Oklahoma GEOLOGY Notes

OKLAHOMA GEOLOGICAL SURVEY VOL. 48, NO. 4 AUGUST 1988

On the cover—

Conjugate Joints in Atoka Formation Sandstones in the Ouachita Frontal Belt, Oklahoma

The lower surface of a 20-cm-thick, fine-grained turbidite sandstone from the Early Pennsylvanian Atoka Formation. This bed is in the steeply dipping southern limb of a major syncline in the Ouachita Mountains frontal belt. The acute bisectrix of the conjugate joints should approximate the greatest-principal-stress direction during joint formation. These sandstones were folded about E–W-trending axes during the Ouachita orogeny, indicating a N–S-oriented greatest-principal-stress direction. The acute bisectrix of these joints, however, is oriented E–W, parallel to the fold axes, indicating that joint formation was not related to the folding event.

This photo was taken on the west side of a prominent road cut in U.S. Highway 259, ~5 mi north of Big Cedar in Le Flore County, Oklahoma (NE ¼ sec. 24, T. 3 N., R. 25 E.).

Charles A. Ferguson

OKLAHOMA GEOLOGICAL SURVEY
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Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

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Oklahoma GEOLOGY Notes

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STATISTICS OF OKLAHOMA OIL AND GAS WELL COMPLETIONS BEING REVISED

***Robert H. Arndt*[1]*, Mary K. Grasmick*[2]*, and A. B. Schwartzkopf*[3]**

Introduction

The intensity of oil and gas drilling is commonly measured by the number of wells completed in a given year. This statistic is favored because it is the only one that accommodates a complete inventory of functions, materials, measurements, and observations entailed in the process of drilling a well, and also has a specific time quality. Therefore, annual publication of the statistics of well completions is eagerly awaited throughout the oil and gas drilling industry. Usefulness of these data as an index of the vigor of the drilling industry in Oklahoma and as a basis for projections has come under intense scrutiny as a result of a recent revision of completion statistics published by the American Petroleum Institute (1986).

Revision changed all of the annual well-completion statistics from 1970 through 1984. The new well count is the number of wells actually completed in each year. According to API (1986) the revision was necessary because the great acceleration of drilling during the middle and latter part of the era made it impossible to record and report all of the data in a timely fashion under the existing system of data management. The explanation does not wholly address the reasons for which revision was required, why statistics changed drastically in revision, or the relationship to other statistics of well drilling that are derived directly from well records. The latter include information such as total drilling footage, depth zones of completion, relative intensity of exploratory and development drilling, geographic distribution of drilling, and other statistics.

The Oklahoma Geological Survey (OGS), Geological Information Systems (GIS), and Oklahoma Mining and Mineral Resources Research Institute (OMMRRI), all at the University of Oklahoma, have undertaken analysis of data from API files to provide the required explanation. This discussion is a preliminary report on results. All data generated through GIS are considered preliminary.

Recording and Reporting Oil and Gas Well Completions

Under Oklahoma law, oil and gas drilling and production functions are regulated by the Oil and Gas Conservation Division (OGCD) of the Oklahoma Corporation Commission. Ignoring all other requirements imposed by OGCD in the drilling of wells, two regulations identify milestones in the history of a well. An operator

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must have a permit to drill for specific objectives at a given locality and must file with OGCD a completion report (form 1002A) when drilling and completion activities have been accomplished. Accompanying the technical history of drilling and completion of the well recorded on form 1002A are two dates that relate to reporting, the date on which the well was completed and the date on which the notice of completion was filed with OGCD. Oil and Gas Conservation Division periodically releases statistics about well completions to the public. Petroleum-industry reporters extract and digest completion data and subsequently publish their versions through their parent journal or service.

Sources of Error

Unfortunately, coincidence of several factors in the original reporting system and the manner in which information has been extracted from OGCD releases have fostered and perpetuated inaccuracies in compilation of completion statistics. First, idiosyncrasies in the procedures used by OGCD in collecting and processing completion reports cause delays of various magnitude in the release of information. Second, the delays have been magnified since 1970 by a vastly increased volume of drilling, particularly the surge in drilling between 1979 and 1983. Third, the number of well completions filed in a given year and reported by OGCD apparently was accepted before 1985 by API, the media, and information services as being the number of wells that were actually completed that year. Fourth, significance of the completion date on form 1002A rather than the filing date as identifier of the year of completion apparently was not widely appreciated until the early 1980s.

Remedial Measures

Upon recognition of the foregoing factors it became apparent that an accurate count of the number of wells completed in a given year would require a reexamination of completions released annually by OGCD and a recount of completions on the basis of recorded completion date. This recognition probably instigated API's revision of completion statistics for the years 1970–84. Table 1 presents both the original and the revised statistics for this period.

The intricacy of the recount process is illustrated in Table 2, a reorganization by GIS of the total number of well completions identified in API annual data tapes for each of the years 1975–85. Columns contain the number of completions reported (filed) in a given year (report year), segregated by year of completion. Rows represent the distribution in time of OGCD reports of completions actually made in a single year (completion year). Thus, the data in each row are an incremental sequence that culminates as an incremental total after a sequence of years. Column 1975 shows that a total of 3,795 completions were reported that year. Of these, 3,189 wells were completed in 1975, and the remainder had been completed in previous years as listed. Conversely, the incremental sequence for 1975 shows that 3,960 wells were completed that year; however, only 3,189 of these wells were reported in 1975. The remainder were reported in following years through 1981. Note that the total completions identified by reporting year and by completion year in Table 2 are respectively essentially the same as the original and revised annual totals published by API (Table 1).

TABLE 1.—OKLAHOMA WELL COMPLETIONS REPORTED BY API, 1970–85

Year	Original	Revised
1970	2,901	2,783
1971	2,490	2,444
1972	2,519	2,502
1973	2,403	2,470
1974	3,189	3,386
1975	3,796	3,960
1976	4,393	4,741
1977	4,976	5,344
1978	5,859	6,164
1979	6,362	6,980
1980	9,073	10,158
1981	11,329	13,125
1982	12,008	11,390
1983	10,043	8,943
1984	9,887	9,302
1985	5,763	

Source: American Petroleum Institute (1985, 1986).

Derived Information

Revision of the annual completion statistics necessitates revision of any derived information. In Table 3, for example, completion data have been organized into the major categories "exploration wells" and "development wells" and into the subcategories "oil," "gas," "oil and gas," and "dry." Original numbers published by OGS and recently revised numbers are shown. The revised data for 1981 identify 13.4% more exploratory wells completed than in the original published report. The number of development wells completed the same year exceeds those originally reported by 18.1%.

Some other data derived from the record of completed wells and commonly reported by OGS are total footage drilled in all wells, footage achieved in various categories of wells, success ratio in drilling in several categories, average depth of wells, number of wells completed in various depth zones, concentration of drilling in various regions or specific counties, etc. Numerous extensions of these data may be made over a span of years for statistical and historical analysis.

Representative Quality of Accumulated and Published Data

One may logically inquire about the representative quality of data under the revised presentation, about what is a total record of the number of wells completed

Table 2.—Total Oil and Gas Wells Completed and Reported in Oklahoma Since 1975

Completion Year	Year of Reporting 1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Incremental Total*
1970	1											1
1971	1	1					1					3
1972	7											7
1973	9	1		2								12
1974	588	26	18	6	2	3						643
1975	3,189	680	55	11	17	6	2					3,960
1976		3,684	952	48	27	18	5	5	2			4,741
1977			3,951	1,200	97	66	20	9	1			5,344
1978				4,591	1,314	162	47	27	23			6,164
1979					4,902	1,809	133	65	53	19		6,981
1980						7,002	2,412	427	243	100	64	10,248
1981							8,705	3,544	669	264	172	13,354
1982								7,915	2,730	465	281	11,391
1983									6,314	2,241	389	8,944
1984										6,795	2,508	9,303
1985											5,770	5,770
Total in reporting year	3,795	4,392	4,976	5,858	6,359	9,066	11,325	11,992	10,035	9,884	9,184	86,866

Source: Extracted by GIS from API data tapes.
*1975–79 are true incremental totals; others are apparent totals of incomplete sequences.

Table 3.—Comparison of Oklahoma Completions by Well Types, Revised and Original Figures, 1980–85

Category	1980		1981		1982		1983		1984		1985	
	Rev.*	Orig.†	Rev.*	Orig.†	Rev.*	Orig.†	Rev.*	Orig.†	Rev.*	Orig.†	Rev.*	Orig.†
Exploration wells												
Oil	95	92	149	134	133	139	97	109	90	93		44
Gas	110	114	130	113	142	149	92	99	54	65		30
Oil & gas	1		1		2							
Dry	351	302	458	404	430	387	378	434	367	372		247
Subtotal	557	508	738	651	707	675	567	642	511	530		321
Development wells												
Oil	5,202	4,600	7,005	6,158	5,527	5,857	4,580	4,901	4,775	5,138		2,880
Gas	2,047	1,949	2,375	2,069	2,272	2,444	1,538	1,787	1,721	1,752		1,094
Oil & gas	25		9		1		4		5			6
Dry	2,379	1,984	3,192	2,422	2,861	2,932	2,219	2,605	2,230	2,347		1,418
Subtotal	9,653	8,533	12,581	10,649	10,661	11,233	8,341	9,293	8,731	9,237		5,398
Grand Total	10,210	9,041	13,319	11,300	11,368	11,908	8,908	9,935	9,242	9,767		5,719

*Compiled by GIS from API corrected data.
†Originally reported by OGS as compiled from uncorrected API tapes; excludes core and stratigraphic tests, service wells, and old wells drilled deeper.

in a given year, or what may be accepted as a working total if the complete record is unavailable. Table 4 shows the history of reporting of completions for each completion year as derived from incremental sequences in Table 2. Both tables demonstrate that a span of six to eight reporting years is required for full reporting of wells for any completion year in the period 1975–79. The number of wells reported during the year of completion during that period ranges from 70.2% to 80.5% of the total. In all cases, more than 90% of the wells completed in a given year had been reported by the end of the second reporting year. Two to three years are required to report 98% of the wells, and three to four years are required to report 99% of the well completions. Clearly, data accumulated in three or more successive years are necessary to produce a working approximation of the actual number of completions in a given year.

TABLE 4.—REPORTING OF COMPLETIONS IN SUCCESSIVE YEARS (CUMULATIVE PERCENT)

Completion Year	Year of Reporting									
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1975	80.5	97.7	99.1	94.4	99.8	99.9	100			
1976		77.7	97.8	98.9	99.4	99.7	99.9	99.96	100	
1977			73.9	96.3	98.2	99.4	99.8	99.98	100	
1978				74.5	95.8	98.4	99.2	99.6	100	
1979					70.2	96.1	98	99	99.7	100

Source: Extracted by GIS from API data tapes.

Recognition of the influence of time in reporting completions by completion year requires a reassessment of some of the statistics published annually by trade journals and industry information services. Some of the statements that commonly accompany published statistics indicate that the numbers are essentially estimates of the number of wells completed in the year of reference; others do not do so. Representative statistics extracted from prominent sources appear in Table 5. Line five in Table 5 repeats corrected gross numbers of wells completed in each year. Line six presents the number of completions made during each year, excluding service wells, stratigraphic tests, and core tests, as extracted by GIS from API data. The difference in numbers reported by GIS and by API generally relates to certain exclusions made by GIS during collection of numbers. A larger difference between GIS and API numbers for 1981 will probably be eliminated after completion of a reconciliation being made between the data files of the two organizations.

All of the numbers presented for 1981 might be interpreted as roughly correlative. However, the figures in the first four lines probably are a conglomeration of information, in contrast to the figures in lines five and six, which include only wells completed during that year. The reader should bear in mind that the rapid

TABLE 5.—COMPARISON OF REPORTED ANNUAL STATISTICS OF WELL COMPLETIONS IN OKLAHOMA, 1981–85

Source	1981	1982	1983	1984	1985
World Oil (1982 et seq.)	11,637	11,956	9,946	10,031	7,916
Oil and Gas Journal (1982 et seq.)	10,420	11,774	9,600	9,704	7,900
Petroleum Information (1982 et seq.)	11,731	12,069	9,997	10,105	9,162
American Petroleum Institute (1985)*	11,329	12,008	10,043	9,887	
American Petroleum Institute (1986)*	13,125	11,390	8,943	9,302	5,763
Geological Information Systems/ Oklahoma Geological Survey†	13,318	11,368	8,908	9,242	5,719

*Includes service wells, stratigraphic and core tests.
†Extracted from API petroleum statistics tape, 1985; excludes service wells, stratigraphic and core tests.

decrease in annual corrected totals of corrected completed wells from 1981 to 1985 presented by API and GIS relates to the decreasing information available for each successive year. None of these totals is the sum of a demonstrably complete incremental sequence (Table 2).

Examples of Use of Completion Statistics

Numerous potential uses of the revised statistics have been cited previously. The following reconstructions are examples of applications of the statistics. Historical summaries of statistics of the oil and gas drilling industry are commonly related to geographical bases. Political units, such as a state or a county, are very commonly used. Geological continuity for statistics is provided through the geological provinces defined by the Committee on Statistics of Drilling of the American Association of Petroleum Geologists; Oklahoma embraces all or parts of six provinces. Figures 1–3 are graphical summaries of footages achieved in drilling, derived from corrected annual completion data for the period 1970–85, and organized by geological provinces. Figure 1 shows gross footage drilled in each of the provinces. Figure 2 shows footage of development drilling in each of the provinces. Figure 3 shows exploration drilling as a percent of annual drilling in each province. Each of these graphs is based on derived data. Many subsets of other information may be derived from completion records.

A New Service

As a service to users of petroleum statistics, OGS and GIS have jointly undertaken the revision of OGS statistics of drilling in Oklahoma since 1970. Well-completion records in the revised API annual data tapes are the basic source of information

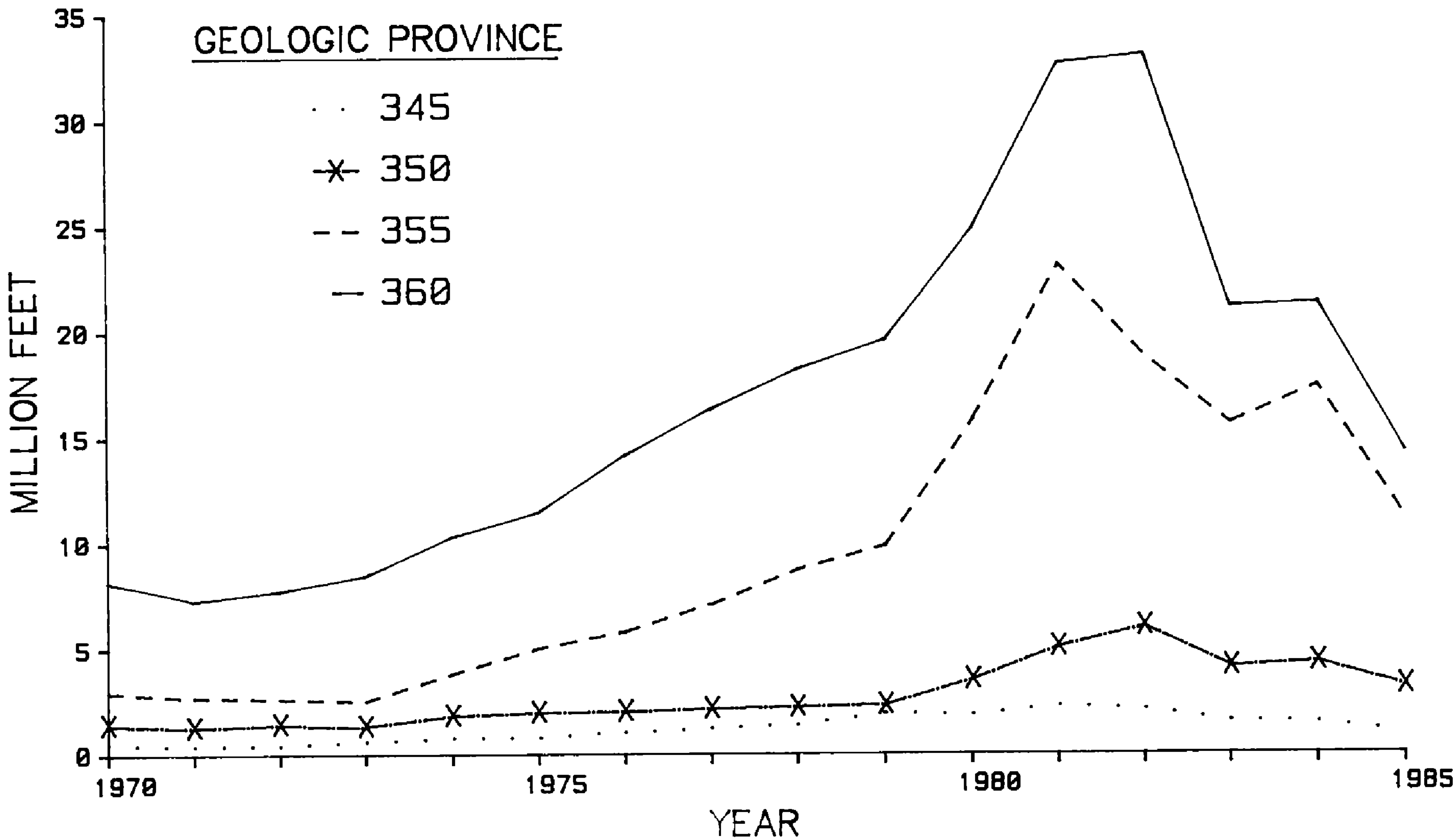

Figure 1. Exploration and development drilling in Oklahoma. Annual total footage in each geologic province, 1970–85. Omits provinces 400 and 435, as total drilling in each of these provinces was less than 500,000 ft in all years except 1984.

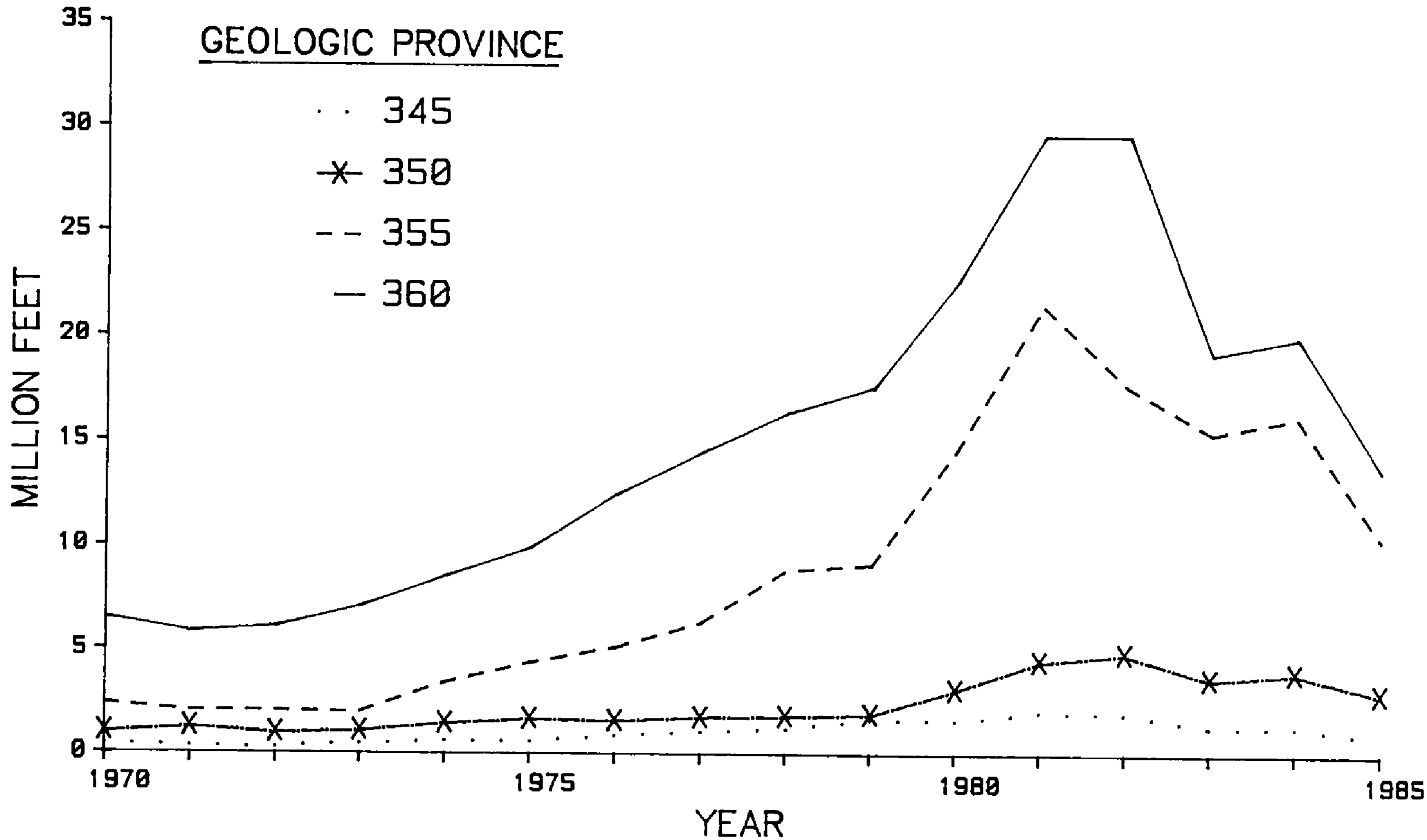

Figure 2. Development drilling in Oklahoma. Annual footage in the geologic provinces, 1970–85. Omits provinces 400 and 435, as development drilling in each of these provinces was less than 350,000 ft in all years.

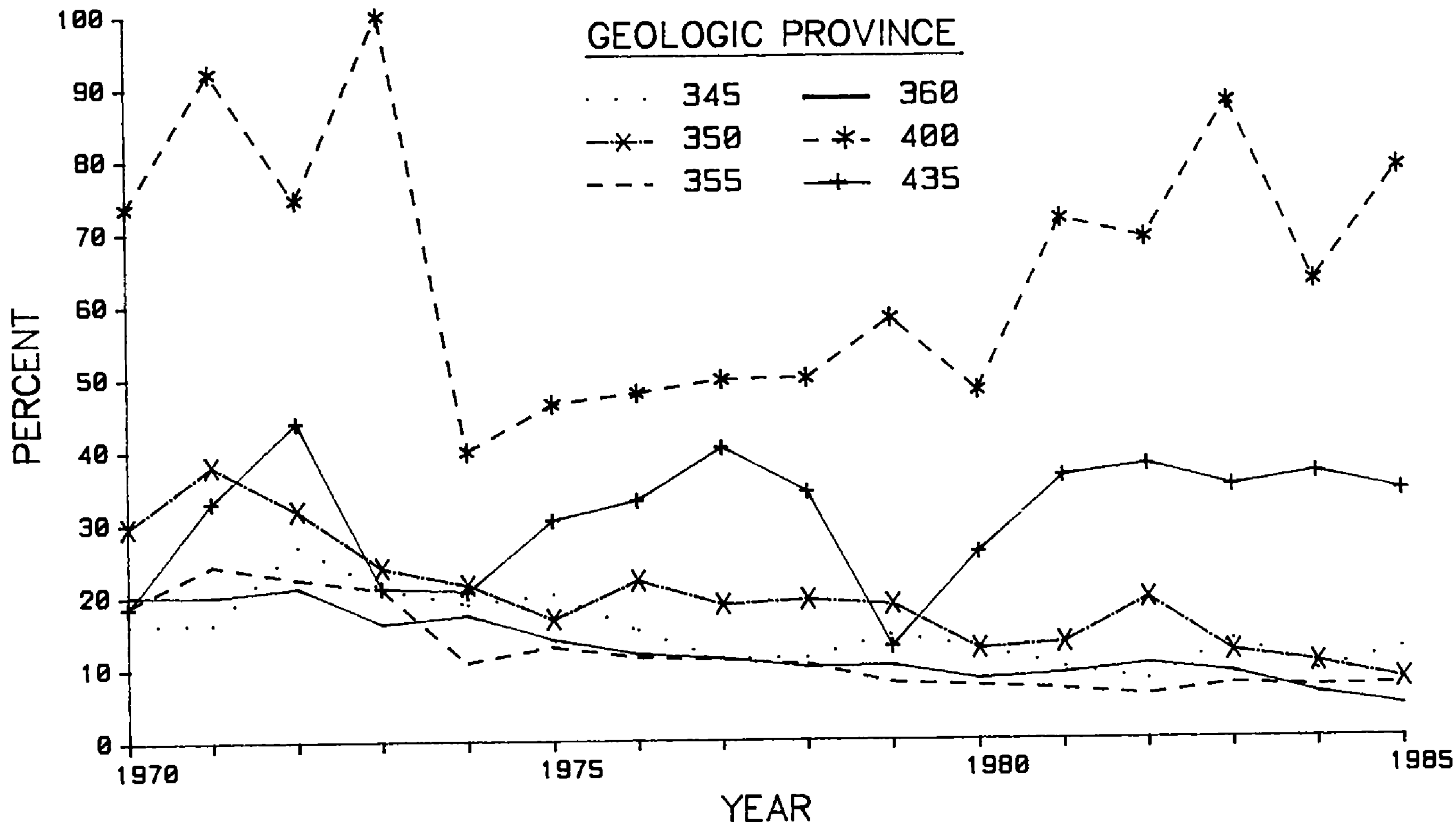

Figure 3. Exploration drilling in Oklahoma, expressed as percent of annual total footage in the geologic provinces, 1970–85.

for the revision. OGS is planning to release the information in its Special Publication series at an unspecified future date. Inquiries about this project may be addressed to Robert H. Arndt at the Oklahoma Geological Survey.

Summary and Conclusions

Determination of the number of wells actually completed in a given year in Oklahoma involves statistics reported in successive years. Data reported in such a succession of years are an incremental sequence. The number of years required to finish an incremental sequence for the completion years 1975–79 is six to eight. Incremental sequences for completion years 1980–85 are unfinished.

Between 1975 and 1979 the percentage of wells reported complete within the year of completion decreased from 80.5% to 70.2%. Ninety-nine percent of the wells completed in 1975 were reported within the first three following years. To report 99% of the wells completed in each of the years 1976–79 required four years.

Revision of the completion statistics by applying the incremental totals affects all data derived from the tally of completions.

Annual completion statistics for Oklahoma reported prior to 1985 by news media, industry organizations, and service organizations differ noticeably from statistics derived from the incremental sequences.

The number of wells reported complete by OGCD in a given year has been a composite number that represents completions made in several years. Without processing, it cannot be used to represent completions made in any given year.

Users of completion statistics should expect to find differences between annual well-completion statistics reported by several information sources. Users should expect information sources to supply a definition of terminology used and to identify the source of information and the manner of accumulation of reported statistics. Consultation with the Oklahoma Geological Survey and the Geological Information Systems staff may be helpful in understanding and evaluating some aspects of reported statistics of oil- and gas-well drilling and completion.

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COAL, AN ARCHITECT'S CHOICE

Brian J. Cardott[1]

Introduction

Coal is known to have many uses, primarily as a source of energy. One unconventional use of coal is as building finishing material. Oklahoma architect Bruce Goff (1904–1982) used coal as facing stone on both exterior and interior walls of the Price House (Shin'enKan, "place of the far-distant heart") in Bartlesville, Oklahoma (Fig. 1). Glass cullets are embedded in the masonry with the coal. Coal was selected by Goff primarily for its aesthetic appearance. The black sheen and coarse texture of the coal provide a stark contrast with the adjacent glass cullets (Fig. 2).

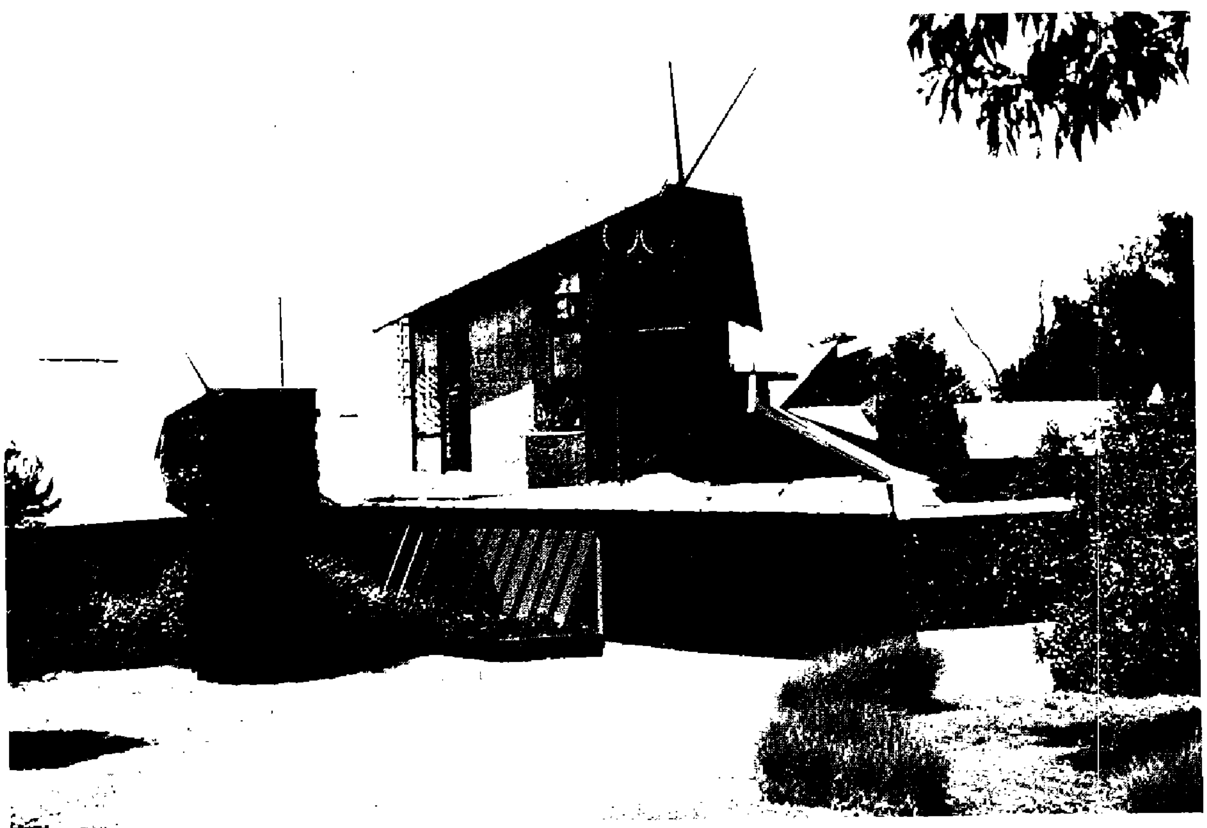

Figure 1. Front view of the Price House, facing west-northwest, showing coal masonry in part of phase 1 (right) and part of phase 2 (left). The second and third stories were constructed in phase 3 (center).

[1]Oklahoma Geological Survey.

Figure 2. Close-up view of one of the pillars containing dull-banded coal and glass cullets in phase 2.

The Price House was donated to the University of Oklahoma's College of Architecture by Joe D. Price, the original owner, in July 1985. The Oklahoma Geological Survey was contacted early in the restoration program initiated by the College of Architecture to provide technical assistance in restoring the coal masonry to its original state.

The house was built in three phases (1956, 1966, and 1976), coinciding with the changing needs of the owner. Coal was used as facing stone in the construction of phases 1 and 2, but not in phase 3. Obviously, the coals used in phases 1 and 2 could not have come from the same mine, and therefore are not necessarily of the same type or quality. Coal masonry occurs in all the exterior walls of pillars, the interior walls of pillars in phase 1, one interior wall of one pillar in phase 2, exterior foundation veneer between pillars in phase 1, fountain in phase 1 garden, and in retaining walls surrounding the house and phase 2 front doorway (Figs. 2,3).

The primary reason for Oklahoma Geological Survey involvement was to determine the extent of deterioration of the coal and to recommend suitable methods of restoration. Of secondary importance is the type of coal used, its rank, and its maceral (organic) composition; this information may be useful in future utilization of coal as building finishing material, and it may add to our understanding of the weathering of coal.

Four grab samples of coal were collected from exfoliated blocks in retaining walls to determine (1) the extent of deterioration of the coal, (2) type, (3) rank, and (4) maceral (organic) composition. Two field surveys of the property were conducted to observe the condition of the coal masonry, the types of coal used in the separate phases of construction, and the orientation of coal blocks in the coal masonry.

Megascopic, Microscopic, and Chemical Analyses

Field Survey

The field surveys revealed that the coal masonry includes both bright and dull coal types. Bright coal (banded) was used in phase 1 (1956), while dull coal (poorly banded) was used in phase 2 (1966). Coal was not used in phase 3 (1976).

The natural bright luster of the bright coal used in phase 1 has become lusterless on both interior and exterior walls, owing to natural oxidation and weathering. From the standpoint of the use of coal as building material, the coal masonry in the interior walls is in good condition. The interior bright coal is compact, with relatively few thin fractures. The exterior bright coal in the pillars and foundation

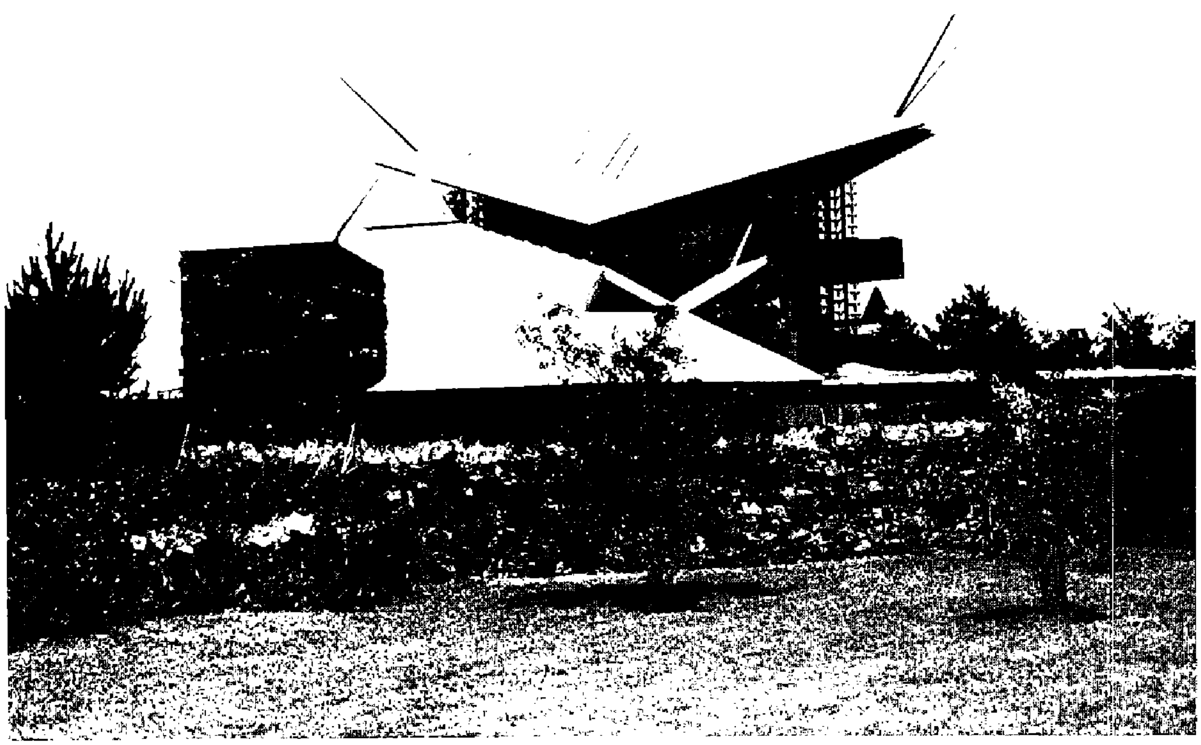

Figure 3. Ground view of the Price House, facing north-northwest, showing the retaining wall (foreground), pillar in phase 2 (left center), and second and third story addition in phase 3 (top center).

veneers is also compact, with a few more thin fractures. The bright coal masonry in the retaining walls has many deep fractures that have shattered the coal blocks (Fig. 4). Early attempts at restoring the luster of selected areas of the exterior bright coal masonry using silicon spray(?) have left a milky film on the coal surface (Fig. 5).

The dull coal masonry used in phase 2, occasionally mistaken for black shale, has a naturally dull appearance (Fig. 6). The dull luster of this coal has apparently not been affected by weathering. All of the dull coals are compact, with virtually no fractures.

The use of bright coal in phase 1 and dull coal in phase 2 makes it possible to distinguish phase 1 construction from phase 2 construction. The assimilation of the two phases required the removal of some bright coal masonry from the right exterior pillar of the phase 1 front doorway. The bright coal was replaced with masonry containing both bright and dull coal. Dull coal occurs above bright coal at the junction of phase 1 and 2 retaining walls and in the retaining wall along the driveway built during phase 1 construction.

The bright coal used in phase 1 classifies as a bright-banded coal. The bands, called lithotypes, alternate in random order of varying thickness. The dominant and thickest lithotype is clarain. Vitrain and fusain lithotypes are less common and are generally 3–5 mm thick. Fusain has a strong tendency to form dust and gives the bright-banded coal its dirty nature. The dull coal used in phase 2 classifies as a dull-banded coal, although some blocks appear nonbanded. The coal is finely laminated and has a dull or faintly greasy luster, a rough surface, and an irregular, granular fracture. The only lithotype present in the dull coal is durain.

Figure 4. Bright-banded coal and glass cullets in phase 1 retaining wall along back of house, showing loss of luster, lack of contrast between bands, and deep fractures.

Figure 5. Silicon(?) spray coating the coal in retaining wall, showing earlier failed attempt at retarding coal weathering.

Bright and dull coal blocks occur in various orientations in the coal masonry. The coal blocks are often oriented with the surface of the bedding plane facing outward (vertical), rather than with the face perpendicular to bedding oriented vertically. The vitrain and fusain lithotypes of the bright coal and the bedding-plane fracture pattern of the dull coal are often oriented vertically.

The two bright-coal grab samples exhibited a 6-mm weathered zone when slabbed. The external portion of the coal samples not surrounded by masonry was the most severely weathered. The dull-coal grab samples did not appear to have a weathered zone when slabbed.

Petrographic Analyses

Two microscopic analyses were performed on the four coal grab samples: (1) vitrinite-reflectance analysis to determine the coal rank, and (2) maceral analysis to determine the organic composition of the coals. Maceral composition relates to coal type (humic versus sapropelic), the type of humic or sapropelic coal (bright, semisplint, splint, cannel, boghead), and the source of the coal.

The vitrinite-reflectance analysis indicates that all of the coal samples are of high-volatile bituminous rank. The bright-coal samples (OPL 657a and 657b) are of high-volatile B bituminous (mean maximum R_o = 0.66%) and high-volatile A bituminous (mean maximum R_o = 0.83%) rank. The two dull-coal samples (OPL

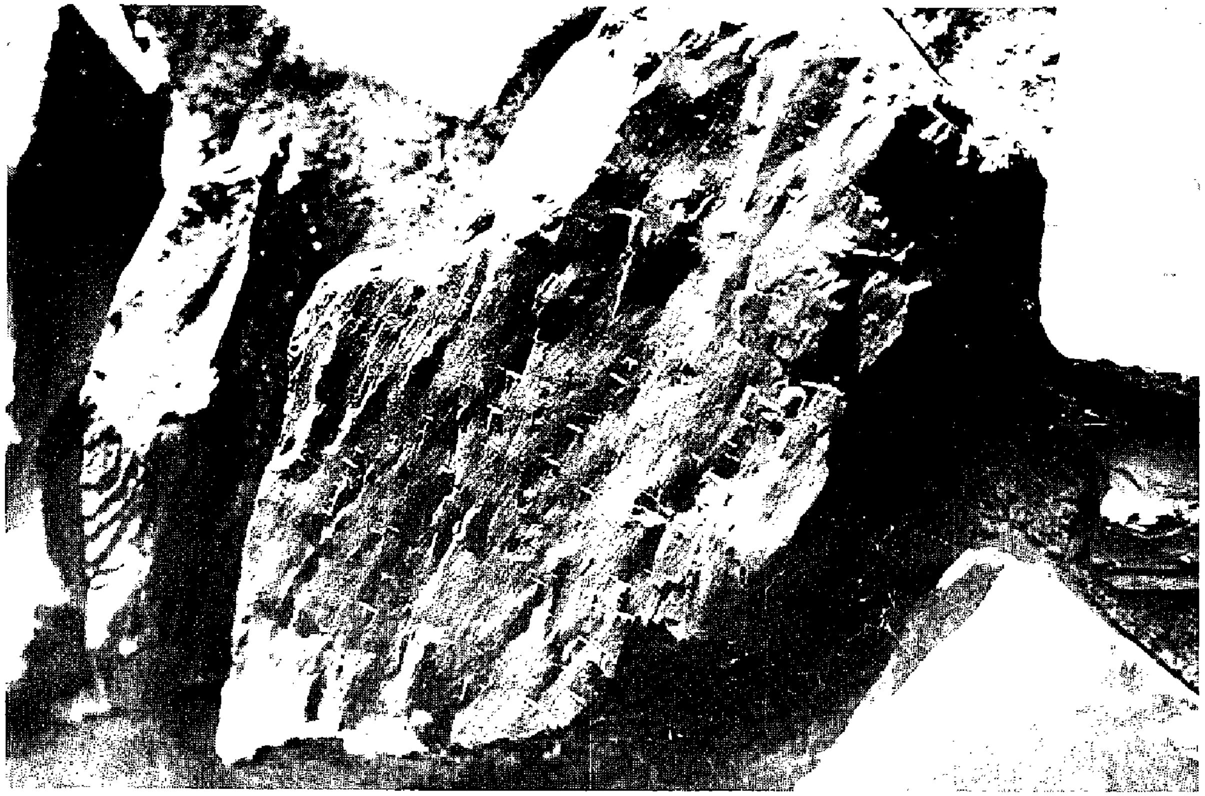

Figure 6. Dull-banded coal and glass cullets at top of retaining wall with view of mortar. The coal is compact, has no fractures, has rough texture, and has an irregular, granular fracture pattern.

657c and 657d) are of high-volatile A bituminous (mean random R_o = 0.73% and 0.72%) rank.

The maceral analysis (Table 1) confirms that the bright coals are banded (humic) coal with dissimilar maceral composition, and the dull coals are banded (humic) coal (not black shale or sapropelic coal) with similar maceral composition (Figs. 7,8). Maceral analysis of all coal samples revealed few occurrences of the typical effects of weathering on the macerals (tarnishing, blind fractures, high relief).

Chemical Analyses

Three chemical analyses were performed on the four coal grab samples: moisture (American Society for Testing and Materials [ASTM], 1986, D 3173), ash (ASTM, 1986, D 3174), and total sulfur (ASTM, 1986, D 3177). Moisture refers to the natural inherent moisture, excluding visible water on the surface of the coal. The moisture content, which relates to coal rank, is used to convert the ash and total sulfur contents from the as-received to the moisture-free (dry) basis. The ash content reflects the amount of mineral matter in the coal. Schopf (1956, p. 525–526) proposed that "the arbitrary definition of coal on the basis of purity can be stated as including less than 50 percent mineral matter by weight, and more than 70 percent carbonaceous matter by volume." Total sulfur measures the total amount of sulfur in the coal distributed in three sulfur forms: pyritic, sulfate, and

Table 1.—Maceral Analysis. Compare the Maceral Composition Between the Bright-Banded Coal Samples (OPL 657a and 657b) and Between the Dull-Banded Coal Samples (OPL 657c and 657d).

Macerals (Volume %)	Identification Number			
	OPL 657a	OPL 657b	OPL 657c	OPL 657d
Vitrinite	74.9	69.3	29.0	28.4
Pseudovitrinite	1.6	9.6	0	0
Semifusinite	0.3	2.7	36.8	37.5
Fusinite	0.2	0.3	1.1	1.7
Micrinite	16.7	13.0	12.6	14.8
Exinite	6.3	5.1	20.2	17.2
Resinite	0	0	0.3	0.4

organic. High amounts of sulfur tend to disintegrate the coal over time by oxidation. Sulfur forms were not determined.

The bright-banded coal samples (OPL 657a and 657b) had the following chemistry: moisture (as-received) of 2.0% and 2.7%; ash (moisture-free) of 2.7% and 3.5%; total sulfur (dry) of 0.7% and 0.6%.

The dull-banded coal samples (OPL 657c and 657d) had the following chemistry: moisture (as-received) of 0.8% and 1.0%; ash (moisture-free) of 14.5% and 12.0%; total sulfur (dry) of 0.6% and 0.5%.

The ash content indicates that all the coal samples are pure coals and not coaly shale. The dull-banded coal has a lower moisture and higher ash content than the bright-banded coal, which is typical for splint coals (Sprunk and others, 1940, p. 33). Cannel coal from Webb County, Texas, also has a low moisture (2.0–4.4%) and high ash (7.8–22.9%) content, in addition to high sulfur (1.0–4.0%) content (Evans, 1974, p. 23). Coals with 8–15% ash are considered medium ash coals (Wood and others, 1983). The medium ash content of the dull-banded coals contributes to its hardness, which is beneficial in the use of coal as a building material. The low-sulfur content of all the coal samples is beneficial in limiting the effects of natural oxidation and weathering of the coal masonry.

Classification of the Coal Masonry

Coal is broadly classified into two types: banded (humic) and nonbanded (sapropelic) (Stach and others, 1982). Cady (1958) and Damberger and others (1984) compared the numerous classifications developed for the field description of coal. The two most widely used megascopic classification systems are the Stopes–Heerlen and the Thiessen–Bureau of Mines. The Stopes–Heerlen, or International Committee for Coal Petrology (ICCP), System classifies banded coal into four lithotypes: vitrain, clarain, durain, and fusain. The Thiessen–Bureau of Mines System classifies banded coal into three types: bright, semisplint, and splint.

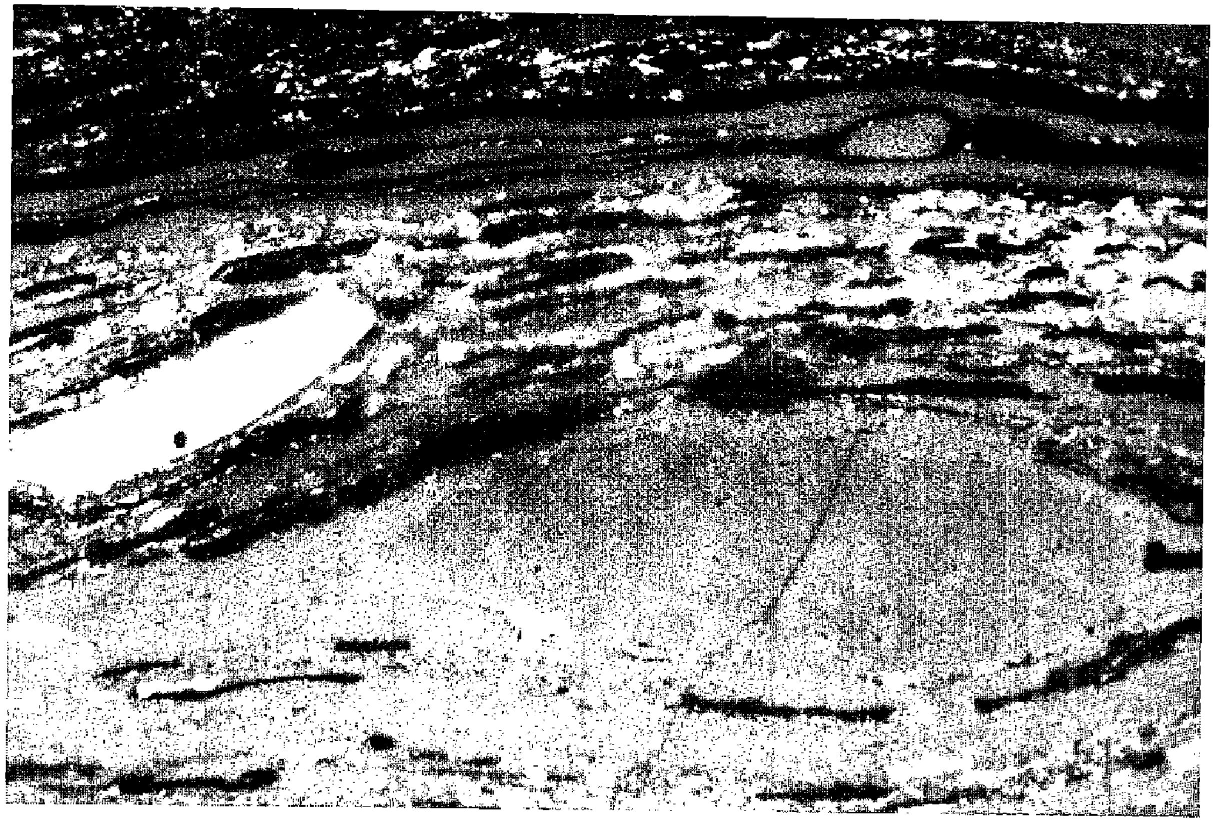

Figure 7. Photomicrograph of bright-banded coal (OPL 657b), showing microlamination. The medium-gray groundmass is the vitrinite maceral; the dark material in the vitrinite is exinite macerals (sporinite and cutinite); the bright shards are semi-fusinite and fusinite macerals; and the bright white specks are the micrinite maceral. Incident white light, oil immersion, 200×; field of view 0.14 mm.

Nonbanded coal is classified into either cannel coal or boghead coal in both systems.

The Stopes–Heerlen System classifies seam profiles according to the relative amount of each lithotype the coal contains, whereas the Thiessen–Bureau of Mines System incorporates several lithotypes in its type designation of bright, semisplint, and splint. For the purpose of classifying the general type of coal used in each phase of the Price House represented by random grab samples, the concept of composite varieties (Cady, 1942) of bright-banded and dull-banded coals will be used. The term "bright-banded coal" will refer to a coal containing mostly clarain and vitrain, with minor amounts of fusain. The term "dull-banded coal" will refer to a coal consisting entirely of the lithotype durain. Thiessen has correlated the term "splint coal" with the lithotype durain (Sprunk and others, 1940, p. 3).

The contractor for phase 1 construction (Calvin Mason, 1987, personal communication) has indicated that Bruce Goff specified cannel coal in construction. Cannel coal would be ideal for use as a building material. Ashley (1918, p. 9) listed several features of cannel coal which would be particularly favorable for use as a building material: "massive; uniform velvety or satiny luster; conchoidal fracture; jointing regular and striking; tough and elastic; weathers slowly; used for foundations of barns, etc." Bright-banded coal, on the other hand, has several features that make it undesirable as a building material: "more or less friable; disintegrates by weathering; soils the hands" (Ashley, 1918, p. 9). Evans (1974, p. 21) summarized the characteristics of the Webb County, Texas, cannel coal as "glossy, black color, fine-grained massive appearance, physically hard, and relatively nonweathering." He stated further that "lack of slacking tendency is confirmed in mine dumps where lumps of cannel coal still appear fresh after 40 years exposure."

Cannel coals are reported to occur in several states in the United States, including Alabama, Arkansas, Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, Ohio, Pennsylvania, Tennessee, Texas, Utah, and West Virginia (Ashley, 1918). Cannel coal does not occur in Oklahoma's coalfield. The contractor had ordered a shipment of maximum-size chunks of cannel coal from Pennsylvania. The predominance of clarain and vitrain lithotypes and of vitrinite macerals clearly classifies this coal as a bright-banded coal. The high-volatile bituminous rank of the banded coal suggests that the coal came from the western two-thirds of the main Bituminous Field in western Pennsylvania (McGraw-Hill Mining Publications, 1986). That the bright coals are of two ranks and have dissimilar maceral composition suggests that the coal did not come from the same coal bed or mine, but probably from the same coal region. However, this does not exclude the possibility that the coals were from the same coal bed or even the same mine. The two coal samples are of different rank, but their dissimilar maceral composition could be the result of the heterogeneity of bright-banded coal (especially true of grab samples). No attempt is made to correlate the coal samples with a specific coal bed. Apparently, bright-banded coal of high-volatile bituminous rank was substi-

Figure 8. Photomicrograph of dull-banded coal (OPL 657c) with microlamination. Maceral descriptions as in Figure 7. Incident white light, oil immersion 200 ×; field of view 0.14 mm.

tuted for cannel coal as specified and ordered from Pennsylvania. This would explain why bright-banded coal of high-volatile bituminous rank from Oklahoma was not used.

The contractor for phase 2 construction (Doran Johnson, 1987, personal communication) has indicated that Bruce Goff also specified cannel coal in phase 2 construction. Cannel coal was ordered from eastern Kentucky, a premier cannel-coal state according to Ashley (1918, p. 82). A very dull-banded coal with appearance similar to cannel coal was received. The dull coal used in phase 2 appears poorly laminated and does not have the typical waxy luster and conchoidal fracture typical of most cannel coals. It is not surprising that the dull coal received was thought to be cannel coal.

The megascopic classification of dull coal includes many possibilities, with end members ranging from shaly coal to nonbanded coal to dull-banded coal. Transitional forms occur between any of the dull coal end-members. White and Thiessen (1913, p. 276) and ICCP (1963, cannel coal) described transitions between nonbanded and banded coals. Sprunk and others (1940, p. 28) stated that "splint coals are known to merge into bright coals on one hand and cannel coals on the other." The similarity in occurrence and appearance of dull-banded and nonbanded coals makes it difficult to classify by megascopic description alone. Cannel coal and dull-banded coals often occur with bright-banded coals (Ashley, 1918, p. 31; Schopf, 1960; ICCP, 1963, splint coal). Similar characteristics are given for both nonbanded and dull-banded coals. The terms "dull and faintly greasy luster" are used to describe both dull-banded (durain) and nonbanded coals (sapropelic) (ICCP, 1963). The most distinguishing megascopic features that separate banded from nonbanded coal are lack of stratification and conchoidal fracture for nonbanded coals. Differentiation of the two types of nonbanded coals and their transitions require microscopic analysis (Schopf, 1960, p. 34; ICCP, 1963, cannel coal; Stach and others, 1982, p. 175; ASTM, 1986, D 2796). The fine stratification of the dull coal suggests that it is a banded coal. Microscopic analysis is used to classify the coal further.

The Thiessen–Bureau of Mines classification system separates banded from nonbanded coals based on 5% vitrinite (banded coals have >5% vitrinite, nonbanded coals have <5% vitrinite) (Parks and O'Donnell, 1956; ICCP, 1963, type of coal). Banded coals are further divided according to the amount of opaque matter (inertinite macerals). The dull coal samples have nearly 29% vitrinite macerals (vitrinite and pseudovitrinite) and nearly 39% inertinite macerals (semifusinite and fusinite, excluding micrinite) (Table 1), classifying as a splint coal (>5% vitrinite, >30% opaque matter). The Stopes–Heerlen classification system does not specify the amount of macerals in each lithotype. Rather, lithotypes contain maceral assemblages called microlithotypes (Stach and others, 1982). The maceral composition of the dull coal plots as clarodurite on a microlithotype ternary diagram (Cady, 1958, p. 10; Chao and others, 1983, p. 4). The lithotype clarodurain (Cady, 1942) is correlated with clarodurite (ICCP, 1963), which is equivalent to splint coal (ICCP, 1963).

In summary, the bright-banded coal used in phase 1 is classified as a bright coal in the banded-coal category, consisting primarily of clarain, with minor amounts of vitrain and fusain. The coal, reported to have come from Pennsylvania, probably came from the western two-thirds of the Main Bituminous Field in western

Pennsylvania, where bright-banded coals of high-volatile bituminous rank are predominant. Cannel coal, as ordered by the contractor, was also available from Pennsylvania (Ashley, 1918). The dull-banded coal used in phase 2 is classified both megascopically and microscopically as a dull-banded coal (durain; splint coal; dull coal). The dull coal is reported to have come from eastern Kentucky, where splint coal is reported to occur (Sprunk and others, 1940; Huddle and others, 1963). Thiessen and Sprunk (1935), Parks and O'Donnell (1956), and ICCP (1963) provide more information on splint coals. Cannel coal, as ordered by the contractor, was also available from eastern Kentucky (Ashley, 1918).

Restoration

Natural oxidation and weathering of coal is destructive and irreversible, changing the physical and chemical properties of the coal. Schopf (1960, p. 47) indicated that "weathering reduces the luster and decreases the contrast between coal ingredients. It is accompanied by oxidation and deterioration of original texture in the coal." Since the effects of weathering are irreversible, chemicals will not dissolve the dull-luster weathered-coal surface. Furthermore, chemicals might soak into the coal and encourage more cracking.

The effects of weathering are more pronounced on the bright-banded bituminous coal than the dull-banded bituminous coal. The bright coal originally had a shiny luster with contrasting layers. The dull coal originally had a dull luster with little contrast.

The subject of coal restoration primarily concerns the bright coal. The appearance of the dull coal has not changed much over the years. The ICCP (1963, splint coal) handbook suggests that splint coal works very well as a building material because it is "probably more resistant to oxidation than bright coal; has a rather low tendency to form dust" and "because of its toughness, tends to concentrate in the larger sizes of commercial coal."

Two methods are available for restoring the brilliance of the bright-banded coal. The first restoration method is not feasible in this case, requiring mechanical abrasion of the coal surface to physically remove the weathered surface. This method would remove the weathered zone of the coal, but would also certainly further disaggregate the coal. The second method does not actually restore the luster of the coal, but rather applies a shiny coating to the coal. This method requires coating the surface with a varnish or clear lacquer to brighten and protect the surface. The glossy appearance will come from the coating, while retaining the banded nature of the coal. Bruce Goff specified that the coal be dipped in lanolin prior to incorporation in the coal masonry (Calvin Mason, 1987, personal communication). The unavailability of commercial quantities of lanolin prevented the application as specified.

Conclusions

The Price House in Bartlesville, Oklahoma, was designed by Bruce Goff and built in three phases (1956, 1966, and 1976). Coal masonry was used as a building finishing material in pillars, foundation veneer, and retaining walls in the first two phases. Coal blocks are oriented in numerous ways in the coal masonry. Although cannel coal (nonbanded coal) was specified by Goff in the first two phases, bright-banded bituminous coal from Pennsylvania was used in phase 1, and dull-banded bituminous coal from eastern Kentucky was used in phase 2. The bright luster of the bright-banded coal has become dull, with associated loss of contrast between bands, owing to natural oxidation and weathering. Weathering has been destructive and irreversible, creating fractures. The dull luster of the dull-banded coal has remained dull, with no apparent affect from natural oxidation and weathering. The coal remains compact, with no fractures.

Since the effect of weathering is irreversible, no chemical treatment will restore the coal to its unweathered state. The weathered zone can be either mechanically removed, thereby disaggregating the coal further (not recommended), or coated with a clear, protective film. The bright luster will come from the film rather than the coal, in addition to sealing the coal from further oxidation and weathering. Small areas of coal should be tested and examined over time to check for long-term effects and desired luster.

Dull-banded or nonbanded coal is recommended over bright-banded coal for use as building material, owing to its favorable maceral (organic) composition (low vitrinite-maceral and high inertinite-maceral content), megascopic characteristics (compact, hard), and resistance to weathering. Coals with medium ash and low sulfur content are preferred.

Those interested in visiting Shin'enKan for a tour or in using the house as a convention center should contact the Oklahoma Center for Continuing Education at the University of Oklahoma at (405) 325-5101 for information on bookings and fees.

Acknowledgments

I would like to thank Irene Fatsea for introducing me to this project, for providing the first few samples for analysis, and for sharing her knowledge of Bruce Goff and the Price House with me. I also thank Junie Janzen for giving me a tour of the inside of the Price House and the property, and the Oklahoma Geological Survey chemistry laboratory for determining the coal chemistry. Thanks go to Calvin Mason and Doran Johnson for providing valuable information on the coal masonry that would not have otherwise been available.

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SEPM MIDCONTINENT SECTION PLANS APPALACHIANS FIELD TRIP

"Depositional History of Paleozoic Sequences: Southern Appalachians" is the topic of a two-day field conference for the 1988 SEPM Midcontinent Section Annual Meeting, scheduled for October 7–9 in Knoxville, Tennessee.

Participants will meet in Knoxville on the evening of October 7 for registration and an icebreaker. On October 8, Dan Walker of the University of Tennessee–Knoxville will lead a one-day field excursion to study tectono-stratigraphic implications of a Lower Cambrian fluvial-to-marine transition. This trip will feature the "rift to drift" transition and the inception of the Iapetos Ocean, as recorded by the Chilhowee Group (latest Precambrian to earliest Cambrian) of East Tennessee. Stops include exposures of fluvial deposits of the Unicoi/Cochran interval and marine shelf deposits of the Hampton-Nichols/Erwin-Hesse interval. A short visit to exposures of "rift" deposits of the Uppermost Ocoee Supergroup is also included. All localities are exposed on prominent ridges in the foothills of the Great Smoky Mountains of Tennessee.

On October 9, Steven G. Driese of the University of Tennessee–Knoxville will lead a one-day field excursion to the Valley and Ridge of East Tennessee to study the genesis of Lower Silurian shelf and shoreface deposits. Participants will examine the basin-wide facies architecture for the Lower Silurian terrigenous inner and outer shelf (Clinch and Rockwood Formations), and transition into a carbonate shelf (Brassfield Formation) in southwestern Virginia and eastern Tennessee. Excellent exposures of storm-related sedimentary structures produced in this complex depositional array will be observed at a number of localities. Examination of a part of the classic Thornhill section and a discussion of shelf hydrodynamic models will be included. The trip will end back in Knoxville by 6:30 p.m.

Cost for the field conference is about $90. For more information contact: Steven G. Driese, 306 G + G Bldg., Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410; (615) 974-2366.

MINERAL INDUSTRY OF OKLAHOMA, 1987

The value of nonfuel mineral production in Oklahoma in 1987 was estimated at $251.8 million, surpassing the record $251.6 million reached in 1985, according to the Bureau of Mines, U.S. Department of the Interior. Construction materials continued to represent most of the output value; crushed stone, portland cement, and construction sand and gravel were the leading commodities produced. Increases in value of production were noted for portland cement, clays, crude gypsum, iodine, lime, construction sand and gravel, and dimension stone.

In 1987, mining employment continued strong, up 6%, according to the Oklahoma Employment Security Commission, but the job gains were in oil and gas extraction; other mining jobs decreased by 100.

Agrico Chemical Co., a subsidiary of Williams Co., was sold to Freeport-McMoRan Resource Partners in January. The 160-employee plant in Rogers County produced 2,700 tons per day of ammonia and 5,000 tons per day of liquid urea ammonium nitrate.

Iochem Corp., Tokyo, Japan, announced that it would finish building an iodine plant near Vici, where it had leased about 4,000 acres. The plant will be supplied with brine from 10,000-ft wells.

Cargill Inc., Salt Division, at Freedom, Woods County, halted salt output from its solar ponds in October because of excessive rains. About two-thirds of the plant's 33 workers were laid off. Cargill hoped to resume production in late 1988.

Eagle-Picher Industries Inc. was awarded a General Services Administration contract to supply the first 2,000 kg of germanium metal from its plant at Quapaw to the National Defense Stockpile.

Resource Associates of Alaska Inc., Fairbanks, and Placer US Inc., San Francisco, explored the Wichita Mountains area for platinum-group metals.

Sequoyah Fuels Corp.'s plant at Gore was expanded to manufacture uranium tetrafluoride, a heavy compound used to make armor-piercing shells. In November, Kerr-McGee Corp., Sequoyah Fuels parent, agreed in principle to sell the subsidiary to GA Technologies Inc. (formerly called General Atomics), of San Diego, California. GA Technologies would continue operations at Gore.

St. Joe Resources Co., a subsidiary of Fluor Corp., sold its zinc refinery at Bartlesville to Horsehead Industries Inc., a New York-based manufacturing firm and parent of New Jersey Zinc Co. New Jersey Zinc was combined with St. Joe and renamed Zinc Corp. of America, becoming the largest domestic zinc producer.

NONFUEL MINERAL PRODUCTION IN OKLAHOMA

Commodity	1986 Quantity[b]	1986 Value (thousands)	1987[a] Quantity[b]	1987[a] Value (thousands)
Cement:				
Masonry (thousand short tons)	50	$ 3,198	45	$ 2,900
Portland (thousand short tons)	1,579	69,075	1,600	70,000
Clays (thousand short tons)	993	2,329	1,042	2,445
Gemstones	—	2	—	W[c]
Gypsum (thousand short tons)	1,683	9,855	1,695	9,921
Sand and gravel:				
Construction (thousand short tons)	10,366	24,585	11,600[d]	27,000[d]
Industrial (thousand short tons)	1,203	16,454	1,160	16,025
Stone:				
Crushed (thousand short tons)	30,900[d]	102,100[d]	29,500	97,400
Dimension (thousand short tons)	19[d]	913[d]	11	977
Combined value of feldspar, iodine, lime, pumice (1985–86), salt, tripoli, and withheld value	—	18,504	—	25,149
Total	—	$247,015	—	$251,817

Source: USBM Denver Regional Office of State Activities in cooperation with the Oklahoma Geological Survey.
[a]Preliminary figures.
[b]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[c]Withheld to avoid disclosing company proprietary data, value included with "Combined value" figure.
[d]Estimated.

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GSA CENTENNIAL MEETING
Denver, Colorado, October 31–November 3, 1988

This is a meeting at a special place with special plans for you. We invite you to attend—prepare now for that "once-in-a-century trip"!

Denver is situated where the vast Interior Plains of the United States meet the spectacular Front Ranges of the Rocky Mountains. It provides one of the most varied geologic settings of any major American city and is an extraordinary location in which to celebrate GSA's 100th year.

The topographic and structural basin beneath the city is an important source of hydrocarbons in the Rocky Mountain foreland region. The Front Ranges to the west are characterized by colorful upper Paleozoic sedimentary rocks, which bring tourists to the Garden of the Gods and to the Red Rocks Amphitheater, and by the historical mining districts in the Precambrian igneous and metamorphic rocks of the Colorado Mineral Belt. The ranges also mark the eastern edge of the geologically complex Cordilleran mountain system that extends from Alaska to Tierra del Fuego.

In addition to their mineral wealth, the mountains to the west provide a dramatic geologic display that you will not want to miss. This is indeed a special place for a special year.

—GSA

GSA Annual Meeting Agenda

Symposia

Phanerozoic Tectonics of North America
Controls on the Distribution and Quality of Cretaceous Coals
Processes of Continental Growth: Geophysical and Geologic Evidence
Hazard Reduction in the 21st Century

Mars: Geologic Analyses and Future Missions
Modern Glaciomarine Deposits: Polar vs. Temperate Environments
Ancient Glaciomarine Deposits: Polar vs. Temperate Environments
History of the Establishment of a Geologic Framework for Human Evolution
New World Geoarchaeology
Use of Geophysical Methods for Hydrogeologic Characterization and for Problems of Contaminant Transport
Chemistry and Physics of Minerals in the Mantle
A Tale of Two Cratons: Contrasts in Crust-Mantle Evolution
Individual Work Stations: Information Supermarkets for Geoscientists
Computer-Assisted Phylogeny Programs in Research and Teaching
Case Histories of World-Class Mineral Discoveries
Sedimentary Petrology: Old Foundations and New Implications for Teaching
Last Interglaciation/Glaciation Transition (122–64 ka) in North America
Role of Geology in the Superconducting Super Collider Site-Selection Process
Andean Magmatism and Its Tectonic Setting
Siljan Ring Well, Sweden: Deep Drilling in Crystalline Rocks
Seismicity, Quaternary Faulting, and Earthquake Hazards in the Rocky Mountain Region
Thermal Evolution of the Sevier Hinterland
Historical Perspectives and Future Directions in Mineral Deposits Research and Major Metals Utilization
EEZ-Scan: Results of the U.S. Geological Survey GLORIA Survey Program
Dynamics of Climate Change
Productivity, Accumulation, and Preservation of Organic Matter: Recent and Ancient Sediment Records
Late Proterozoic Evolution of Western North America: A Reevaluation
Mineral Resources of Solution-Collapse Breccias and Filled Sinkholes
Fractals in Geology
Paleomagnetism and North American Apparent Polar Wander Paths: Cenozoic to Precambrian

Field Trips

Premeeting Trips

Crust of a Young Earth—Guide to the Precambrian Continental Core of Southeast Wyoming, *October 27–30*
Proterozoic Plutons and Pegmatites of the Pikes Peak Region, Colorado, *October 28–30*
An Integrated View of Depositional Systems of the Early Tertiary Coal Measures, Powder River Basin, Montana and Wyoming, *October 28–30*
In Search of Hayden's Tertiary Lakes of the High Plains: The White River Formation Revisited, *October 27–30*
Geology and Hydrogeology of the Nebraska Sandhills, *October 28–30*
Paleohydrology and Hydrogeology of the Carbonate Rock Province of the Great Basin (East-Central Nevada to Southern Nevada), *October 28–30*

From the Basin and Range to the Edge of the Plains in the Tracks of Wheeler, Powell, and Hayden, *October 27–30*

Pennsylvanian and Permian Depositional Systems and Cycles in Eagle Basin (Vail to Glenwood Springs), Northwest Colorado, *October 29–30*

Archaeological Geology in the Colorado Piedmont and High Plains of Southeastern Wyoming, *October 28–30*

Northeastern Front Range Revisited: Compression and Crustal Wedging in a Classic Locality for Vertical Tectonics, *October 31*

Geomorphology and Quaternary Geology of Canyonlands, Utah, *October 28–30*

In the Footsteps of G. K. Gilbert—Lake Bonneville and Neotectonics of the Eastern Basin and Range Province, *October 28–30*

Hydrogeology and Phytogeomorphology of the Mountains and Foothills Near Denver, Colorado, *October 30*

Geology and Vertebrate Paleontology of Western Colorado and Eastern Utah, *October 27–29*

Major Landslides and Geotechnical Construction Problems in the Mountains of Colorado, *October 28–29*

Precious-Metal Telluride Deposits at Gold Hill, Boulder County, Colorado, *October 29*

Postmeeting Trips

The Earth Has a History, *November 4*

Styles and Deformation of the Cordilleran Orogenic Belt and the Mid-Tertiary Tectonic Overprinting, Southeast Arizona, *November 3–6*

Glacial-Marine Sedimentation, Mineral Fork Formation (Proterozoic III), Utah, *November 3–5*

Upper Cretaceous Shannon, Frontier, and Haystack Mountains Formations Shelf Sandstones, *November 3–6*

Dinosaur Trackways and Red Beds of the Purgatoire Valley: Early Mesozoic Depositional Environments and Paleoecology of Southeastern Colorado, *November 3–5*

Cretaceous–Tertiary Boundary in the Raton Basin—Evidence of Asteroid Impact, *November 3–5*

Geology and Mineral Resources of Central Colorado, *November 4–5*

Pleistocene and Recent Floods in the Big Thompson River Drainage, Northern Colorado Front Range, *November 4*

SEG-Sponsored Trips

Epithermal Precious-Metal and Base-Metal Systems, San Juan Mountains, Colorado, *October 26–29*

Deposits of the Colorado Mineral Belt: Leadville and Gilman Areas, *October 29–30*

Epithermal Precious-Metal Deposits Associated with an Island-Arc Environment: Japan, *November 4–13*

The Ga, Ge, Cu, Pb, Ag, and U Deposits of Southwestern Utah and the Arizona Strip, *October 27–29*

Short Courses/Workshops/Forums

Use of Microcomputers in Structural Geology, *October 28–30*
Ore Deposition Associated with Magmas, *October 28–30*
Geographic Information Systems: A Tool for Geological Data Analysis and Interpretation, *October 29*
Introduction to the Scientific Applications of Ocean Drilling Program Downhole Logging, *October 29*
Glacial Facies Models, *October 29–30*
Seismic Imaging of the Continental Crust, *October 29–30*
Geological Considerations in Hazardous-Waste Site Characterization, *October 29–30*
Quantitative Sedimentary Basin Modeling, *October 29–30*
Hydrous Phyllosilicates Exclusive of Micas, *October 29–30*
Geoscience Writing, *October 30*
Planning and Management of Hydrogeologic Investigations and Reports, *October 30*
Molecular Evolution and the Fossil Record, *October 30*
GeoRef Beginners' Workshop, *October 31*
GeoRef Advanced Workshop, *November 1*
Geology and Public Policy Forum: Fibrous Minerals, Mining and Disease, *November 1*
GIS Data Base Forum, *November 3*
Evolution of Reef Communities, *November 4–5*

For further information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020. The preregistration deadline is October 7.

THE GEOLOGICAL SOCIETY OF AMERICA ·1888·

UPCOMING MEETINGS

Ter-Qua '88, Symposium and Field Conference on Global Climate and the Future of the High Plains Aquifers, October 6–9, 1988, Lincoln and North Platte, Nebraska. Information: Institute for Tertiary–Quaternary Studies, 2739 Centenary, Houston, TX 77005; (713) 661-4038.

West Texas Geological Society, Fall Field Seminar, Guadalupe Mountains, Texas, October 13–16, 1988. Information: West Texas Geological Society, P.O. Box 1595, Midland, TX 79702; (915) 683-1573.

IGCP Project 254, Metalliferous Black Shales and Related Ore Deposits, Annual Meeting, October 29, 1988, Denver, Colorado. Information: Richard I. Grauch, U.S. Geological Survey, M.S. 973, Federal Center, Denver, CO 80225; (303) 236-5551.

American Association of Stratigraphic Palynologists, Annual Meeting, November 10–12, 1988, Houston, Texas. Information: John A. Clendening, Amoco Production Co., P.O. Box 3092, Houston, TX 77253; (713) 556-3549.

American Geophysical Union, Fall Meeting, December 5–9, 1988, San Francisco, California. Information: Ann E. Singer, American Geophysical Union, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6903.

Society of Economic Paleontologists and Mineralogists, Annual Meeting, April 23–26, 1989, San Antonio, Texas. Abstracts due October 1, 1988. Information: Jeanne Couch, Meetings Coordinator, SEPM, P.O. Box 4756, Tulsa, OK 74159-0756; (918) 743-9765.

Society of Mining Engineers, Western Surface Coal Mining Meeting, May 3–5, 1989, Gillette, Wyoming. Abstracts due October 15, 1988. Information: Society of Mining Engineers, Meetings Dept., P.O. Box 625002, Littleton, CO 80162; (303) 973-9550.

NOTES ON NEW PUBLICATIONS

Selected Chemical Analyses of Water from Formations of Mesozoic and Paleozoic Age in Parts of Oklahoma, Northern Texas, and Union County, New Mexico

Chemical analyses of samples collected from wells selected for use in the Central Midwest Regional Aquifer System Analysis (CM RASA) project are compiled in this 222-page USGS water-resources investigations report. The CM RASA is a study of the regional ground-water flow system in formations of Paleozoic and Mesozoic age in the central United States. The tabulated chemical analyses, grouped by county, and a statistical summary of the analyses, listed by geologic unit, are presented by Renee S. Parkhurst and Scott C. Christenson.

Order WRI 86-4355 from: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Bldg. 41, Box 25425, Denver, CO 80225. The price is $4 for microfiche and $34 for a paper copy; add 25% to the price for foreign shipment. A limited number of copies are available for distribution free of charge from the U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; (405) 231-4256.

OKLAHOMA ABSTRACTS

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

Influence of Mixed Carbonate-Terrigenous Clastic Regimes on Middle Ordovician Communities from the Mountain Lake Member (Bromide Formation), Oklahoma

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Six benthic macroinvertebrate communities were delineated from fossil assemblages in the Mountain Lake Member using Q-mode cluster analysis. Species abundance were determined using the bioarea technique, a method of determining abundance that is more accurate than using absolute counts of individuals or colonies. The bioarea technique is a method which compares relative surface areas of suspension feeding structures to obtain an estimate of biomass.

Four communities were dominated by strophomenid brachiopods. Two communities were dominated by trepostome bryozoans. Community structure was characterized using the parameters of dominance diversity, equitability, and trophic structure. All communities were dominated by epifaunal suspension feeders. All Mountain Lake communities developed on a shallow marine shelf at or below wave base on a mixed carbonate-terrigenous clastic substrate. Variations in substrate type, turbidity, water depth, terrigenous clastic influx, and nutrient supply were major factors regulating the distribution of communities.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988,* v. 20, no. 2, p. 93.

The Fluorescence Properties of the Hartshorne Coal of East-Central Oklahoma and West-Central Arkansas

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Hartshorne coals of the Arkoma Basin have petrographic and fluorescence properties that are similar to other North American Carboniferous coals and record an increase in coal rank from west to east within the basin. Hartshorne medium-volatile and low-volatile bituminous coals exhibit excellent swelling properties. High-volatile bituminous coals possess a liptinite assemblage that is more conspicuous in blue-light than in white-light. Statistical analysis of fluorescence parameters discriminates two varieties of fluorinite and sporonite whereas resinite fluorescence may be characterized as a spectral continuum. Cutinite emission is characterized by weak orange fluorescence intensities. Fluorinite displays strong blue-green

fluorescence, and is commonly associated with exsudatinite. Sporinite spectra peak broadly in the yellow wavelengths. Primary liptinite fluorescence is not detected in the medium-volatile and low-volatile bituminous coals; however, fluorescing secondary macerals, first observed in the high-volatile A bituminous coals associated with vitrinite and semifusinite, persist well into the low-volatile bituminous coals. The variety associated with semifusinite occurs as void-fillings and varies with increasing coal rank along a path parallel to the well-known inertinite coalification trend. The moderately intense greenish-yellow bodies progress in their hosts to the orange wavelengths in the low-volatile bituminous samples where their fluorescence begins to fade beyond detection. These results demonstrate that the utility of fluorescence microscopy extends over a much broader rank range than previously suspected.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 121.

Petrology of the Arbuckle Mountain, Oklahoma, Granitoids

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The chemistry and mineralogy of the three middle Proterozoic plutons (Unnamed granodiorite, Troy and Tishomingo granites) from the Arbuckle Mountains indicate that they formed as part of a magmatic arc sequence. Major and trace element chemistry, petrography, and phase relations suggest that the plutons represent a composite of melt and restite in which each magma evolved independently from its respective source.

Petrographically, three groups of mineral assemblages are recognized: (1) early apatite + magnetite + sphene ± zircon which record resorption effects; (2) biotite + hornblende + plagioclase ± zircon which may record resorption or be subhedral to anhedral; and (3) interstitial quartz and alkali feldspar which is either porphyritic or subhedral. The partially resorbed crystals are interpreted as restite phases; those phases not showing resorption are interpreted as having crystallized from a melt.

The alkali feldspars are perthites in which Or contents of homogenized crystals vary from Or_{82-75} (Unnamed granodiorite) to Or_{70-60} (Troy and Tishomingo granites). Similarly, the anorthite contents of plagioclases decrease from An_{40-27} (Unnamed granodiorite) to An_{25-15} (Troy granite) to An_{16-9} (Tishomingo granite). Biotites have Fe/(Fe + Mg) ratios of 0.50–0.40 and $Al_{(Total)}$ contents which decrease from 2.90–2.55 (Unnamed granodiorite) to 2.70–2.50 (Troy granite) to 2.50–2.35 (Tishomingo granite). Hornblendes are edenitic in all three plutons with the Tishomingo having the highest Fe/(Fe + Mg) ratios. The biotite and hornblende are distinct from those of anorogenic granitoids, and are similar to those from the Sierra Nevada batholith.

The plutons crystallized at moderate depths of $\leq$5 Kbars and at temperatures of 550–800°C under high f_{O_2} and high f_{H_2O}. Phase relations in the system Q–Ab–An–Or under water-saturated conditions at 5 Kbars are consistent with the observed

mineral parageneses and the interpretation of earlier-formed phases derived from restite.

Based on major element discrimination and chemistry of co-existing minerals, the Arbuckle granitoids have orogenic affinities and are different from anorogenic granitoids of the central midcontinent, thus providing important evidence of an orogenic event along the southern margin of the midcontinent during middle Proterozoic time.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988,* v. 20, no. 2, p. 123–124.

Geohydrology of the Great Salt Plains, Oklahoma

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Shallow groundwater of the delta sediments adjacent to the western edge of the Great Salt Plains Lake of Alfalfa County, Oklahoma, is highly mineralized with Na^{+} and Cl^{-} being predominant, and Ca^{2+} and $SO_4{}^{2-}$ being next in abundance. Lower Permian salt and anhydrite bearing sediments in the subsurface are thought to be sources of dissolved ions which are brought upward by artesian groundwater flow. Capillary draw raises these shallow brines to the surface where halite and selenite gypsum are precipitated within the upper 1 m of the silty deltaic sediments.

Water samples and selenite crystals, where present, were collected over the southern ⅔ of the delta during early August and late December. The brine surface was encountered between about 5 cm and 1.2 m below the ground surface. Water chemistry was highly variable, and depended on location in the collection area, yearly season, and other less obvious factors. Maximum chlorinity was about 190,000 ppm, and sulfate concentration maximum was about 5000 ppm. The best formed selenite crystals occurred in areas of highest chlorinity. Changes in the groundwater chemistry have taken place since an earlier study in 1968. Whether the changes are permanent or cyclic is not known.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988,* v. 20, no. 2, p. 129.

Paleoecology and Biostratigraphy of Deep and Shallow Water Upper Pennsylvanian (Missourian) Corals of Oklahoma

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Cyclical lithologies deposited during Late Pennsylvanian eustatic rise and fall of sea level contain two exclusive coral fauna faunas. One, the *Lophamplexus–Amandophyllum* Assemblage is found mostly in regressive limestones but is common in transgressive–regressive units and rare in transgressive limestones.

This assemblage, dominated by dissepimental Rugosa, occurs in limestones and associated shales that carry normal marine floras and faunas. Because it occurs in most midcontinent states, it has been particularly useful biostratigraphically. Two, the *Lophophyllidium–Amplexizaphrentis* Assemblage is found only in the Midcontinential states or in Texas and Oklahoma where the core shales are extremely thick. The corals dominated by zaphrentids and lophophyllidids, grew in deep water, well below normal wave and storm base and in conditions ranging from aerobic to dysaerobic. This assemblage is accompanied by radiolarians, conularids and molluscans particularly ammonoids. It has been useful in correlating units both within and between Texas and Oklahoma.

Reprinted as published in the Geological Society of America North-Central Section *Abstracts with Programs, 1988,* v. 20, no. 5, p. 339.

Stratigraphic Evidence of Holocene Faulting in the Mid-Continent: The Meers Fault, Southwestern Oklahoma

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Stratigraphic relations and ten ^{14}C ages show that movement occurred on the Meers fault in late Holocene time. Movement on the fault postdates the Browns Creek Alluvium, which began to be deposited between 14,000 and 13,000 yr B.P., and predates the East Cache Alluvium, which was deposited between 800 and 100 yr B.P. Surface warping along the fault led to local stream incision on the upthrown side of the fault and deposition of slopewash and fan alluvium on the downthrown side. Three ^{14}C ages of charcoal and soil humus buried by fan alluvium indicate that faulting probably occurred between 1400 and 1100 yr B.P. The soil that formed in the fan alluvium is only slightly more developed than that in the East Cache Alluvium, and the weak development of both soils indicates a geologically recent age that is consistent with the radiocarbon ages obtained for these deposits.

Reprinted as published in the Geological Society of America *Bulletin*, v. 100, p. 392.

Rb–Sr and Sm–Nd Isotopic Study of the Glen Mountains Layered Complex: Initiation of Rifting Within the Southern Oklahoma Aulacogen

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Rb–Sr and Sm–Nd isotopic data for rocks and minerals of the Glen Mountains layered complex (GMLC), a midcontinent mafic layered intrusion in the Wichita Mountains of southwestern Oklahoma, constrain the time of initiation of rifting within the southern Oklahoma aulacogen and provide information on the chemistry of the early Paleozoic mantle. Four whole-rock samples define a Rb–Sr

isochron corresponding to a maximum crystallization age of 577 ±165 Ma and an initial Sr isotopic composition of 0.70359 ±2. These whole-rock analyses do not define a Sm–Nd isochron; rather, they display a significant range in initial Nd isotopic composition (ϵ_{Nd} = 3.63–5.35). A three-point Sm–Nd mineral-whole-rock (internal) isochron for an anorthositic gabbro provides a crystallization age of 528 ±29 Ma. These data suggest that the GMLC was emplaced into the southern Oklahoma aulacogen during the initial phase of rifting along the southern margin of the North American craton in the early Paleozoic. This Sm–Nd internal isochron age is within analytical uncertainty of U–Pb zircon ages for granites and rhyolites from the Wichita Mountains; therefore, mafic and felsic magmatism may have been contemporaneous within the rift during the early stages of development. Hybrid rocks and composite dikes in the Wichita Mountains provide field evidence for contemporaneous mafic and felsic magmas. Initial Sr and Nd isotopic data suggest that magmas parental to the GMLC were derived from a depleted mantle source. However, Nd isotopic data for the GMLC plot distinctly below data for the depleted mantle source cited by DePaolo and thus suggest that the parental magmas of the GMLC were either contaminated by Proterozoic crust of the southern midcontinent or were derived from a heterogeneous mantle source region that had variable initial Nd isotopic compositions.

Reprinted as published in *Geology*, v. 16, p. 13.

Fracture Patterns on Western Benton Uplift, Arkansas

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Paleozoic rocks exposed on the western Benton uplift of the Ouachita Mountains include pervasive joint sets, which are mostly very well preserved with planar surfaces and no trace of mineralization in all lithological units. Conjugate shears, oblique joints, and three orthogonal joint sets are all present throughout the area. Joints perpendicular to the layering display a spacing that is a function of rock type and bed thickness. Joints have spacings of more than 1.0 m in sandstones, and up to 3.0 m in massive novaculites and cherty layers. In thin beds of shale, however, this range is less than 1.0 m. An attempt is made to examine the origin of the systematic joint sets as well as their relationship with other structures in the area.

The three orthogonal sets exhibit a systematic relationship to the folds with one set being perpendicular to the fold hingeline, the second set paralleling the bedding plane, and the third set fanning around the axial surface of these folds (radial joint). This genetic relationship is evidenced by, (1) comparison of orientation diagrams of these joints with the folds in different lithological units, (2) the orientation of penetrative pencil fractures that have formed by the intersection of the bedding planes and the radial joints. These pencils maintain an E–W orientation parallel to the fold axes of the folds and clearly represent synchroneity of these structures, and (3) existence of conjugate shear joints on the plunging hingelines of the chevron folds. Analyses show that the acute bisector of the conjugate joints

is in N–S direction parallel to the direction of the maximum stress axis ($\sigma 1$) responsible for the development of these folds. Reports on the mechanical origin of these joints from eastern plunge of the Benton uplift are ambiguous and contradictory. In some areas, similar relationship between folds and orthogonal joint sets have been reported as described above, while other workers relate these joints to post-deformational uplift of the Ouachita Mountains.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 90.

Plant Megafossils from the Savanna Fm., West Central Arkansas: A New Interpretation of the Age of the Arkansas Coal Fields

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Recent collections of plant megafossils from the roof shales of the Charleston and Paris coals at the base and top, respectively, of the Savanna Fm. have allowed a re-interpretation of the age of this formation. Characteristic species of the Charleston coal are *Asterophyllites Charaeformis*, *Linopteris* sp., *Neuropteris scheuchzeri*, *N. rarinervis*, *Pecopteris* cf. *arborescens*, and *P. unita*. The Paris coal is characterized by abundant detached pinnules and occasional terminal pinna of *Linopteris* cf. *obliqua* (previously reported as *Linopteris rubella*, Lx.). The Savanna Fm. correlates well with the upper part of the Kanawha Fm. in the proposed Pennsylvanian stratotype and with Westphalian C equivalents worldwide. Underlying the Savanna Fm. are the McAlester Fm. (150–600 m), Hartshorne Ss. (3–100 m), Atoka Fm. (500–3,000 m), and Bloyd Fm. (60–70 m). The Bloyd Fm. contains a coal, the Baldwin coal, that correlates with Westphalian A equivalents. The coal field of the Arkansas River Valley thus ranges in age from Westphalian A to C (New River and Kanawha equivalents.

Reprinted as published in the Geological Society of America North-Central Section *Abstracts with Programs, 1988*, v. 20, no. 5, p. 333.

Duplex-Like Structures in Submarine Fan Channels, Ouachita Mountains, Arkansas

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Submarine fan channel sequences of the Jackfork Formation (Lower Pennsylvanian) at DeGray Dam section in the Ouachita Mountains, Arkansas, contain discrete units (10–75 cm thick) with moderately dipping (25°–40°), sigmoidal imbricate slices. Adjacent units with opposing imbricate slices are common. The sigmoidal structures are similar in geometry to a tectonic feature known as a duplex. A tectonic origin of sigmoidal structures, however, seems unlikely because opposing directions of imbrication in adjacent units would require an unrealistic

tectonic movement history for the area. We propose that the Jackfork sigmoidal structures were formed by a process kinematically similar to that responsible for generating duplex structures. Unlike tectonic duplexes, however, the sigmoidal structures were formed by soft-sediment deformation of sand and mud layers as high-energy sediment gravity flows glided over these layers. Sediment gravity flows, responsible for forming the sigmoidal deformation, were probably generated by slumping of adjacent channel walls. Dip direction of sigmoidal slices is perpendicular to channel axes. Thus, recognition of sigmoidal deformation structures may be useful in inferring the trend of channels in ancient submarine fan complexes.

Reprinted as published in *Geology*, v. 16, p. 229.

Palynological Correlation of Major Pennsylvanian (Upper Carboniferous) Time-Stratigraphic Boundaries in the Illinois Basin with Those in Other Coal Regions of Euramerica

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Palynological data provide the basis for time-stratigraphic correlations of Pennsylvanian (Upper Carboniferous) strata between the Illinois Basin, other coal regions in the United States, western Europe, and the Donets Basin.

Correlations of Morrowan–Atokan and Atokan–Desmoinesian boundaries are only approximate because of different stratigraphic and paleontologic interpretations of the boundaries in the type areas. The two boundaries are correlated in Illinois with positions in the lower Abbott Formation and the lower Spoon Formation, respectively. The Desmoinesian–Missourian boundary is identified on the basis of a pronounced change in composition of coal swamp floras throughout the Upper Carboniferous equatorial coal belt.

The Lower–Middle Pennsylvanian boundary proposed by the U.S. Geological Survey is at the base of the Pounds Sandstone in Illinois; it is older than the Lower–Middle Pennsylvanian boundary, as commonly used in the Midcontinent, which is equivalent to the top of the Morrowan Series. The Middle–Upper Pennsylvanian boundary as used by the U.S. Geological Survey is probably younger than the Middle–Upper boundary in the Midcontinent. This boundary is correlated with a position in the lower part of the Modesto Formation in Illinois.

The top of the Westphalian A is correlated with the base of the Abbott Formation; the top of the Westphalian B with the middle of the Abbott; and the top of the Westphalian C with the lower Spoon Formation. The Westphalian–Stephanian, Desmoinesian–Missourian and Middle–Upper Pennsylvanian boundaries are equivalent.

The Bashkirian–Moscovian boundary correlates with the lower one-third of the Abbott Formation, and the Moscovian–Kasimovian boundary is slightly younger than the Desmoinesian–Missourian boundary.

Reprinted as published in the Geological Society of America North-Central Section *Abstracts with Programs, 1988*, v. 20, no. 5, p. 384.

Preliminary Conodont Biostratigraphic Characterization of Middle-Upper Pennsylvanian Eustatic Cyclic Sequence in Midcontinent North America

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About 60 cycles of glacial-eustatic marine transgression and regression are now recognized in the mid-Desmoinesian to mid-Virgilian sequence along the Midcontinent outcrop belt from Iowa to Oklahoma. Recognition of biostratigraphically useful species of conodonts in offshore shale horizons, particularly within the abundant genus *Idiognathodus* (includes *Streptognathodus*), has initiated faunal characterization of each of the major marine cycles, which is leading to a refined conodont zonation of the sequence. Lithostratigraphic relations combined with conodont biostratigraphy of long cores and outcrops already have led to correction of longstanding miscorrelations of several major marine cycles in the Missourian Series along outcrop. The conodont zonation combined with zonations based on ammonoids, fusulinids, palynomorphs and other groups should provide a reliable framework for correlation of eustatic cycles with those in other basins in North America and possibly elsewhere in the world. The Desmoinesian–Missourian Series boundary stands out as a distinctive horizon of extinction of genera among many groups, including marine conodonts, fusulinids, ammonoids, brachiopods and chaetetids, and terrestrial palynomorphs. The Missourian–Virgilian boundary has been placed at several different horizons in different states, none of which are faunally distinct among the groups under consideration.

Reprinted as published in the Geological Society of America North-Central Section *Abstracts with Programs, 1988*, v. 20, no. 5, p. 347.

Depositional Pattern of the Galesburg Shale (Missourian; Midcontinent)

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The nearshore to terrestrial shales of Midcontinent cyclothems may lack deltaic facies, but since the marine facies are consistently developed, eustatic fluctuation is the probable cause of the cyclic deposition.

The Galesburg Shale lies between the Swope and Dennis limestone formations of the Bronson Group. The fusulinid *Triticites* first appears in the overlying Dennis Formation, providing a biostratigraphic marker and suggesting the presence of a major gap in the underlying succession.

The fluvial-deltaic facies of the Galesburg is marked by an illite–kaolinite–chlorite clay suite and contains abundant detrital muscovite. In southeastern Kansas and northeastern Oklahoma the Coffeyville deltaic system formed during the low stand of sea level between the Swope and the Dennis. In the Illinois Basin, the alluvial system that fed the delta occurs between the Macoupin and the Carthage/Shoal Creek limestones. The fluvial and deltaic facies may be more than 30 meters thick.

In contrast, in the Forest City Basin of Iowa, Nebraska, Missouri, and Kansas, the Galesburg is a thin (less than 2 meters) greenish underclay, characterized by an illite-chlorite clay suite and lacking muscovite. It represents subaerial soil development on the Swope cyclothem; there is no evidence of a delta within the basin. Nevertheless, the lithologic and paleontologic succession in the following Dennis cycle is the same in the Forest City Basin as it is in Kansas and Illinois.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 128.

Sulfur-Isotope Variations in Pennsylvanian Shales of the Midwestern United States

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Conditions of sedimentation have affected isotopes in coarse-grained sulfides from Pennsylvanian shales. For example, the Mecca Shale Member (Desmoinesian Series) contains highly variable values for $\delta^{34}S$ (≈ -10 ‰; σ, standard deviation, ≈ 9) near the ancient shoreline of the Illinois basin, whereas equivalent strata in Missouri and Kansas, farther from the ancient shoreline, have more negative and less variable values (-14.5 ‰; $\sigma \approx 5$). Sulfides from younger beds in the Missourian Series contain still lighter and less variable sulfur ($\delta^{34}S \approx -27$ ‰; $\sigma \approx 3.1$). Because low $\delta^{34}S$ values are typical of sediments deposited in anoxic deep waters, these results suggest that Missourian shales formed slowly in deep waters. The Desmoinesian shales may have been deposited more rapidly in shallower seas. Alternatively, secular shifts for $\delta^{34}S$ in sea-water SO_4 may have been stronger than previously realized.

Reprinted as published in *Geology*, v. 16, p. 18.

Hierarchical Genetic Stratigraphy in Midcontinent Upper Paleozoic Rocks

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Small scale changes (with durations of tens to hundreds of thousands of years) in sea level/climate are readily apparent when hierarchal genetic stratigraphy is used to examine Upper Carboniferous and Lower Permian rocks in the midcontinent. By careful examination at a scale of centimeters or less genetic surfaces are recognized that can be used to compare outcrops and address auto vs. allogenesis of these surfaces. Genetic surfaces may be recognized as changes in organic diversity within a lithologically homogeneous sequence or by differences in contemporaneous depositional environments which produce a reasonable facies mosaic. Correlation of genetic (i.e., transgressive or climate-change) surfaces over large areas provide strong evidence of allogenic phenomena.

With a framework based on recognition of genetic "packages" (T–R units) it is possible to make meaningful interpretations of geographically closely spaced,

coeval, but lithologically different, stratigraphic sequences. On a larger, regional, scale detailed palaeogeographic maps can be constructed that provide interpretations of lithologically variable rock sequences with testable ideas related to relative water depth, palaeotopography, and depositional environments in adjacent areas.

There seems to be little doubt that small scale sea level fluctuations are largely reflections of climate "forcing" related to or controlled by Milankovitch cycles. These periodicities are becoming more widely recognized in the geologic record, with particularly well known and well documented examples from the Cretaceous and Pleistocene. A "nested" hierarchy of these small scale genetic units (hierarchal genetic stratigraphy) is an extremely useful framework within which to address basic questions of earth history, including palaeoecology and evolution.

Acknowledgement is made to the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 132.

Origin of Plio-Pleistocene Lake Basins, Deaf Smith and Randall Counties, Texas Panhandle

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A series of lake basins developed along the drainages of segments of Tierra Blanca Creek and the Prairie Dog Town Fork of the Red River in the Texas Panhandle during the late Tertiary and early Quaternary. The valleys of these streams are underlain by a localized area of thin Seven Rivers salt that apparently resulted from accelerated salt dissolution. Structure-contours on the base of the Tertiary Ogallala Formation below these valleys show several structural lows and closed structural basins that probably resulted from dissolution-induced subsidence. These structural lows are overlain by a series of large, breached lacustrine basins that are drained by Tierra Blanca Creek and the Prairie Dog Town Fork. Outcrops of the Ogallala Formation dip beneath the lacustrine sediments. These lakes occupied structural basins that apparently resulted from subsidence following dissolution of salt in the Salado and Seven Rivers Formations. Lacustrine sediments filling these basins contain Blancan vertebrates, Pleistocene mollusks and ashes of the Pearlette family including the Lava Creek B ash. The age range of these sediments indicates that dissolution and subsidence began during the Pliocene and that the lakes remained extant throughout the early Quaternary. Valley segments downstream of the lake basins are narrow, straight, and steep walled. Parts of lake basin floors remain essentially undissected. The limited degradation of the lake basins and their outlets also suggests that these lakes remained extant into the late Quaternary. Lacustrine sediments show no evidence of significant deformation, indicating that little or no dissolution or subsidence has occurred since these lakes drained. Work supported by U.S. DOE/SRPO. Author's conclusions not necessarily endorsed or approved by DOE.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 101.

Cenozoic Subsidence Basins in the Northern Texas Panhandle Result from Subsurface Dissolution of the Permian Flowerpot Salt

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Natural dissolution of Permian salt deposits in the Texas Panhandle during Cenozoic time has locally caused overlying strata to subside and settle into dissolution cavities. Surface depressions created by this process were partly or totally filled by lacustrine sediments, and some of these subsidence basins are now exposed due to modern-day stream incision.

Two such subsidence basins occur several kilometers apart in the northern Texas Panhandle, along Palo Duro Creek and Horse Creek. The Flowerpot salt, the shallowest salt in the area, is 0 to 107 m thick and is 200 to 335 m beneath the present land surface, based upon a study of the geophysical logs of boreholes drilled in and near the subsidence basins. Examination of the Cenozoic (Ogallala and post-Ogallala) sediments in these basins indicates that the last episode of salt dissolution and subsidence probably occurred at least several hundred thousand years ago. There is no evidence to indicate that salt dissolution is occurring now, or has occurred in the recent past.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 103.

Natural Dissolution of Permian Salt Causes Contamination of Surface and Ground Waters in Western Oklahoma and the Texas Panhandle

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Permian salt beds in western Oklahoma and the Texas Panhandle are being dissolved locally in the shallow subsurface. Fresh ground water comes in contact with the salt and dissolves it, to become partly or fully saturated with respect to NaCl. The resultant brine moves laterally and/or upward towards the land surface where it degrades shallow aquifers and surface waters. The most conspicuous results of this process are the many natural salt springs and salt plains present along the main stems and tributaries of the Red River, Cimarron River, and Arkansas River.

Ground water dissolves salt at depths ranging from 10 to 250 m below the current land surface. The supply of fresh ground water is recharged through permeable rocks, alluvium, terrace deposits, karstic features, and fractures. The brine migrates through caverns, fractures in disrupted rock, and clastic or carbonate aquifers until it reaches the land surface. In many areas, salt dissolution is a self-perpetuating process: dissolution causes cavern development, followed by collapse and subsidence of overlying rock; then the resulting disrupted and fractured rock has a greater vertical permeability that allows increased water percolation and additional salt dissolution.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 103.

Applications of Borehole Geophysics to the Site Characterization of a High-Level Radioactive Waste Repository in Bedded Salt of the Permian San Andres Formation, Palo Duro Basin, Deaf Smith County, Texas

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The suitability of a potential high-level radioactive waste repository in bedded salt of the Permian San Andres Formation is presently being evaluated by the Department of Energy. Information from geophysical logs from wells in the vicinity of the site can be used to produce reliable stratigraphic correlations and address geotechnical concerns associated with waste isolation.

The approximately 165-foot-thick salt interval that has been targeted for disposal occurs within a cyclic succession of mudstone, limestone, dolomite, anhydrite, and halite. The variation of physical properties and corresponding geophysical log responses of lithologies in this sequence allow for detailed subsurface mapping. Standard gamma, density, neutron, acoustic, resistivity, and spontaneous potential logs from cored and noncored wells were used to document diagnostic geophysical log responses, generate lithologic logs, and correlate units within the San Andres and overlying formations. In addition, the geophysical logs were used to identify or exemplify previously identified zones of natural and drilling-induced salt dissolution, repository-level salt impurities, and potentially permeable intervals within and above the San Andres Formation.

The existence of impurities in the repository-level salt reduces the certainty of predicting the thermal/mechanical response of the host rock to mature repository operations. Permeable zones are potentially problematic in terms of sealing the repository shafts and as pathways for the groundwater transport of released radionuclides.

The results of this study demonstrate that geophysical logs from cored and noncored wells in the vicinity of the Deaf Smith County site can be used to accurately define the stratigraphy and identify areas that require further investigation during site characterization.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 131–132.

Circulation of Ground Water in Salt-Dissolution Zones, Texas Panhandle*

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Permian halite deposits beneath the Southern High Plains in the Texas Panhandle are possible host rocks for a high-level nuclear waste repository. However, extensive salt beds have been dissolved along the northern perimeter of the Southern High Plains. Data from six test wells confirm that meteoric ground water moves downward from aquifers in post-Permian formations and dissolves halite and anhydrite. Two samples of NA–Cl ground waters in salt-dissolution zones peripheral to the Southern High Plains plot along the meteoric water line (δD of

−51 and −72 ‰; $\delta^{18}O$ of −7.2 and −9.4 ‰), have salinities of 68,000 and 95,000 mg/L, and are undersaturated with halite but saturated with gypsum. The ^{14}C ages of the two samples are approximately 16,200 ±3,500 and 23,500 ±1,000 yr. In contrast to peripheral salt-dissolution zones, NA–Cl ground water in a salt-dissolution zone beneath the Southern High Plains is near saturation with both halite and anhydrite; its age is unknown. Hydraulic conductivities are larger in peripheral salt-dissolution zones (0.2 to 0.5 m/day) than beneath the Southern High Plains (0.00006 to 0.007 m/day), primarily reflecting rock type; dissolution of evaporite cements and fracturing or collapse related to salt dissolution influence hydraulic properties. Ground-water velocities are probably greater in peripheral salt-dissolution zones than beneath the Southern High Plains because of the greater hydraulic conductivities and steeper hydraulic-head gradients. Holocene rates of salt dissolution most likely are lower than rates prevalent during the Tertiary and Pleistocene owing to changes in physiography and climate that probably decreased the recharge rate to the salt-dissolution zones. Circulating ground waters continue to dissolve halite, but the rate of dissolution at the proposed nuclear-waste repository site is unknown.

*Supported by U.S. Dept. of Energy (DOE) Salt Repository Project Office; conclusions are not necessarily endorsed or approved by DOE.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 98.

Regional Stratigraphy and Facies of the Middle Ordovician Simpson Group, Southwest Kansas

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The Middle Ordovician Simpson Group in the subsurface of the southwest quarter of Kansas was investigated using information from sample logs, well logs, and cores. In this area, the Simpson ranges from slightly over 200 feet thick in the southeast part of the study area to completely absent in some of the north parts. The Simpson is lithologically diverse and consists of green shale, clean to dolomitic sandstone, and sandy carbonate rocks. Fossils, which are uncommon, include vertical burrows, bryozoans, echinoderms, conodonts, and fragmentary fish.

Most notable of the facies relations is a carbonate/clastic interface at about long. 99° W. (between Pratt and Kiowa Counties). East of this interface, the Simpson is almost entirely clastic and consists of sandstone and green shale and, commonly, a thin sandy carbonate unit at the top. West of this interface, the carbonate units are thicker but still occur primarily in the upper part of the Simpson. Chert is more common in the carbonate units to the west of the interface than to the east.

In the northeast part of the study area, in and near Rush County, the Simpson progressively thins by erosion over the central Kansas uplift; the upper parts of the section are lost first. In the northwest part of the study area, in and near Greeley County, the Simpson consists of only a thin sandy dolomite or dolomitic sandstone or is absent altogether. Toward the southwest corner of Kansas, the Simpson also thins but mostly retains the sequence of sandy carbonate units over clastic units that it has to the east.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 94.

Subsurface Structural Geology of the Nemaha Tectonic Zone, Kansas

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The Nemaha Tectonic Zone (NTZ) is recognized as a major NNE-trending system of folds and faults extending through eastern Kansas. The NTZ continues into Nebraska to a junction with the NE-trending Thurman–Redfield Structural Zone, and south through Oklahoma to the E–W Pauls Valley Uplift. The Nemaha Tectonic Zone incorporates the Nemaha Uplift, the Humboldt Fault, and minor subsidiary structures.

The Nemaha Uplift in Kansas is an antiformal structure containing many individual domal culminations separated by synclinal troughs, sigmoidal anticlinal closures, and deep, rhombiodal-shaped grabens. The uplift is bounded continuously on the east by the Humboldt Fault system, a complex zone of faulting, and on the west by a series of discontinuous fault segments.

The NTZ is intersected by NW-trending cross-structures, some of which can be related to major, through-going fold-fault systems, such as the northwest extension of the Bolivar–Mansfield and the Fall River. Structures within the NTZ are complex at these junctions.

The Nemaha Tectonic Zone is believed to be the reactivated faulted eastern margin of the Proterozoic Midcontinent Rift System. Structures mapped along the length of the NTZ suggest that the entire fold-fault system was subjected to a sinistral strike-slip motion in the Pennsylvanian, probably in response to the Ouachita collisional orogeny to the south.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 91.