedings of the 34th Forum as Circular 102 (Johnson, 1999a).

The remainder of this report, modified from Johnson (1993b, 1999b), is a description of the State's nonfuel minerals, arranged alphabetically. Many of the data are based upon reports by Johnson (1969a, 1977), Morris (1982), and the Oklahoma Department of Mines (1999); the reader is referred to these reports, as well as to other reports that are referenced separately for several of the commodities. In addition, the U.S. Geological Survey each year releases nonfuel-mineral production

data on Oklahoma in *Minerals Yearbook, Area Reports: Domestic, Volume II* (U.S. Geological Survey, 1999). These data also are reprinted annually in *Oklahoma Geology Notes* (see p. 217, this issue). The many companies that mine Oklahoma's mineral resources are listed in OGS Special Publication 93-1, "Directory of Oklahoma Mining Industry" (Arndt and Springer, 1993).

Asphalt

Asphalt is an oil-based commodity, but, because it has been used mainly as a road-surfacing and tar material in Oklahoma, it is considered herein as a nonfuel mineral resource. Asphalt forms where crude oil migrates upward near the land surface. There, the lighter hydrocarbons evaporate, leaving a thicker, heavy residue that impregnates the rocks as rock asphalt or that fills voids as a tar-like substance called asphaltite.

The major sources of rock asphalt and asphaltite are in sedimentary rocks in and around the Arbuckle and Ouachita Mountains of southern Oklahoma (Jordan, 1964). Additional smaller deposits occur in sedimentary rocks surrounding the Wichita Mountains and in northeastern Oklahoma. From the State's large resources, about 3 million tons of asphalt were produced between 1891 and 1960, chiefly from asphaltic sandstones and limestones in the Sulphur and Dougherty districts of the Arbuckle Mountains. Principal mines for asphaltite were operated near Page, Sardis, and Jumbo in the Ouachita Mountains; these shaft mines and surface mines operated between 1890 and 1916.

Most of the rock asphalt mined in Oklahoma was used as paving material for roads in Oklahoma and adjacent states. Petroleum refineries now produce the large quantities of asphaltic material needed for road construction and maintenance, and all natural-rock-asphalt quarries currently are inactive. Asphaltite was used mainly in making roofing pitch, paints, varnishes, rubber substitutes, and electrical-wire insulation. Future demands for asphaltic materials and/or heavy oils can readily be satisfied by the vast resources that remain in the State.

Cement

Raw materials for the manufacture of portland cement and masonry cement are limestone and clay or shale. Oklahoma has an abundance of these resources, and they are discussed in the "limestone" and "clay and shale" sections in this report. Three cement plants currently are operating, one each in Mayes, Pontotoc, and Rogers Counties. Production in 1998 was 2 million metric tons, with a value estimated at $146 million (see table 1, p. 218 of this issue).

Chat

Chat, which consists of crushed limestone, dolomite, and chert, was produced as a waste by-product of mining and milling of lead/zinc ores in the world-famous Tri-State District of northeastern Oklahoma. The material, which now exists in large piles in the Miami-Picher area of Ottawa County, has been used as road metal, railroad ballast, concrete aggregate, and rock fill.

Chemical Raw Materials

Oklahoma has vast resources of certain high-purity minerals suitable as raw materials for various chemical industries (Johnson, 1969b). Major deposits of lime-

stone, dolomite, and glass sand are in the south-central and eastern parts of the State, whereas gypsum and salt are widespread in the west; these individual resources are discussed elsewhere in this report. The abundance and purity of these minerals should enable manufacture of caustic soda, soda ash, chlorine, sulfur, sulfuric acid, lime, sodium silicate, and other chemical products. Oil, natural gas, and water, needed in the manufacture of these chemical products, are plentiful in most parts of the State, and bituminous coal is abundant in eastern Oklahoma.

Clay and Shale

Clay and shale are present in almost every county in Oklahoma, and deposits suitable for manufacture of red brick and tile products are widely distributed. Light-firing clays, low-grade refractory clays, and clays suitable for making pottery are present at a few localities, and clay suitable for making lightweight aggregate is common in the eastern portion of the State.

Most of the shale deposits in Oklahoma contain illite as the dominant clay mineral, and the illite is associated with varying mixtures of clay-sized quartz and other clay minerals. Chlorite, kaolinite, montmorillonite, and mixed-layer clays generally are less important, although each of these clays is predominant in certain localities. In addition to these common shales, there are several types of specialty clays in parts of Oklahoma: small to moderate-sized deposits of bentonitic clay (montmorillonite) are associated with, and altered from, volcanic ash, mainly in northwestern Oklahoma. Recent reports on clays and shales in Oklahoma are by Bellis (1972) and Johnson and others (1980). In addition, Luza and Hemish (1999) have described the characteristics and potential uses of the Croweburg coal underclays in the eastern Oklahoma coal field.

Shale has been an important part of the construction industry in Oklahoma since before statehood. More than 120 brick plants have operated since 1888, with most of them being in the central part of the State (Morris, 1982). Also, shale is one of the major ingredients at the three cement factories now operating in the State. In 1998, 36 companies were producing clay and shale in many different parts of Oklahoma (Oklahoma Department of Mines, 1999), and in 1998 the State produced 666,000 metric tons of clay and shale valued at about $4.5 million (table 1, p. 218).

Dimension Stone

Oklahoma has a variety of sandstones, limestones, dolomites, and granites suitable for building and ornamental purposes, and native stone has been used extensively in residence and building construction. The quality of some sandstones in eastern Oklahoma and of oolitic limestone in southern Oklahoma compares favorably with any in the nation, and several of the limestones and dolomites have unusual beauty and texture. The various types of dimension stone are discussed further in this report under the rock names. In 1998, Oklahoma produced about 6,180 metric tons of dimension stone, valued at about $1 million (table 1, p. 218).

Dolomite

Large resources of high-purity Cambrian dolomite are present in the Arbuckle Mountains (Ham, 1949); the stone is quarried for high-purity material at one site and is quarried for crushed stone at two other sites in the Arbuckle Mountain region. The high-purity Royer Dolomite is about 500 ft thick in the area, and other dolomite units are also 400–500 ft thick. Smaller deposits or thinner beds, generally

of lower purity, are known in the Wichita Mountains, in Delaware and Osage Counties, and in widely scattered Permian outcrops of western Oklahoma; several of these deposits are worked for dimension stone and/or for crushed stone.

Current and potential uses of dolomite are for fluxing stone, glass manufacture, refractories, dolomitic lime, magnesium metal, fertilizers, feeds, and as a soil conditioner. Quantity and value of current production are included within the estimates for crushed and dimension stone (table 1, p. 218).

Gemstones

Gemstone production consists of the harvesting of freshwater mussel shells from lakes and rivers, chiefly in eastern Oklahoma. The shells then are cut up and rounded, and the shell pellets are implanted in oysters for creating cultured pearls. Small quantities of freshwater pearls are also recovered from the mussels, but these are only a minor by-product of the shell production. Three firms are currently buying freshwater mussels from independent divers in Oklahoma, and almost all the shell material is being exported to Japan. The value of freshwater mussel shells and pearls harvested in 1998 was $30,000 (table 1, p. 218).

Although there are about 300 species of freshwater mussels, only about 15–20 are suitable for use as shell pellets for implanting. Also, about 100 species are already declared endangered species, or are proposed for such a listing. Thus, great care must be exercised in harvesting shells. Licensing of divers and shell buyers is carried out by the Oklahoma Wildlife Conservation Department.

Glass Sand

Large deposits of high-purity silica sand (Ordovician Simpson Group) are worked at two places (Johnston and Pontotoc Counties) in the Arbuckle Mountains region (Ham, 1945), with plant-run sands containing 99.8% silica and normally only 0.01–0.03% iron oxide. The origin of these multicycle sands that have undergone eolian transport is described by Denison (1999). Ordovician sand almost as pure is present in northeastern Oklahoma, and scattered exposures of Cretaceous sands with 98.5–99.5% silica are reported south and east of the Arbuckles. Alluvial sand from the Arkansas River is being specially treated in Muskogee County to produce a high-purity feldspathic sand for glass manufacture. The processed sand includes about 75% quartz (silica), about 25% feldspar, and less than 0.04% iron oxide. In 1998, Oklahoma's production of glass sand (reported as industrial sand in table 1, p. 218) was 1.38 million metric tons, with a value of about $28 million.

A number of glass-manufacturing plants in eastern and central Oklahoma produce a variety of glass products, including bottles, jars, window panes, tumblers, tableware, and Pyrex glass. Sand also is shipped from the State for glass making, foundry sands, ceramics, and the manufacture of sodium silicate. One glass-sand plant produces ground silica for use in ceramics and abrasives and as an inert filler.

Granite

Granite and similar igneous or metamorphic rocks of the Wichita and Arbuckle Mountains of southern Oklahoma (Figs. 1,3) are extensively produced as dimension stone for the monument and building trades; crushed granite and rhyolite are also produced, mainly for railroad ballast (stone in the railroad bed) and intermittently for aggregate and rip-rap. Granite and similar rocks in Oklahoma are Precambrian and Cambrian in age. Colors are red, pink, gray, and black, and the tex-

tures range from fine to coarse crystalline. The character and uses of granite and rhyolite in Oklahoma recently have been described by Gilbert and Denison (1999).

At present, eight companies are regularly producing granite and rhyolite from quarries in Greer, Kiowa, Jackson, Johnston, and Murray Counties, and the State produced about 4.6 million short tons of granite and rhyolite in 1998 (Oklahoma Department of Mines, 1999). The major production (3.4 million tons) was from Johnston and Murray Counties, where granite and rhyolite are being quarried for railroad ballast. The value of granite and rhyolite production is divided between two categories (dimension stone and crushed stone) in table 1, p. 218.

Gypsum

Enormous resources of high-purity Permian gypsum crop out in western Oklahoma (Fig. 3). The gypsum beds of the Blaine Formation are 5–30 ft thick and 95–99% pure in the northwest and southwest, and the Cloud Chief gypsum of Washita and Caddo Counties is 25–100 ft thick and 92–97% pure. Anhydrite crops out only locally, but is present underground where overburden is 25–100 ft, or more.

Total gypsum resources in Oklahoma are estimated at 48 billion short tons (Johnson, 1978). These resources are well suited for open-pit mining or quarrying, because gypsum typically forms hills in the semiarid climate of western Oklahoma, and the gypsum layers are nearly flat lying, without folds or faults. Sharpe and Schroeder (1999) recently described the gypsum resources and products of Oklahoma.

Oklahoma ranks first in the United States in crude-gypsum production, with about 3.1 million metric tons produced annually by 14 companies in 6 western counties. The value of gypsum produced in 1998 was about $22 million (table 1, p. 218). Presently gypsum produced in Oklahoma is used for plaster, wallboard, as a retarder in portland cement, in surfacing unpaved roads, and as a soil conditioner. In the future sulfur may be extracted commercially from gypsum or anhydrite.

Helium

Helium, a colorless, odorless, and nonpoisonous gas, is the second lightest of all elements. Helium was extracted for many years from natural gas at the U.S. Bureau of Mines plant near Keyes, in Cimarron County, but production has ceased. The helium-producing field is largely depleted, although some resources still remain.

Iodine

Iodine is a grayish-black, nonmetallic element that is a solid at ordinary temperatures. In Oklahoma, it is dissolved in iodine-rich natural brines (>300 ppm iodine) 6,000–10,000 ft below the land surface in the Woodward, Vici, and Dover areas in the northwestern part of the State (Johnson, 1994; Johnson and Gerber, 1999). The major production is in the Woodward and Vici areas, where iodine occurs in Morrow sandstones (basal Pennsylvanian) preserved in a south-trending paleovalley, informally called the "Woodward trench." Other iodine production comes from several Paleozoic sandstones, limestones, and dolomites, as a by-product of oil and gas production. Iodine-rich brines are produced from wells drilled into these rock units, and the iodine is then treated chemically and precipitated from the brine. After being stripped of its iodine, the waste brine is treated and then reinjected into the same producing formation (Cotten, 1978). The Oklahoma brines range from 100 to 1,560 ppm iodine; they average 300–350 ppm iodine in most of

the producing wells, and are the richest-known iodine brines in the world (Johnson, 1994; Johnson and Gerber, 1999).

Oklahoma's production of iodine began in 1977, and, with the cessation of iodine production in Michigan in 1987, Oklahoma is now the sole source of iodine in the United States. The U.S. (Oklahoma) produces about 10% of the world's annual output. At present, three companies operate three major plants and one miniplant in northwestern Oklahoma, and annual production is about 1.3 million kg (reported in "metric tons" in table 1, p. 218), valued at about $25 million. A new plant was built in Woodward to make about 50 iodine-derivative products from the iodine being produced. Major uses of iodine include catalysts, stabilizers, animal feeds, disinfectants, pharmaceuticals, photography, and colorants.

Lime

Quicklime, made by calcining high-purity limestone, has many chemical and industrial uses, as well as uses in construction and agriculture. High-calcium limestone is mined to produce lime in Sequoyah County, and other deposits of high purity are present in northeastern, south-central, and southeastern Oklahoma.

Limestone

Limestone is abundant in northeastern Oklahoma, in the Wichita and Arbuckle Mountain areas, and in southeastern Oklahoma (Rowland, 1972) (Fig. 3). It is used mainly as aggregate (crushed stone) in concrete, in building roads, and in other construction, and it also is used in making cement, dimension stone, and chemical-grade lime. In the western and Panhandle districts, extensive deposits of caliche are acceptable substitutes for some purposes, and at other places dolomite is quarried for crushed stone.

Major limestone formations of the Arbuckle and Wichita Mountains are several hundred to several thousand feet thick, and, because they crop out over large areas, they are an almost unlimited resource of stone. The principal market for stone from these two areas is the Oklahoma City metroplex, although some stone also is shipped to major cities out of the State. Usable limestones in the southeastern, northeastern, and north-central parts of the State commonly are 10–50 ft thick, and they are quarried to provide stone mainly for local markets. A report by Bliss (1999) characterized a number of Oklahoma limestones, and he showed that the lower Paleozoic carbonates are best suited for use as aggregates.

About 90 companies are quarrying limestone at various sites in Oklahoma. Limestone production in 1998 was nearly 34 million short tons (Oklahoma Department of Mines, 1999). Most of the limestone production is reported as crushed stone in table 1, p. 218, and the value of crushed stone produced in 1998 was about $117 million.

Salt

Thick sequences of Permian rock salt (NaCl) underlie most of western Oklahoma (Fig. 3), at depths ranging from 30 ft to >3,000 ft (Jordan and Vosburg, 1963). Individual salt beds are 5–25 ft thick and are interbedded with thinner layers of shale and anhydrite. The depth and thickness of salt beds in the region make them suitable for either underground or solution mining. No attempts have been made at opening a conventional underground dry mine in Oklahoma, but such mines have operated in the same salt beds for many years in Kansas, just 60 mi north of the State line. Solution mining of salt has been carried out intermittently near

Sayre, in Beckham County, with marketing either of high-salinity brine or of salt that is precipitated from the brine by evaporation of water.

A number of major natural salt plains and salt springs are present along the rivers of western Oklahoma. Saturated brine, formed by dissolution of salt in the shallow subsurface, is discharged at 11 natural salt springs or salt plains in the State, with emissions ranging from 150 to 3,000 tons of salt per day at each salt plain. These natural springs have been used commercially since the beginning of this century, and even earlier by Native Americans. Several small salt producers have tapped salt plains in the northwestern and southwestern parts of the State in the past, and each company produced about 2,000–10,000 tons of solar salt per year. At present, a single major producer of solar salt, Cargill Inc., is operating on Big Salt Plain near Freedom, in Woods County (Joachims, 1999), and a small company operated until recently in northern Harmon County.

Oklahoma's vast salt resources, estimated at 20 trillion tons (Jordan and Vosburg, 1963), are virtually untapped. Production from the one solar-salt plant in Woods County during 1998 was 190,500 short tons (Oklahoma Department of Mines, 1999). The salt was used primarily in recharging water softeners and for stockfeed, but other potential uses include chemical industries (chlorine, caustic soda, soda ash, and sodium), human consumption, and snow removal.

Sand and Gravel

Sand and gravel, which are essential to almost all types of construction, are widespread and available in most parts of Oklahoma. Principal deposits are along present-day major rivers, in terrace-like remnants of Pleistocene river beds, and in Tertiary deposits covering much of the northwest. Gravels are common in the western third of the State, as well as in and around the Wichita and Arbuckle Mountains, and in Cretaceous rocks south of the Arbuckle and Ouachita Mountains.

Sand and gravel are used in the building industry chiefly as aggregate, which is the term used for inert and hard, fragmental material that is bound by a cementing material to form concrete, mortar, or plaster. In the paving industry, sand and gravel are used as aggregate in both asphaltic mixtures and portland-cement concrete.

In 1998, 238 companies operated sand and gravel pits in 53 of Oklahoma's 77 counties (Oklahoma Department of Mines, 1999). Construction sand and gravel produced in 1998 was 8.9 million metric tons, and it was valued at about $32 million (table 1, p. 218). Industrial sand and gravel consists mainly of glass sand, described earlier in this report.

Sandstone

Sandstone is a common rock type in most parts of Oklahoma. Deposits in the eastern half of the State are mostly hard, are gray, brown, or buff, and some are suitable for dimension stone or aggregate. Those in the western half of Oklahoma are mostly soft or friable, are reddish-brown, and are only locally suitable for building material. Sandstone is quarried as dimension stone at several sites in east-central Oklahoma, and has been quarried for riprap and aggregate at several places in the eastern half of the State.

Stone

The State has many types of stone that can be used in the construction industries. Sandstones, limestones, dolomites, and granites are widely distributed in

most parts of Oklahoma, and each of these resources is discussed separately elsewhere in this report.

Tripoli

Tripoli is a white or cream-colored, microcrystalline form of high-purity silica that is porous, lightweight, and friable. It is derived from a partly siliceous parent sedimentary rock from which soluble carbonate minerals have been leached (Quirk and Bates, 1978). Important tripoli deposits are present in northeast Oklahoma, with the first mine having been opened in the Missouri-Oklahoma tripoli district in 1869. Tripoli deposits typically are 2–20 ft thick, and they occur in Mississippian cherty limestones beneath 2–10 ft of overburden.

After quarrying, tripoli is dried, crushed, and screened to various grain sizes. Ground tripoli is used mainly as a mild abrasive or in buffing-and-polishing compounds. It is prized for its abrasiveness, porosity, permeability, absorption, and low specific gravity. One company operated a number of pits during 1998 in Ottawa County, and produced about 25,000 short tons of tripoli (Oklahoma Department of Mines, 1999).

Volcanic Ash

Small to large deposits of uncemented volcanic ash occur in western and east-central Oklahoma (Burwell and Ham, 1949). They result from local accumulations of ash and dust blown from volcanoes that erupted in New Mexico, Wyoming, and other western states during Tertiary and Pleistocene times. Some of the ash deposits are altered in part to bentonite clays.

Volcanic ash is used as an abrasive, mainly in polishing powders, scouring soaps, and cleansing powders; it also can be used as an admixture in pozzolan cement and as an insulating compound. Three companies mined about 300 short tons of volcanic ash in Okfuskee County during 1998 (Oklahoma Department of Mines, 1999).

Miscellaneous Minerals

Several other industrial minerals, described below, are present in small or low-grade deposits; attempts at mining them have not been successful so far.

Barite nodules, veins, and concretions are sparingly present in some shales and sandstones south of the Wichita Mountains and in central and south-central Oklahoma (Ham and Merritt, 1944). At a few localities there are surface concentrations of high-grade nodules that may have possibilities for limited production.

Celestite and minor amounts of *strontianite* are associated with dolomite and gypsum in eastern Washita and Custer Counties, but these deposits are quite small and apparently are not commercial.

Diatomite deposits are small and of low grade, and are widely scattered in western Oklahoma.

Phosphate occurs as nodules, plates, and lenses in several limestones and black shales of eastern Oklahoma and the Arbuckle Mountains (Oakes, 1938). The P_2O_5 content of these nodules and plates is generally 15–30%, whereas that of selected whole rocks is commonly 1–10%.

Quartz occurs as large vein deposits and some well-formed crystals in the Ouachita Mountains, especially in central McCurtain County (Honess, 1923).

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NONFUEL-MINERAL INDUSTRY OF OKLAHOMA, 1998[1]

In 1998, the preliminary estimated value[2] of nonfuel-mineral production[2] for Oklahoma was $408 million, according to the U.S. Geological Survey (USGS). This was about a 6% increase from that of 1997[3], following a 4.6% increase from 1996 to 1997. The State climbed in rank to 32nd from 33rd among the 50 states in total nonfuel-mineral-production value, of which Oklahoma accounted for 1% of the U.S. total.

In 1998, portland cement and crushed stone were Oklahoma's leading nonfuel-mineral commodities, accounting for about 34% and 29%, respectively, of the State's total preliminary nonfuel-mineral value. The combined values of construction materials (portland and masonry cements, crushed stone, construction sand and gravel, gypsum, and common clay, in descending order of value) accounted for almost 79% of the total value. Oklahoma's increase in value in 1998 mostly resulted from the higher values of portland cement, crude iodine, crushed stone, crude gypsum, and construction sand and gravel, in descending order of relative increase (Table 1). Only feldspar, gemstones, and dimension stone showed relatively small value decreases, while industrial sand and gravel and tripoli remained at 1997 levels. Shell production for gem material declined considerably, resulting in a 92% decrease in the value of gemstones, but this had a relatively small effect on the State's overall total increase in value. One year earlier, in 1997, increases in port-

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[1]From U.S. Geological Survey Minerals Yearbook, 1998, v. 2—Area reports: domestic, Oklahoma chapter. Prepared under a Memorandum of Understanding between the U.S. Geological Survey 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.usgs.gov/minerals/pubs/state/ok.html. The text and tables are the PDF file labeled "The Mineral Industry of Oklahoma, 1998"; the map is PDF file "Map of Principal Mineral-Producing Localities"; both files can be 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.

[3]Values, percentage calculations, and rankings for 1997 may vary from the *Minerals Yearbook, Area Reports: Domestic 1997, Volume II,* owing to the revision of preliminary 1997 to final 1997 data. Data for 1998 are preliminary and expected to change, while related rankings may also be subject to change.

Note: All 1998 USGS mineral-production data published in this article are estimates as of February 1999 and are expected to change. 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 USGS information at (703) 648-4000 for the specialist's name and number, or for a telephone listing of all mineral-commodity specialists, call MINES FaxBack at (703) 648-4999 from a fax machine with a touch-tone handset, and request document no. 1000. This telephone listing may also be retrieved from the Web site http://minerals.usgs.gov/minerals/contacts/comdir.html. All mineral-industry surveys—mineral commodity, state, and country—also may be retrieved from 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)

Mineral	1996 Quantity	1996 Value	1997 Quantity	1997 Value	1998[c] Quantity	1998[c] Value
Cement:						
Masonry	101	$8,850[d]	89	$6,500[d]	91	$6,800
Portland	1,750	118,000[d]	1,900	132,000[d]	1,970	139,000
Clays						
Common	799	4,090	653	4,430	666	4,520
Fire	23	W	—	—	—	—
Gemstones	NA	603	NA	354	NA	30
Gypsum, crude	2,690	16,500	3,100	17,500	3,080	21,500
Iodine, crude (metric tons)	1,270	14,600	1,320	19,600	1,340	24,500
Sand and gravel:						
Construction	7,910	27,700	8,250	29,000	8,930	32,300
Industrial	1,350	27,200	1,380	28,200	1,380	28,200
Stone:						
Crushed[e]	28,300	117,000	31,900	112,000	32,500	117,000
Dimension (metric tons)	9,710	2,220	5,770	995	6,180	966
Combined value of feldspar, helium, lime, salt, stone (crushed shell and traprock [1996], crushed shell, traprock, and misc. [1997–98]), tripoli, and values indicated by symbol W	XX	32,300	XX	35,800	XX	33,100
Total	**XX**	**$369,000**	**XX**	**$386,000**	**XX**	**$408,000**

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]Preliminary.
[d]Estimated.
[e]Excludes certain stones; kind and value included with "Combined value" figure.

land cement, grade-A helium, and crude iodine far outweighed decreases in crushed stone, masonry cement, and salt, resulting in the State's increase for the year (Table 1). 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 quantity and value of construction sand and gravel sold or used in Oklahoma by major use category and district. The general distribution of Oklahoma's principal nonfuel mines is shown in Figure 1.

Oklahoma's mines exclusively produced industrial minerals in 1996–1998; no metals were mined in the State. Based on USGS estimates of the quantities produced in the 50 states during 1998, Oklahoma remained the only state that produced iodine, and it continued as first in production of crude gypsum; third of

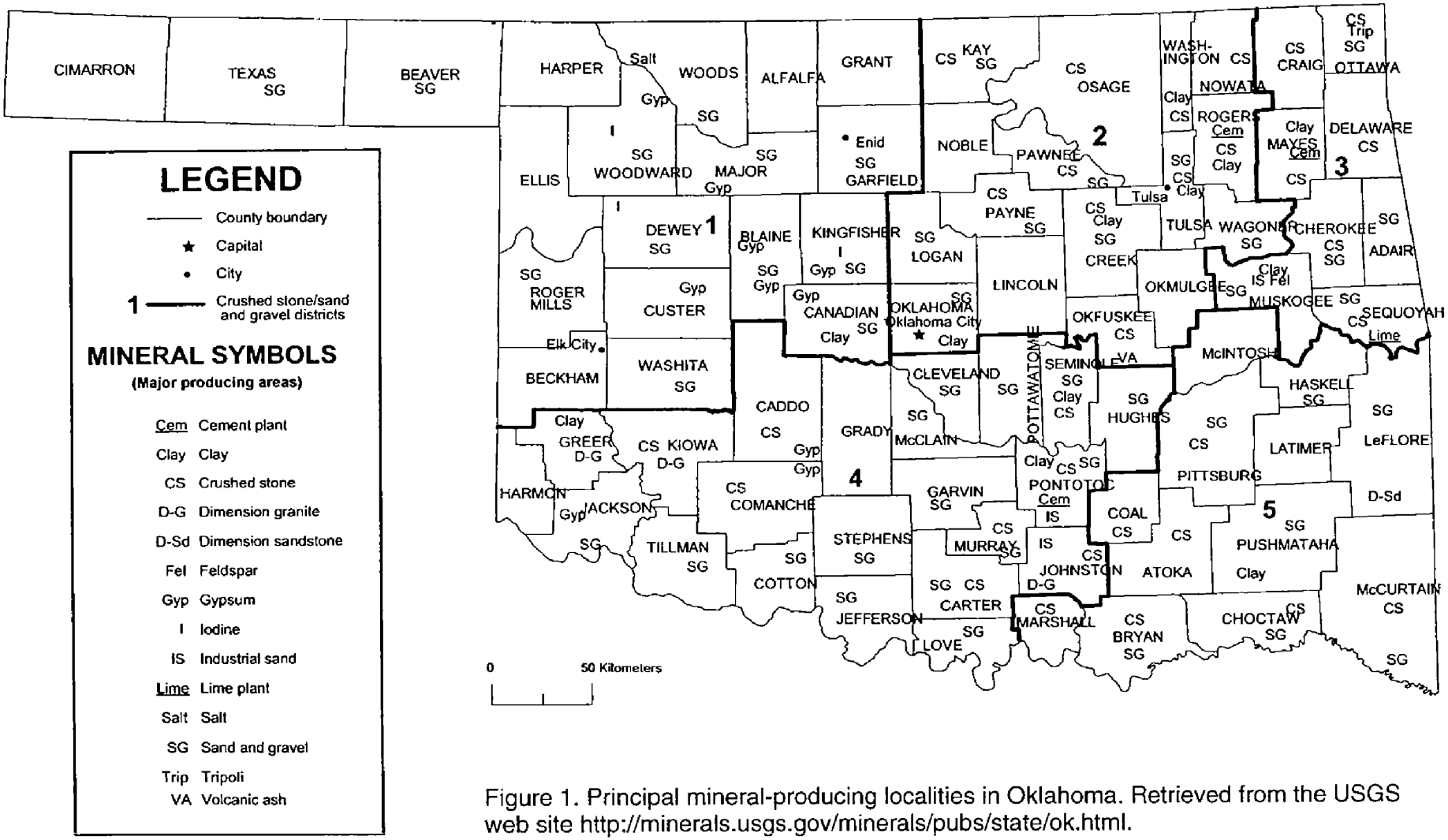

Figure 1. Principal mineral-producing localities in Oklahoma. Retrieved from the USGS web site http://minerals.usgs.gov/minerals/pubs/state/ok.html.

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

Kind	1996 Number of quarries	1996 Quantity (thousand metric tons)	1996 Value (thousands)	1996 Unit value	1997 Number of quarries	1997 Quantity (thousand metric tons)	1997 Value (thousands)	1997 Unit value
Limestone	45	21,500[b]	$84,400[b]	$3.93[b]	41	24,300	$75,600	$3.10
Dolomite	4[b]	2,400[b]	10,600[b]	4.43[b]	4	2,950	13,300	4.49
Granite	3	1,930	9,940	5.15	3	1,770	9,840	5.57
Traprock	1	(c)	(c)	(c)	1	(c)	(c)	(c)
Sandstone	7[b]	2,420	11,900	4.93	7	2,820	13,400	4.75
Shell	2	(c)	(c)	(c)	2	(c)	(c)	(c)
Slate	(d)	(d)	(d)	(d)	—	—	—	—
Misc. stone	1	91	402	4.42	1	(c)	(c)	(c)
Total or average	XX	28,300[b]	$117,000	$4.14	XX	31,900	$112,000	$3.52

XX = Not applicable.
[a]Data are rounded to three significant digits; may not add to totals shown.
[b]Revised.
[c]Excluded from State total to avoid disclosing company proprietary data.
[d]Revised to zero.

three states in crude helium; fourth of six states in grade-A helium; and eighth in industrial sand and gravel. The State dropped from fourth to fifth in feldspar. Additionally, significant quantities of portland and masonry cements, crushed stone, and common clays were produced in the State.

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 1998. Overall, production has been level or rising steadily over the past several years for the following mineral commodities: crushed stone for aggregate, railroad ballast, and fill; cement for highways, housing, and commercial buildings; dimension stone for houses and commercial buildings; sand and gravel for a variety of construction projects; gypsum for wallboard and plasters; and iodine for pharmaceuticals, disinfectants, and animal feed. Construction activities that held steady or increased somewhat in 1998 were highway construction and residential and commercial building.

Crushed-stone demand rose in 1998, due largely to highway construction, to the need for granite and rhyolite as railroad ballast, and to increased housing and commercial-building construction. Most Oklahoma highways are now being built with a concrete surface, which increases the demand for cement. In 1998, Oklahoma authorized $700 million in road construction, including turnpikes and federal and State highways.

Sand and gravel production increased in 1998. New and expanded activity is occurring in south-central and southeastern Oklahoma to help supply the Dallas–Fort Worth, Texas, market area. Texas Industries, Inc. (TXI), opened a new pit on the Red River, just south of Durant in Bryan County; although TXI mines sand and gravel in Oklahoma, the material is sent by pipeline across the state line to the company's plant in Texas, owing to better and shorter highway access to the Dallas area.

TABLE 3.— OKLAHOMA: CRUSHED STONE SOLD OR USED BY PRODUCERS IN 1997, BY USE[a,b]

Use	Quantity (thousand metric tons)	Value (thousands)	Unit value
Coarse aggregate (+1½ in.):			
Riprap and jetty stone	462	$1,360	$2.95
Filter stone	68	361	5.31
Other coarse aggregate	93	724	7.78
Coarse aggregate, graded:			
Concrete aggregate, coarse	3,780	16,000	4.23
Bituminous aggregate, coarse	365	2,070	5.68
Bituminous surface-treatment aggregate	616	3,410	5.54
Other graded coarse aggregate[c]	2,010	10,200	5.09
Fine aggregate (–⅜ in.):			
Stone sand, concrete	134	198	1.48
Stone sand, bituminous mix or seal	456	2,150	4.72
Screening, undesignated	6,080	11,000	1.81
Other fine aggregate	369	1,420	3.85
Coarse and fine aggregates:			
Graded road base or subbase	1,530	6,010	3.92
Unpaved road surfacing	W	W	3.75
Crusher run or fill or waste	4,970	12,200	2.45
Other coarse and fine aggregates	934	4,910	5.26
Other construction materials[d]	366	1,270	3.46
Agricultural:			
Agricultural limestone	119	446	3.75
Poultry grit and mineral food	(e)	(e)	4.15
Chemical and metallurgical:			
Cement manufacture	(e)	(e)	2.83
Lime manufacture	(e)	(e)	4.15
Chemical stone	(e)	(e)	4.14
Sulfur oxide removal	394	1,800	4.57
Special: Other fillers or extenders	(e)	(e)	6.61
Unspecified:[f]			
Actual	5,300	22,600	4.26
Estimated	1,600	6,420	4.03
Total or average	**31,900**	**$112,000**	**$3.52**

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

[a]Includes dolomite, granite, limestone, and sandstone; excludes miscellaneous stone, 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 railroad ballast.

[d]Includes unpaved-road surfacing.

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

[f]Includes reported and estimated production without a breakdown by end use.

TABLE 4.—OKLAHOMA: CRUSHED STONE SOLD OR USED BY PRODUCERS IN 1997, 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]	128	$871	W	W	W	W	117	808
Coarse aggregate, graded[e]	1,490	8,170	W	W	W	W	2,240	10,700
Fine aggregate (–⅜ in.)[f]	507	1,570	W	W	W	W	530	1,790
Coarse and fine aggregate[g]	2,090	8,010	491	9,400	3,130	5,600	1,950	8,550
Other construction materials	—	—	222	1,170	10,000	28,100	([h])	([h])
Agricultural[i]	32	144	([h])	([h])	—	—	([h])	([h])
Chemical and metallurgical[j]	([h])	([h])	([h])	([h])	([h])	([h])	394	1,800
Special[k]	—	—	—	—	([h])	([h])	—	—
Unspecified[l]:								
Actual	([h])	([h])	2,090	6,770	([h])	([h])	([h])	([h])
Estimated	71	107	21	86	522	2,160	981	4,070
Total	**8,170**	**$35,300**	**3,070**	**$10,800**	**14,100**	**$36,800**	**6,560**	**$29,200**

District boundaries are shown in Figure 1.

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 miscellaneous stone, 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, crusher run (select material or fill), and other coarse and fine aggregate.

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

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

[j]Includes cement manufacture, chemical stone, lime manufacture, and sulfur oxide removal.

[k]Includes other fillers or extenders.

[l]Includes reported and estimated production without a breakdown by end use.

According to the OGS, silica-sand production (reported as industrial sand and gravel in Table 1) was up significantly in 1998. U.S. Silica Co. and Unimin Corp. hydraulically mine high-purity quartz sand in the Arbuckle Mountains of south-central Oklahoma, and Arkhola Sand and Gravel Co. is dredging a feldspathic sand from the Arkansas River at Muskogee in northeast Oklahoma. These sands are used for glassmaking, foundry sands, ceramics, and the manufacture of sodium silicate.

According to OGS estimates, gypsum production increased slightly during 1998, and some companies reported a record year. Also, the price of gypsum increased moderately. The output of plasters and other industrial-gypsum products was higher than in 1997. Healthy building activity helped to keep Oklahoma wallboard plants operating at near-capacity during the year, and there was little room to ex-

TABLE 5.— OKLAHOMA: CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN 1997, BY MAJOR USE CATEGORY[a]

Use	Quantity (thousand metric tons)	Value (thousands)	Value per ton
Concrete aggregate (including concrete sand)[b]	3,470	$13,900	$4.02
Concrete products (blocks, bricks, pipe, decorative, etc.)	44	209	4.75
Asphaltic concrete aggregates and other bituminous mixtures	272	720	2.65
Road base and coverings[c]	266	867	3.26
Fill	1,010	1,910	1.89
Other miscellaneous uses	2	33	13.32
Unspecified[d]:			
Actual	1,650	6,240	3.79
Estimated	1,540	5,090	3.30
Total or average	8,250	$29,000	$3.51

[a]Data are rounded to three significant digits, except value per ton; may not add to totals shown.
[b]Includes plaster and gunite sands.
[c]Includes road and other stabilization (lime) and snow and ice control.
[d]Includes reported and estimated production without a breakdown by end use.

TABLE 6.— OKLAHOMA: CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN 1997, BY USE AND DISTRICT[a]

(thousand metric tons and thousand dollars)

Use	District 1		District 2		District 4		Districts 3 & 5	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Concrete aggregate and concrete products[b]	726	$2,460	1,290	$4,380	1,040	$4,960	456	$2,350
Asphaltic concrete aggregates and road base materials[c]	220	825	208	555	W	W	W	W
Fill	149	409	693	1,270	W	W	W	W
Other miscellaneous uses	2	33	—	—	—	—	—	—
Unspecified[d]	322	1,200	930	2,550	998	4,270	937	3,310
Total	1,420	$4,920	3,120	$8,760	2,250	$9,560	1,460	$5,770

District boundaries are shown in Figure 1.
Dashes (—) indicate that no production was reported.
W = Withheld to avoid disclosing company proprietary data; included in "Total."
[a]Data are rounded to three significant digits; may not add to totals shown.
[b]Includes plaster and gunite sands.
[c]Includes road and other stabilization (lime) and snow and ice control.
[d]Includes reported and estimated production without a breakdown by end use.

pand to meet the rising national and regional demand. Republic Gypsum Co. added a second board line at its plant in Duke, Oklahoma, increasing the company's capacity by another 80%.

Iodine production increased marginally during 1998, and based on USGS preliminary data (Table 1), the value rose 25% above that of 1997. The price of iodine held steady at $18 to $19 per kilogram during the year, a significant increase over

the $11 to $15 per kilogram price just two years earlier. Three companies are operating four facilities in northwest Oklahoma. The companies drilled several new producing wells during the year, and plugged several wells that were only marginally productive. Oklahoma produced about 26% of the nation's iodine needs.

The number of mining permits in Oklahoma dropped slightly in 1998, but the acreage under permit has risen. The Oklahoma Department of Mines (ODM) issued a total of 409 permits in 1998, covering a total of about 22,000 hectares (about 55,000 acres). According to ODM, many more companies are obtaining 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 five years. Of permits on file for 1998, ODM reports that 225 (55%) have been secured under the Life Expectancy provision.

ODM reported that during 1997 about 3.5 million man-hours were worked in Oklahoma's noncoal-mining activities, a moderate increase over the 3.3 million man-hours worked in 1996.

Recent federal legislation provides an accelerated depreciation for mining and other business and industry activity on former American Indian reservations in Oklahoma. A 1993 federal law first provided for such assistance on existing reservations in the United States, but a U.S. Congressman from Oklahoma sponsored a portion of the Tax Relief Act of 1997 that extended depreciation allowances to Oklahoma lands that were within reservation boundaries just prior to opening the lands for settlement in the late 1800s and early 1900s. These former American Indian reservations comprise about two-thirds of Oklahoma.

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 177 specialists in the geology, production, and marketing of a wide range of industrial minerals throughout the United States and elsewhere in the world. Attendees came from Canada, Chile, England, Greece, Turkey, and the United States. A total of 54 talks and posters were presented; they were published in 1999 as OGS Circular 102, *Proceedings of the 34th Forum on the Geology of Industrial Minerals, 1998.* The forum was sponsored by the OGS, the USGS, the ODM, and the Oklahoma Mining Commission.

portunistic species such as *L. oklahomae* usually occur in large, isolated populations, as is illustrated by the slab.

Another characteristic of opportunistic species is that they can adapt to a broad range of environments, particularly to harsh habitats or to ones with variable conditions—habitats that are hostile to most other forms of life. Nearshore marine environments—because of the close proximity of land—are just such environments. Conditions are extremely variable; there are wild fluctuations in temperature, salinity, oxygen content, and food availability. Except for some hardy and resilient species, such as opportunistic types, most animals and plants have a difficult time living in nearshore marine habitats.

The log of petrified wood on the cover probably is *Dadoxylon adaense* (Wilson, 1963), a member of the now-extinct order Cordaites, which consisted of primitive conifer trees. Petrification of wood is a complicated process, but it typically involves the impregnation of the cell walls by silica-bearing solutions. Once the solutions saturate the woody material, silica replaces the organic material in the cell walls, followed by late-stage filling of microscopic void spaces with minerals such as quartz, opal, and chalcedony. The largest single specimen of *D. adaense* in the world can be seen in Wintersmith Park, Ada. It measures ~58 ft long and ~2 ft in diameter. The much smaller specimen on the cover measures only 21 in. long and 26 in. in diameter.

The occurrence of petrified wood of terrestrial origin and brachiopods of marine origin in the same formation and location is somewhat unusual, and it suggests that at least part of the Wewoka Formation was deposited in very nearshore marine environments, at least in this geographic setting. The most likely explanation for the co-occurrence of these two fossils is that the Wewoka Formation was deposited near the mouth of a river that flowed into an ancient, Pennsylvanian-aged sea. (A similar situation can be seen today off the Louisiana coast, where the modern-day Mississippi River empties into the Gulf of Mexico.) It is likely that the wood was washed down the ancient river and deposited in a nearshore marine environment inhabited by the brachiopods. Sometime after deposition, silica-rich ground water flowed through the rock and preserved the tree as petrified wood.

Close-up view of pedicle valve of *Linoproductus oklahomae.*

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Thomas M. Stanley and Neil H. Suneson

Cover photographs by Robert Taylor, University of Oklahoma, Electronic Media and Photographic Services

In Memoriam

Donald A. Preston

Donald A. Preston, 73, a former Oklahoma Geological Survey geologist, died Dec. 21, 1999, in Fredericksburg, Texas, after a short illness.

Don was born in Minneapolis, Minnesota, in 1926. His family moved to Los Angeles when he was 8 years old. He graduated from Los Angeles High School when he was 16 and promptly enlisted in the U.S. Marine Corps. Because he had to be 18 before he could be called to active duty, he spent two years working as a civilian metallurgical chemist for the Navy. He went on to serve in the Pacific and China from 1943 to 1946.

At the end of the war Don was sent to northern China as a printer, where he printed the Japanese surrender and repatriation papers. He had the only unsigned copies of these historically significant papers in existence.

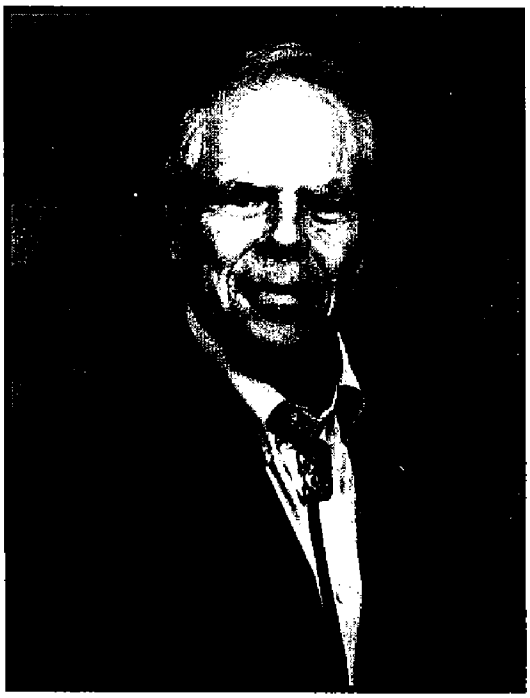
Under the provisions of the G.I. Bill, Don returned to Los Angeles to do his undergraduate and graduate work at the University of California. He joined Shell Oil Company in 1951 as a field geologist, and for the next 12 years mapped several areas of the western United States, including basins in Alaska, California, Utah, Wyoming, Nevada, and Colorado. In 1963 he was invited to join the structural geology research efforts being conducted by the Shell Development Company in Bellaire, Texas, where he spent the next 16 years. During this time, Don carried out numerous field-oriented investigations in rock mechanics and stress analysis in various regions of the United States and Mexico. His studies became critical as the Shell Development structural research program successfully linked sophisticated theoretical principles with verified field observations. He became one of the leading industry experts in pre-drill fracture prediction.

Don went to work for the OGS in 1979. He participated in various reservoir-related studies and was the senior author on OGS Special Publication 82-3, *An Evaluation of Water Resources for Enhanced Oil Recovery Operations, Cement Field, Caddo and Grady Counties, Oklahoma.*

Don also was one of the OGS geologists to study highly unusual surface eruptions of natural gas that occurred in Woods County in 1980. He used his expertise in rock fracturing and field studies to help explain the phenomenon. His photographic expertise also served him well on the project—one of his photos of the Woods County gas "bubbles" appeared on the cover of *Geotimes* (October 1980).

Industry lured Don back after a few years, and he joined an independent oil company in Oklahoma City, where he contributed to successful exploration efforts in the western United States. He also served the University of Oklahoma School of Geology and Geophysics as an adjunct faculty member for several years, teaching a number of courses in the application of quantitative, statistical, and computer methods to geology. I recently learned that Don was the first to participate in the Kansas Geological Survey "visiting scientist" program in mathematical geology and geostatistics.

Don didn't use retirement as an excuse to quit working. An avid traveler, he journeyed to places like Borneo and Tonga to participate in



Don Preston
1926–1999

scientific studies. After moving to Fredericksburg, he also took part in civic and community activities. He served as a docent at Fredericksburg's Nimitz Museum, where he shared his firsthand perspective on World War II activities in the Pacific Theater. He contributed to the Habitat for Humanity program, helping the organization build its first house in Fredericksburg. Don also was a mentor at a local elementary school, was active in the Fredericksburg United Methodist Church, and joined the Rotary Club.

Don showed his continued zeal for science and technology in his activities with the Rotary Club. Just a few weeks before his death, Don contacted me and asked if I had any material that would help him illustrate that global warming has occurred in the geologic past and in the absence of human activity. He collected and evaluated information from various sources and presented it to the Club. In typical Preston fashion, his talk was superbly organized and presented, and was very well received by an audience eager to hear a perspective different from what he called the "Washington D.C. Beltway press releases." This effort also demonstrated Don's belief that scientists should help take scientific messages to the public.

Everyone who came into contact with Don during his final weeks eventually remarked on the way he faced his terminal illness with "courage and dignity." When you add a few additional traits like his gentle nature, inexhaustible kindness, inquisitive mind, and his very significant intellect, you get a pretty good picture of what made him tick. It was my good fortune to be associated with Don personally and professionally for more than 20 years, and I am sure I speak for all who knew him in saying he will be missed.

—*William E. Harrison*
Kansas Geological Survey

NEW OGS *Publications*

EDUCATIONAL PUBLICATION 6. ***Oklahoma Generalized Geologic Time Scale—The Story Told by Rocks,*** by James R. Chaplin. Poster, 22″ × 34″. Price: $3 folded, $4 laminated and rolled.

From the formation of Precambrian granites in the Arbuckle Mountains to the appearance in the Holocene of the Meers Fault, the history of Oklahoma—as revealed by its rocks and fossils—is told in detail on this large full-color poster.

For each time span, the time scale describes the important geological events that took place in Oklahoma, as well as the origins of many of the State's mineral, energy, and water resources. The poster also notes the life forms that characterized each age, and illustrations depict many of the animals and plants as they looked in life or as they appear now as fossils.

Intended as a resource for teachers and students, the time scale summarizes and organizes much of what is known about Oklahoma geology. It also serves as a convenient and attractive reference for geology professionals.

Author James R. Chaplin is a geologist with the Oklahoma Geological Survey. Pen-and-ink illustrations were done by Coral McCallister, biological illustrator for the Department of Zoology at the University of Oklahoma.

SPECIAL PUBLICATION 99-5. ***Oklahoma Oil and Gas Production by Field, 1995–98.*** 445 pages. Price: $12.

This annual publication provides data on reported oil and gas production and related information for each formally recognized field in the State. The volume contains the following types of field data:

- Field name;
- County or counties in which the field is located;
- Total acreage of the field;
- Date the Oklahoma Nomenclature Committee named the field and date of the last revision of field boundaries;
- Annual production from 1995 through 1998 by type of product: oil, condensate, total liquids, associated gas, natural gas, and total gas;
- Cumulative production from 1979 through 1998 by type of product.

Part 1 of this publication includes oil and gas production by county; Part 2 is a summary of production within each county that is not assigned to any formally recognized field. Part 3 is an alphabetical list of all fields, districts, and gas areas that have been formally recognized by the Oklahoma Nomenclature Committee. Part 4 is a listing of discontinued field names.

This publication has been developed from data contained in the Natural Resources Information System (NRIS), a computerized data base of oil and gas information for the State of Oklahoma. NRIS currently contains data files of

monthly oil and gas production by lease that can be aggregated by such categories as field, producing interval, geologic play, petroleum province, and political area (e.g., county). NRIS also contains digitized records for 433,339 well completions and recompletions dating from statehood (1907) to present. The well records include latitude/longitude coordinates that permit plotting and use in a GIS system.

The NRIS data base can be used by the public at the OGS Computer Facility, 1218-B W. Rock Creek Road, Norman, Oklahoma. It is open by appointment only; for information call Jane Weber at (405) 360-2886, (405) 325-3031, or (800) 330-3996.

SPECIAL PUBLICATION 83-3. ***Tar-Sand Potential of Selected Areas in Carter and Murray Counties, South-Central Oklahoma,*** by William E. Harrison and Margaret R. Burchfield. 104 pages. Price: $5.

Although this report was compiled in 1983 to fulfill a U.S. Department of Energy contract, this is its first release as an OGS publication. The information contained in this report has been requested on numerous occasions, and it has not been superseded by other studies.

For several years the OGS conducted studies to evaluate the heavy-oil and tar-sand potential of the State. The major objectives of the program were to provide information on heavy-oil and tar-sand deposits upon which more detailed exploration and development efforts might be based. The present and projected energy situation in the United States is heavily oriented toward fossil fuels, and it is obvious that extraction technology directed toward enhanced oil recovery, oil shales, and tar sands will become increasingly important.

If resource-appraisal studies are maintained at reasonable levels, then perhaps such technology can be implemented as it is developed, and significant delays in producing these "unconventional" resources may be avoided.

In Oklahoma, most of the reported tar-sand occurrences are in the areas of the Wichita Mountains, Ardmore–Marietta basins, and Arbuckle Mountains. Solid bitumens (material soluble in organic solvents) such as grahamite and asphaltite are known only from the Ouachita Mountain region. The bitumen-bearing rocks in Oklahoma are mainly sandstones, although one of the major deposits, near Dougherty, occurs in Ordovician limestone. The geologic age of the deposits in southern Oklahoma varies from Middle Ordovician to Early Cretaceous.

Carter and Murray Counties contain a total of 45 tar-sand deposits, which vary from small outcrops and prospect pits to the large quarries that were actively worked until 1960. Carter and Murray Counties also have both shallow heavy oil (<25° API) and conventional crude-oil production.

Appendixes include lithologic descriptions and bitumen contents of selected cores from deposits discussed in the text.

Authors William E. Harrison and Margaret R. Burchfield both were geologists with the Oklahoma Geological Survey.

OPEN-FILE REPORT 2-99, *Geologic Map of the Bethany and Britton Quadrangles, Canadian and Oklahoma Counties, Oklahoma,* and **OPEN-FILE REPORT 3-99,** *Geologic Map of the Spencer and Jones Quadrangles, Oklahoma County, Oklahoma.* Scale 1:24,000. Xerox copies. Price: $5.20 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) some new developments are built on clay-rich weathered bedrock with a moderate shrink-swell potential; and (5) parts of the city and eastern suburbs overlie a major aquifer that provides municipal drinking water.

The Bethany–Britton Quadrangles, by Neil H. Suneson, Thomas M. Stanley, and Jonathan D. Price, and the Spencer–Jones Quadrangles, by Stanley and Suneson, were mapped in fall 1998 and spring 1999 and are the third and fourth maps in the series of STATEMAP geologic maps of the OCMA. Permian bedrock formations are widely exposed in the northern parts of the quadrangles and Pleistocene terrace and sand-dune deposits and Recent alluvium cover large areas.

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.

OGS **EP 6, SP 99-5, SP 83-3, OFR 2-99,** and **OFR 3-99** can be purchased by mail from the OGS at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-366-2882; e-mail ogssales@ou.edu. Add 20% to the cost for postage with a minimum of $2 per order for SP 99-5, SP 83-3, and folded copies of EP 6. Postage for laminated EP 6 rolled in a tube, OFR 2-99, and OFR 3-99 is $2.50 for 1–5 copies; $3.50 for 6–25 copies; and UPS rates for orders of more than 25.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886.

Workshop Announcement

PETROLEUM SYSTEMS OF SEDIMENTARY BASINS IN THE SOUTHERN MIDCONTINENT

Oklahoma City, Oklahoma, March 28–29, 2000

A two-day program cosponsored by the OGS, the National Petroleum Technology Office of the U.S. Department of Energy, and the Kansas Geological Survey will focus on generation, migration, and trapping of petroleum, and methods used to explore for, and develop, these resources. Sedimentary rocks are major sources of oil and gas in the southern Midcontinent, and they have great potental for additional recovery using advanced technologies.

The workshop will consist of papers presented orally and informal poster presentations. It will cover research and studies dealing with petroleum resources in sedimentary basins: deposition, diagenesis, thermal histories, overpressuring, reservoir characterization, 3-D seismic, exploration, and petroleum production. Between 200 and 300 participants are expected.

This is the 13th workshop in an annual series designed to aid in the search for, and production of, our oil and gas resources. It will be held at the Clarion Meridian Hotel and Convention Center in Oklahoma City. The program for talks and posters is listed below:

Oral Presentations

Petroleum Systems of Sedimentary Basins in Oklahoma—Robert A. Northcutt, *Independent Geologist;* and Jock A. Campbell, *OGS*

Petroleum Systems in Late Paleozoic Elevator Basins, Southern Ancestral Rocky Mountains—Ronald F. Broadhead, *New Mexico Bureau of Mines and Mineral Resources*

Significance of Accurate Reservoir Nomenclature and Its Impact on Identifying Petroleum Systems in the Anadarko Basin—Paul W. Smith, Walter J. Hendrickson, and Ronald J. Woods, *IHS Energy Group*

Pre-Atoka Petroleum Systems of the Arkoma and Ouachita Basins—Raymond W. Suhm, *Consultant;* and Jock A. Campbell

Gravity-Tide Tectonics and Sedimentary Basins—P. Jan Cannon, *Planetary Data*

Comparison of Production and Reservoir Characteristics in "Granite Wash" Fields in the Anadarko Basin— Ronald J. Woods, Paul W. Smith, and Walter J. Hendrickson

Petrophysical and Petrographic Reservoir Evaluation of Gunsight Limestone, Schleicher County, Texas—Mohamed A. Eissa, James M. Forgotson, Jr., Huaibo Liu, and James Anderson, *University of Oklahoma*

Hydrocarbon System Related to a Pennsylvanian Pull-Apart Graben, Cottle and King Counties, Texas—Brian S. Brister, *New Mexico Bureau of Mines and Mineral Resources*; William C. Stephens and Gregg A. Norman, *Gunn Oil Co.*

The Signal Mountain Formation—A Source Rock in Hiding—R. Nowell Donovan and Bob Critchfield, *Texas Christian University*

Structural Geometry and Evolution of Thrust Faulting along the Eastern Continuation of the Wilburton Triangle Zone, Arkoma Basin, Southeastern Oklahoma—Ibrahim Cemen, Jeff Ronck, Justin Evans, and Syed Mehdi, *Oklahoma State University*

A Statistical Method for Correcting Log-Derived Temperatures, and Implications for Modeling of Thermal Histories—Douglas W. Waples, *Consultant;* and Mahadir Ramly, *Petronas Carigali*

An Exploration Strategy for the Salina Basin in Kansas Based on Organic Geochemical Data and Maturation Modeling—K. David Newell, *Kansas Geological Survey;* and Joseph R. Hatch, *U.S. Geological Survey*

Compartmentalization of Overpressured Interval in the Anadarko Basin—Zuhair Al-Shaieb and Jim Puckette, *Oklahoma State University*

Overpressuring in the Anadarko Basin: Static or Dynamic?—Youngmin Lee and David Deming, *University of Oklahoma*

Midcontinent Geothermal Gradients—W. D. Gosnold, *University of North Dakota*

Thermal Regime of a Large Midcontinent Oil Field (El Dorado, Kansas) from High-Resolution Temperature Logs and Thermal Modeling—Jason McKenna, Kenneth Wisian, and David Blackwell, *Southern Methodist University*

Estimation of Heat-Flow Density from Nuclear Logs and Drill-Stem (DST) Temperature Data—John H. Doveton, *Kansas Geological Survey*; Andrea Förster, *GeoForschungsZentrum Potsdam*; and Daniel F. Merriam, *Kansas Geological Survey*

Reservoir Characterization Using Interwell Seismic in a Shallow-Shelf Carbonate Reservoir—James Justice and Craig Woerpel, *Advanced Reservoir Tech's, Inc.*; George P. Watts and Wade H. Waddell, *OXY USA*

Determination of Flow Potential from Oil Reservoirs to Aquifers Through Abandoned Wells: Implications—Robert C. Laudon, D. L. Warner, Leonard F. Koederitz, and S. Dunn-Norman, *University of Missouri—Rolla*

Poster Presentations

Paleogeomorphology of the Pre-Pennsylvanian Unconformity on the Arbuckle Group—Jason R. Cansler and Timothy R. Carr, *Kansas Geological Survey*

Thermal Maturation of the Woodford Shale in Eastern Oklahoma—Brian Cardott, *OGS*

Exploitation and Optimization of Reservoir Performance in a Retrograde-Oil-Cut (ROC) Hunton Reservoir, West Carney Field, Lincoln County, Oklahoma: A Five-Year, U.S. DOE-Sponsored Study—James R. Derby, *Consultant*; Mohan Kelkar, *University of Tulsa*; Joe Podpechan, *Independent*; Brian Keefer and Joe Mueller, *Marjo Oil Co.*

The Arbuckle Group and Its Lateral Equivalents: The Texas–Scotland Connection—R. Nowell Donovan, Amy Callaway, and Briann Zimmermann, *Texas Christian University*

The Signal Mountain Formation: A Source Rock in Hiding—R. Nowell Donovan and Bob Critchfield

Petrophysical and Petrographic Reservoir Evaluation of Gunsight Limestone, Schleicher County, Texas—Mohamed A. Eissa, James M. Forgotson, Jr., Huaibo Liu, and James Anderson

Temperature Analysis in the Mature Hydrocarbon Province of Kansas: Utilizing a Large Database of Petrophysical Well Logs—Andrea Förster; Daniel F. Merriam and W. Lynn Watney, *Kansas Geological Survey*

Small-Scale Inversion Features on the Flanks of the Ardmore Basin—Robert Harmon and Bryan Tapp, *University of Tulsa*

Regional Correlation of the Mountain Front "Washes" and Their Relationship to the Marine Sediments of the Anadarko Basin and Shelf—Walter J. Hendrickson, Paul W. Smith, and Ronald J. Woods

Significance of Accurate Reservoir Nomenclature and Its Impact on Identifying Petroleum Systems in the Anadarko Basin—Paul W. Smith, Walter J. Hendrickson, and Ronald J. Woods

Improved Modeling of a Shallow Shelf-Carbonate Reservoir Using 3-D Seismic Attributes, Welch Field, Permian Basin, Texas—George P. Watts; Gregory D. Hinterlong, *Texaco*; and Archie R. Taylor, *Continental Resources*

Sequence Stratigraphy of the Swope Formation (Missourian Series, Pennsylvanian System) in Eastern Kansas and Western Missouri—Nathan Wilke and Timothy R. Carr, *Kansas Geological Survey*

Comparison of Production and Reservoir Characteristics in "Granite Wash" Fields in the Anadarko Basin—Ronald J. Woods, Paul W. Smith, and Walter J. Hendrickson

Registration Information

The fee for advance registration (by March 9) is $50, and includes lunches and a copy of the proceedings; late and on-site registration is $70. Student rates are available.

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

Fayetteville, Arkansas • April 3–4, 2000

The Department of Geosciences of the University of Arkansas at Fayetteville, in conjuction with the Arkansas Water Resource Center, Department of Earth Sciences of the University of Arkansas at Little Rock, Department of Physical Science–Geology of Arkansas Tech University, Arkansas Geological Commission, and Fort Smith Geological Society, will host the 2000 annual meeting of the South-Central Section of the Geological Society of America.

The following agenda is planned:

Symposia

Alkalic Rocks of North America
Advances in Structural Geology
Atokan Series: A Centennial Reexamination
Hydrogeology of Mantled Karst
General Hydrogeology
Environmental Hydrogeology: Annual Research Conference
Geological and Geochemical Studies in Southern Lakes
Pander Society Symposium

Field Trips

Premeeting

Peralkalic Rhyolite of the Davis Mountains, *March 31–April 2*
Geomorphology, Hydrology, and Environmental Issues in a Mantled Karst Terrain, *April 2*
Sequence Stratigraphy of the Atokan Series, Northwest Arkansas, *April 2*
Carboniferous Fossil Localities of Northwestern Arkansas, *April 1*

Postmeeting

Alkalic Rocks of Central Arkansas, *April 5*

Short Courses

Hydrogeology and Geochemistry of Salt Water Contamination, *April 5*
Out of the Rocks: Bringing Fossils to Life *(National Association of Geoscience Teachers Workshop)*

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.

Oklahoma ABSTRACTS

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Discover Earth—A Manual for Training Elementary Teachers in Inquiry-Based Earth Science

VERNON P. SCOTT, School of Geology, Oklahoma State University, Stillwater, OK 74075

The Collaborative for Excellence in Teacher Preparation (CETP) is a NSF-funded project intended to remediate the decline of science teaching in Oklahoma elementary schools. One of the four science components of CETP is a 3-credit-hour earth science lab that is required for elementary teacher certification. The inquiry-based lab manual contains 72 open-ended investigations that are intended to resolve specific curiosities about the earth. These mini-labs are integrated with 24 broader synthesis-style activities such as computer modeling of local terrain, charting moon and planet motions, weather observations, etc.

The lab is organized into six units: Space, Atmosphere, Hydrosphere, Geologic Resources/Processes, and Earth History. Each unit requires six 2-hour lab sessions to complete 12 mini-labs, two synthesis activities and a unit evaluation. Students work with randomly assigned partners during each lab and produce procedural journals. A specifically trained teaching assistant supervises the labs. The professor, instead of providing lectures, conducts a discussion of the theoretical and pragmatic implications of the curriculum during the last hour of lab. After students have tested and discussed their personal hypotheses, they integrate their knowledge by reading a systems-based earth science text.

The mini-labs have been tested and revised until they satisfactorily function for teacher training. They can also be used in the elementary classroom because the necessary materials are inexpensive and readily available. (The synthesis activities, however, are only intended for secondary or college level.) A limited number of free manuals will be available after the presentation or may be requested by email transfer.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-228.

Incorporating GLOBE into Preservice and Inservice Teacher Education

MARGARET M. AVARD, BRYON K. CLARK, and *P. ALAN LENNON*, Southeastern Oklahoma State University, Durant, OK 74701

GLOBE, Global Learning and Observations to Benefit the Environment, is a federal K–12 environmental education program instituted by NASA, NOAA, and NSF. Preservice and inservice teachers may attend a workshop to learn GLOBE protocols and become certified as GLOBE instructors. The GLOBE program consists of five basic parts: atmosphere, hydrology, soils, biology/land cover, and remote sensing. Students learn proper procedures for gathering data, laboratory techniques for data analysis, how to

submit data to an international database via the web, and how to access data from other schools for comparative studies. Instructors receive a GLOBE teaching manual, two Landsat images centered at their schools, and access to a free geographic information system to manipulate the images. GLOBE is a powerful teaching tool because students obtain hands-on experience collecting and analyzing data. Since all GLOBE data is readily accessible, students may see their data, or the data of any other GLOBE school, on the web. GLOBE data has become a valuable source of infommation for scientists around the world. Current studies utilizing GLOBE data include soil moisture, bud bursts, and atmospheric modeling. Students of all ages can be involved, so GLOBE may be used effectively in K–12 classrooms as well as in preservice and inservice teacher education. For more information visit www.globe.gov.

An inservice teacher workshop, funded by a grant by the Dwight D. Eisenhower Math and Science Program, was held at Southeastern Oklahoma State University. Over a two-week period, teachers learned basic GLOBE protocols, formed questions concerning each of the sections, collected data in the field, performed data analysis, compared data submitted by various schools around the world, learned about remote sensing and how to view/manipulate images using a geographic information system, and became familiar with the geology of Oklahoma. Teachers were excited about experiencing environmental science and felt able to pass this knowledge on to their students. Since enthusiasm was high as a result of the workshop, GLOBE protocols will be incorporated into preservice teacher education at Southeastern Oklahoma State University beginning this fall.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-270–A-271.

Crystal Growth in Space: A Program Dedicated to Elementary Students

ROBERT R. J. MOHLER, M. JUSTIN WILKINSON, and *LISA R. ROVINELLI*, Lockheed Martin Space Operations, 2400 NASA Road 1, Houston, TX 77258; *JOHN R. GIARDINO*, Office of the Vice President for Research and Associate Provost for Graduate Studies and Geology and Geophysics and Geography Depts., Texas A&M University, College Station, TX 77843; *JOHN D. VITEK* and JACK MILLS

This volunteer effort is dedicated to providing elementary students (Kindergarten through fifth grade) access to experiments involving the microgravity of space flight. Scientists from Lockheed Martin, Texas A&M, Oklahoma State, and University of Texas, Tyler, donate their time and act as mentors to the participating teachers and students. Most of the expenses related to space flight are shouldered by Instrumentation Technology Associates, Exton, PA, whereas material expenses are shouldered by Lockheed Martin Space Operations. The effort is centered around reaching children at an early age and exposing them to the challenges, especially the fun of science and mathematics. Previous space experiments, involving these scientists and schools across the USA, centered around the disciplines of botany and zoology. These very successful experiments involved many thousands of children. The experimental designs and overall learning processes are now mature enough to concentrate on more ambitious experimentation, specifically crystal growth. The poster displays information on how elementary schools can become involved in these crystallography experiments, lesson plans, current experiment design, materials required, and information on the development and current status of this program.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-229.

The Geosciences Summer Academy at the University of Oklahoma: A Multidisciplinary Approach for Engaging High-School Students in the Physical Sciences

M. J. SOREGHAN and *J. P. HOGAN*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; *T. H. LEE WILLIAMS*, College of Geosciences, University of Oklahoma, Norman, OK 73019; and *D. ASKEY*, Norman Public High School, 911 W. Main, Norman, OK 73069

The College of Geosciences at the University of Oklahoma runs a very successful 3-week summer program that engages students in aspects of geology, geography and meteorology. The program, called "Exploring the Environment: Earth, Atmosphere and Environment," allows between 30 and 40 high school students from across Oklahoma to learn about the geosciences in a "hands on" technology-rich environment. Our program has evolved over the years such that most of the student activities are coupled field- and laboratory-based investigations. The program is evaluated by students through a series of surveys and by an outside evaluator contracted by the Oklahoma State Regents for Higher Education, who sponsor the summer academy. A high-school science teacher acts as Academic Director and monitors instruction and student understanding. This paper concentrates on the Geology portion of the Summer Academy.

Summary from an extended abstract. Reprinted as published in the American Association of Petroleum Geologists *1998 Annual Convention, Extended Abstracts*, v. 2, p. A626.

An Approach to Revising a Large Enrollment Introductory Geology Course

MICHAEL J. SOREGHAN and *R. DOUGLAS ELMORE*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

We are in the second year of a complete revision of our Introductory Physical Geology course. Our overall goal is to increase critical thinking skills, convey a core body of knowledge, and increase the relevance of geology for non-science-major students. Our approach includes: (1) covering fewer topics in greater detail; (2) employing a discussion intensive case-study approach in lecture; (3) utilizing web-based exercises as pre-lab assignments; and (4) integrating lab and lecture, such that labs illustrate geologic principles relating to lecture discussions.

The course consists of three main content areas. We begin with a series of introductory lectures (minerals, rock cycle and geologic time) that are complemented by relatively traditional lab exercises. This is followed by lectures on external processes (groundwater, rivers/floods, energy from the Earth) and internal processes (volcanoes, earthquakes, plate tectonics). In lecture, these topics are complemented by case-studies. Background and a series of directed questions for each case-study are presented to students via the web. After students complete the web-based questions, the instructor leads a discussion of the case-study in class. The lab assignments during the later two-thirds of the class develop the background principles for the case studies through exploration-type activities as well as analysis and synthesis of integrated datasets. Web-based, pre-lab assignments include background information as well as problem-based activities that relate to both the current case-study as well as the principles to be explored in lab. Each of the pre-lab activities includes a short quiz that is graded electronically and is part of the students' overall lab grade.

Our preliminary results from student surveys indicate that the changes have positively affected student attitude. In comparing pre- and post-course surveys, the revised

course appears to have increased students' awareness of the relevance of geology in their lives relative to a course concurrently taught with a more traditional approach. In contrast, students' belief in the amount of knowledge about geology that they have learned during the semester does not differ between the two courses.

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The Use of Case Studies to Expand the Relevance of Sedimentary Geology for Future Geoscientists

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We are restructuring our sedimentary geology course to highlight the broad application of sedimentary geology and enhance the relevance of the material for future geoscientists. Our primary goals are to: (1) produce geoscience graduates with broad competence in the many applications of sedimentary geology, (2) shift from a "topical roll call" approach that emphasizes classification and memorization skills to a problem-solving approach that emphasizes critical thinking and communication skills, and (3) produce a model with web-based and hardcopy materials that can be adopted at other institutions. We aim not to achieve an exhaustive coverage of the multitude of material encompassed in typical sedimentary geology courses, but to cover fundamental and selected concepts in the context of the large array of problems to which sedimentary geology is applicable. Upon completion of the restructuring, we will divide the course into several modules representing fundamental and applied case studies in sedimentary geology. Following introductory materials on fundamental concepts, present and future modules cover aspects of basin analysis, reservoir characterization, environmental geology, natural hazards and global change. The case studies utilize real data from academic, governmental and industrial sources. Background and supplemental data for some of the case studies are presently available to students through a series of web pages designed for the course. Student teams complete each module and make and present detailed recommendations or interpretations based on the available data. Class time is not divided into lab and lecture; instead class time includes student group work, laboratory analyses, topical seminars, field work and instructor and student-led discussions.

This is the first semester in which we are attempting most of these changes, and therefore we do not have summative results. Both student and peer evaluations prior, during and after full implementation will provide a measure of the effectiveness of our approach. Industrial recruiters will evaluate selected case studies and will participate in evaluation of student-team presentations. Upon completion we will request instructors from other institutions to evaluate the case studies.

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Integrating Digital Technology into the Traditional Geologic Field Experience: Example from the University of Oklahoma Fieldcamp

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Geology is a field-based science and geological mapping is an integral part of every undergraduate geology and geophysics program offered worldwide. Developing a spatial insight into subsurface distributions of rocks and sediments is a critical portion of

training for every professional geologist in any capacity, and students may only gain this insight by frequent excursions into the field. Digital technology such as GPS, handheld and laptop computers, digital mapping, and GIS, is commonplace in professional geologic applications. The U.S. and Canadian Geological Surveys and many state surveys are implementing digital mapping and field work procedures, and many environmental assessment and reclamation programs now take advantage of digital technology.

In response to these changing demands on geologists, the field geology curriculum at the University of Oklahoma is integrating digital technology with existing field methods. Topographic maps derived from 7.5-minute Digital Elevation Models (DEMs), superimposed with 100 meter UTM grids, supplement and in some cases replace traditional air photo and topographic basemaps. Students navigate using handheld GPS units, and compare GPS field locations with estimations from topography (i.e., ridges, streams). In some cases, after-the-fact differential GPS correction enables great precision in waypoint locations. Students record data (e.g., bedding, foliations) directly onto palmtop computers. To facilitate structural and mapping analysis, data is downloaded onto laptop computers and imported into stereonet and/or CAD-based mapping software for analysis. In this way, students gain hands-on experience with data acquisition and management associated with popular GIS-based techniques.

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Creation of the North Texas Geoscience Technology Training Center at Brookhaven College, Dallas, Texas

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Computer applications for collecting, processing and interpreting geological and geophysical data are rapidly advancing. The ability to use these computer methods is becoming a requirement for new employment and maintaining current employment. Only the largest companies provide new technology training which is typically conducted by outside vendor representatives teaching the vendors proprietary programs. While these vendors also offer training to the broader industry, their courses can be expensive and conducted at inconvenient times or locations for most independents. Few geoscientists and small companies are willing to commit to the significant initial investment for this new technology without some basic instruction and review of the various options available.

In response to the need for affordable and accessible training, the geoscience community of Dallas has created the North Texas Geoscience Technology Training Center at Brookhaven College. The Center is a unique collaborative effort including geological and geophysical societies, Brookhaven College, industry sponsors, and vendors. The purpose of the Center is to be a permanent regional training facility serving geoscientists throughout North Texas, Oklahoma, Louisiana and Arkansas. Courses will be offered for both credit and continuing education in a flexible community education setting with most classes during evenings and weekends. The Center will be operational in January 1998 with initial instruction in Unix and PC-based 3-D seismic interpretation. In addition to workstation instruction, the Center will provide a permanent location for all geoscience continuing education and short courses in the region and a certification program for geotechnicians.

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INDEX[1]

Volume 59, 1999

[1]Reference is to first page of article containing indexed item.

C

I–J

K

L

T–V

W–Z