Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY/VOL. 45, NO. 4—AUGUST 1985

On the cover—

Grayhorse Limestone, Payne County, Oklahoma

The cover photo shows a good exposure of the Grayhorse Limestone overlying thin shale and sandstone of the Gano Shale. The Gano and Grayhorse are units of the Vanoss Group of Late Pennsylvanian (Gearyan) age.

This exposure lies in sec. 16, T19N, R5E, in northeastern Payne County, Oklahoma. Here, the Grayhorse is relatively thick and is a light-gray, fossiliferous limestone. Fusulinids are abundant in this area; present in lesser amounts are corals, bryozoans, brachiopods, pelecypods, and gastropods.

The photo constitutes figure 4 of a new report issued by the Oklahoma Geological Survey as Bulletin 137, *Geology and Mineral Resources of Payne County, Oklahoma,* by John W. Shelton, John S. Ross, Arthur J. Garden, and James L. Franks. The 85-page bulletin treats the overall surface and subsurface geology of Payne County, north-central Oklahoma, including current and potential economic mineral deposits, such as oil and gas.

The principal author of the report, John Shelton, is a former professor of geology at Oklahoma State University in Stillwater, and his coauthors worked under his direction as graduate students.

Four large sheets accompany the report, folded in a pocket, as plates 1–4: a geologic map in color, a set of stratigraphic sections, a subsurface structure map of the Viola Limestone (Ordovician) showing oil and gas fields, and a map indicating depth to the base of fresh water.

Bulletin 137 can be ordered from the address below or by calling (405) 325-3031. The price is $19 for hardbound copies and $15 for softbound.

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Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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THE COOL CREEK FORMATION (ORDOVICIAN) AT TURNER FALLS IN THE ARBUCKLE MOUNTAINS OF SOUTHERN OKLAHOMA

Deborah A. Ragland[1] and R. Nowell Donovan[2]

Abstract

The Cool Creek Formation, Arbuckle Group, of Early Ordovician age is well exposed at two localities near Turner Falls in the Arbuckle Mountains of southern Oklahoma. Here, the Cool Creek consists predominantly of limestone. Algal boundstones constitute the principal lithologic type, with other types being intraformational conglomerates, oolitic grainstones, pellet-rich wackestones, mudstones, and alternations of quartz-rich carbonate sandstones and mudstones. In addition, sulfate molds, pseudomorphs, and minute traces of anhydrite preserved in cherts provide clear evidence of evaporite precipitation. Our analysis suggests that the Cool Creek was deposited in a shallow-marine semiarid or arid setting.

Introduction

Turner Falls is a popular tourist attraction in the Arbuckle Mountains of southern Oklahoma (fig. 1). The best known view of the falls is from the overview gift shop on U.S. Highway 77. At two nearby localities the Cool Creek Formation in the Arbuckle Group of Early Ordovician age can be examined. These localities present the best exposures of this formation that we have found in either the Arbuckle or the Wichita Mountains.

The longer section is exposed on the cliff below the gift shop and can be examined conveniently from the stairway leading to the bottom of the falls (fig. 2). The second is across the road from the gift shop (fig. 3).

Description of Lithologies

In common with other formations in the Arbuckle Group, the Cool Creek Formation consists primarily of limestone. The following

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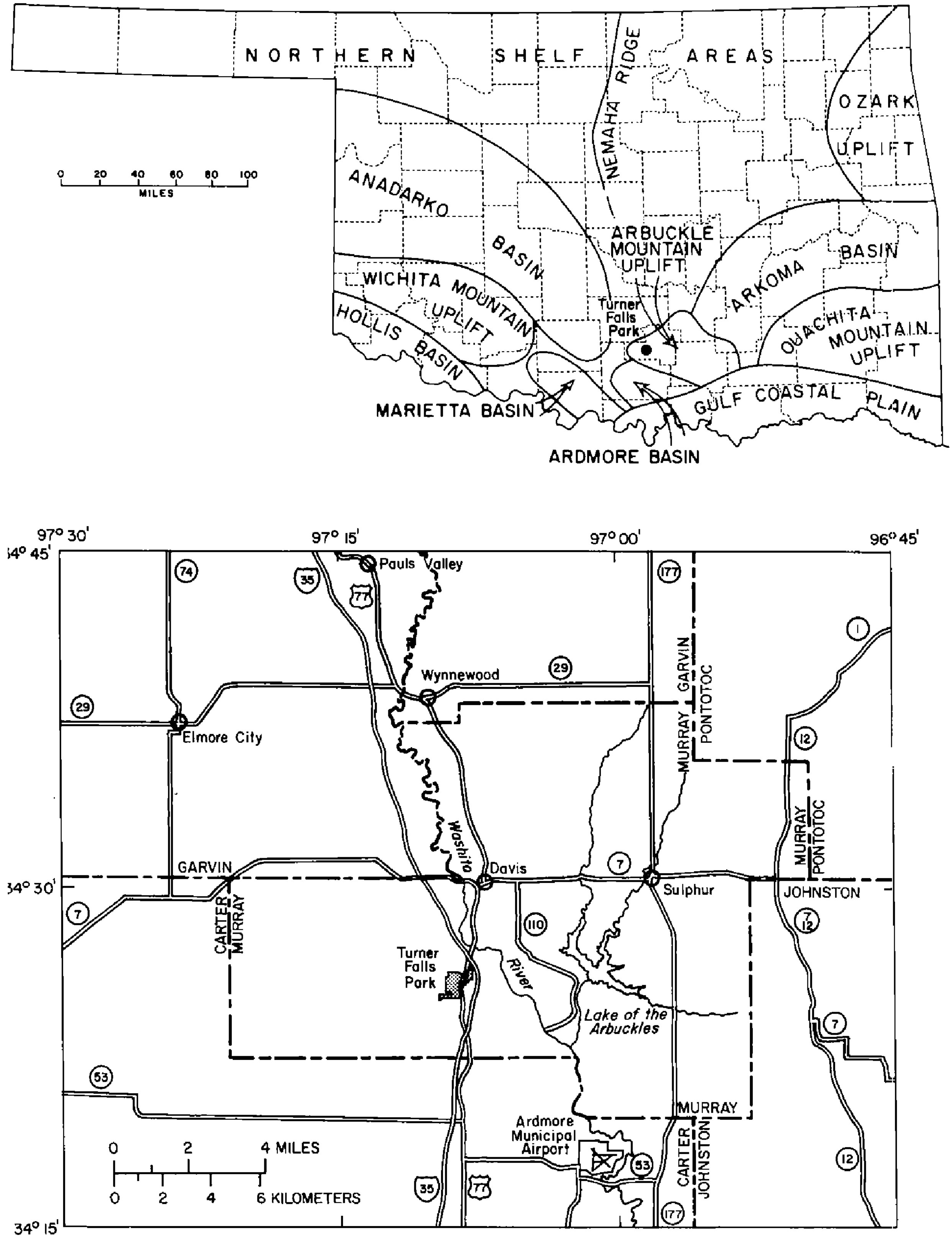

Figure 1. Map of Oklahoma showing location of Turner Falls in the Arbuckle Mountains, Murray County, Oklahoma.

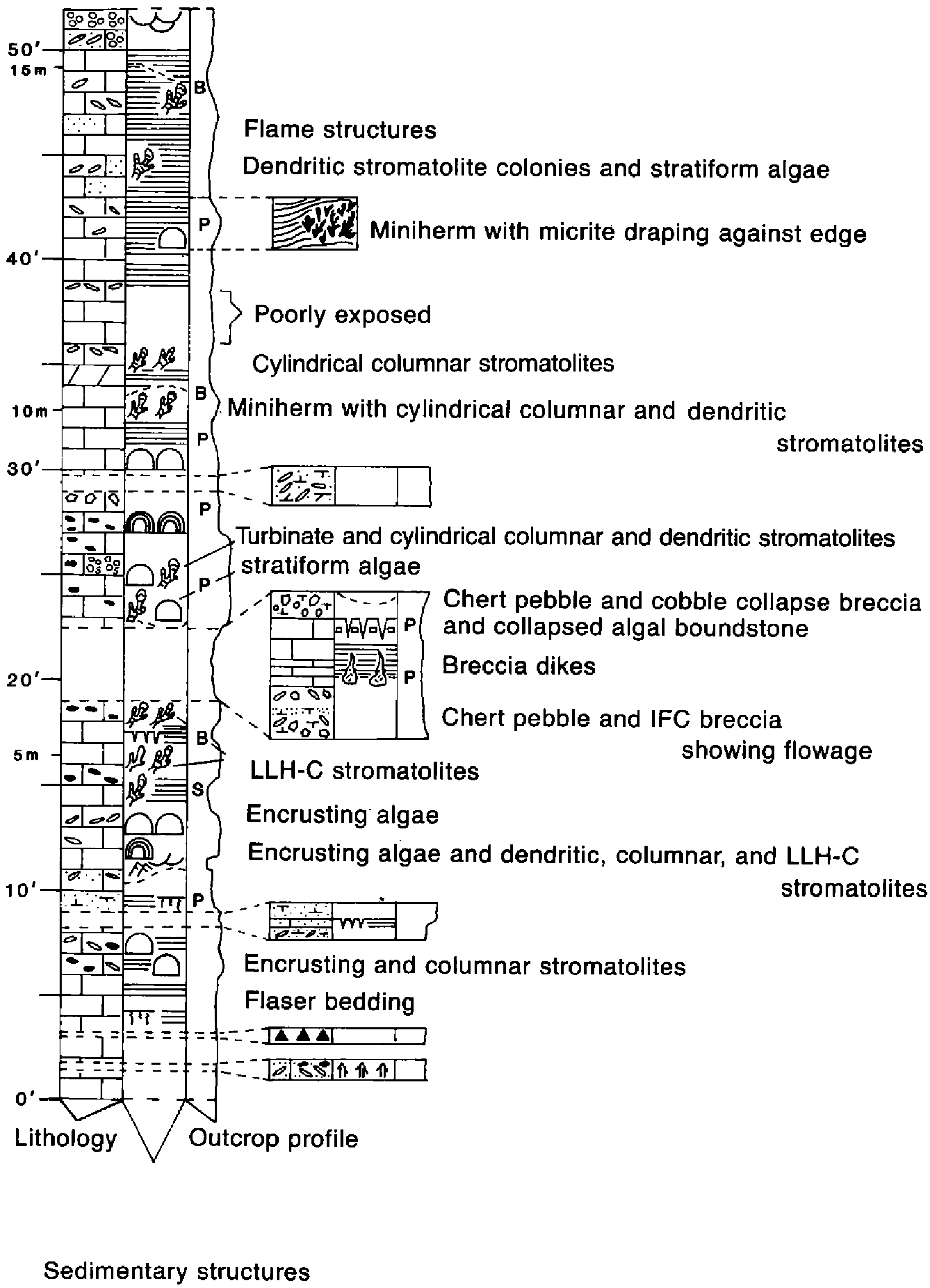

Figure 2. Stratigraphic section of Cool Creek Formation measured on cliff below gift shop at Turner Falls overlook (U.S. Highway 77).

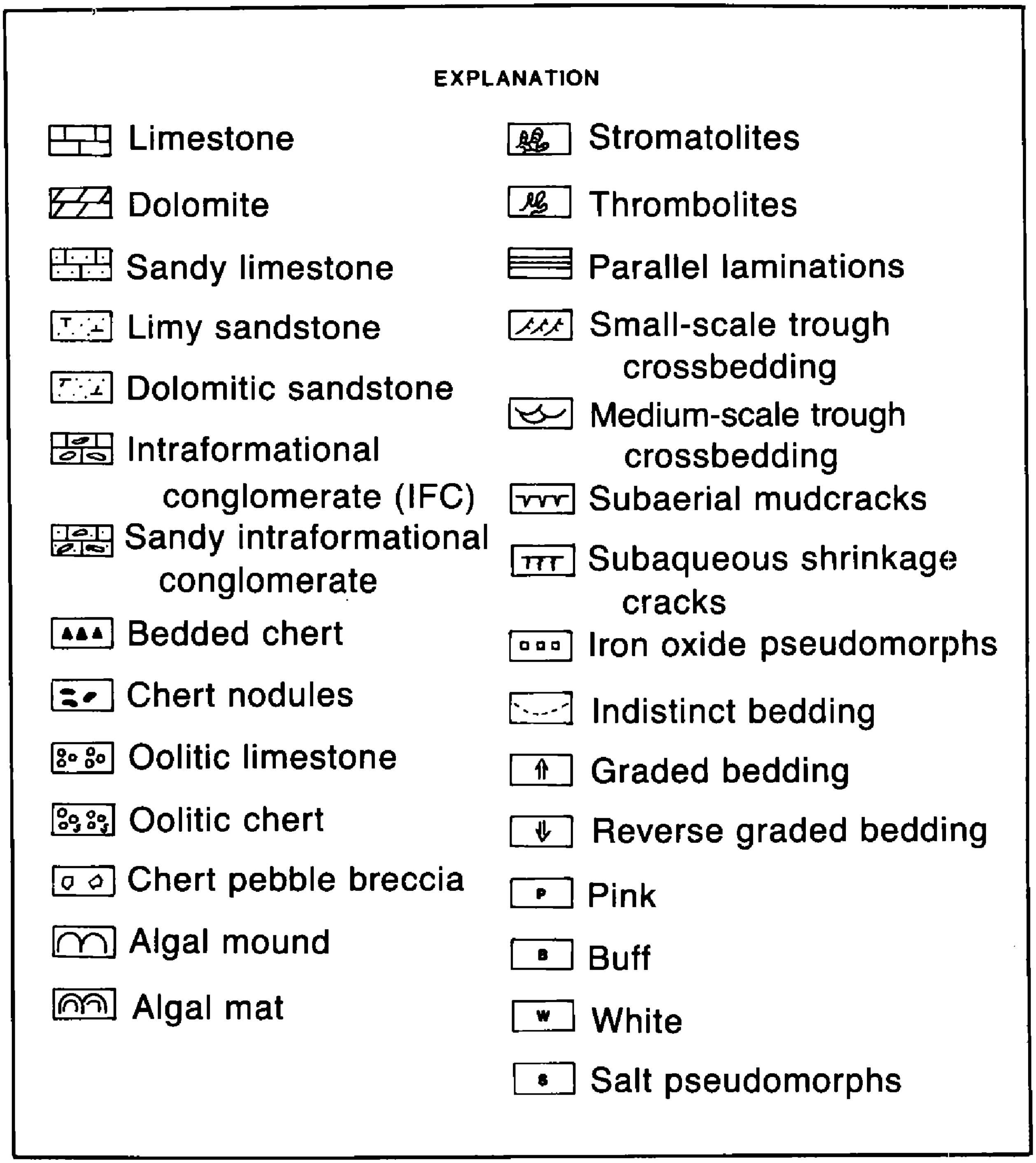

Figure 2. *Continued.*

lithotypes can be recognized in the field: algal boundstones, intraformational conglomerates, intraformational breccias, quartz-rich oolitic grainstones, peloidal limestones, lime mudrocks, and heterolithic units (Ragland, 1983). Chertification and dolomitization have affected all of these lithologies in varying degrees (fig. 4).

Algal boundstones constitute approximately 50% of the formation. The external forms of algal boundstones (Logan and others, 1964; Aitken, 1967; Hofmann, 1969) that have been recognized in the formation are encrustations, mats, mounds, and reefs (Ragland, 1983). Internal

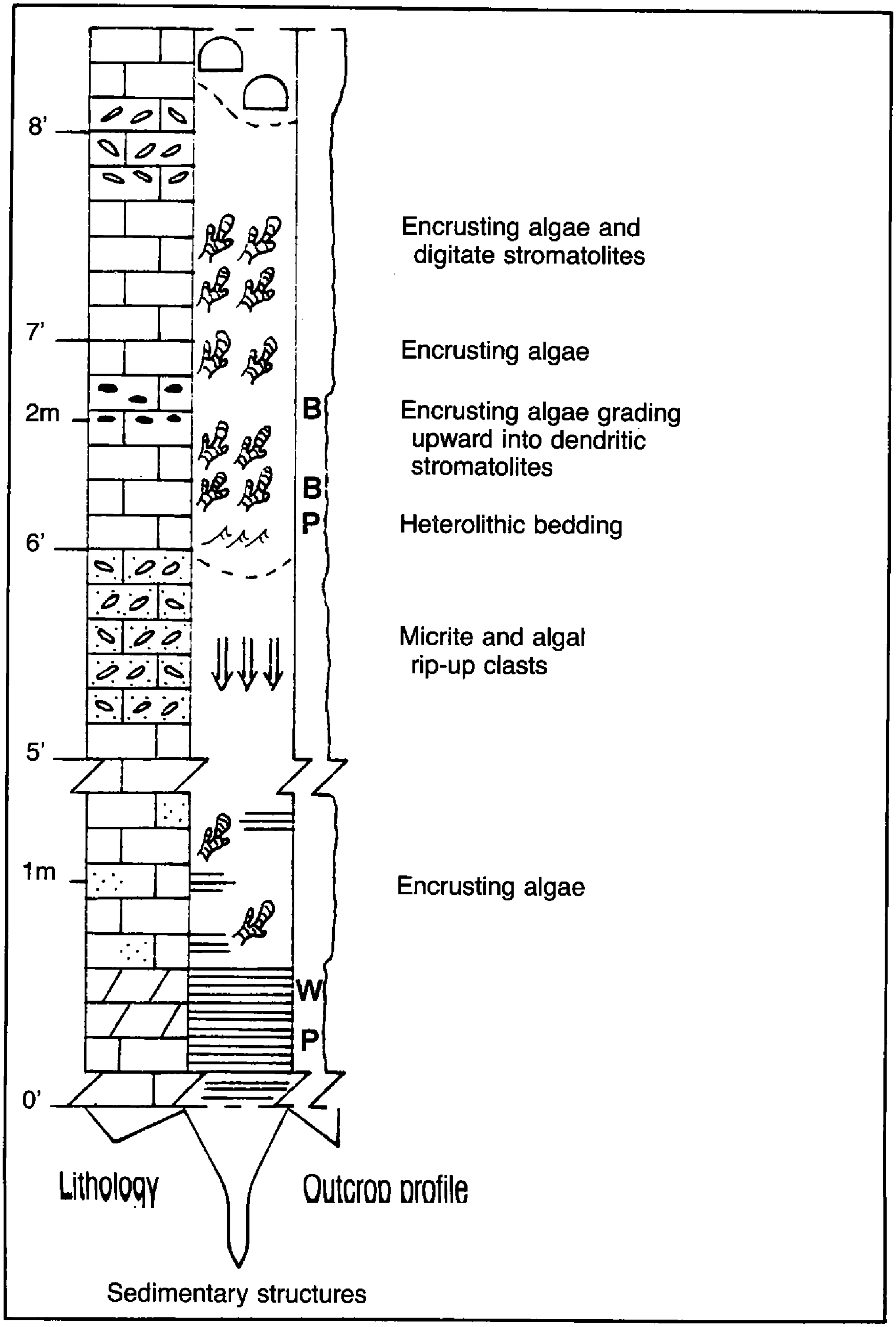

Figure 3. Stratigraphic section of Cool Creek Formation measured along U.S. Highway 77, across from gift shop at Turner Falls overlook.

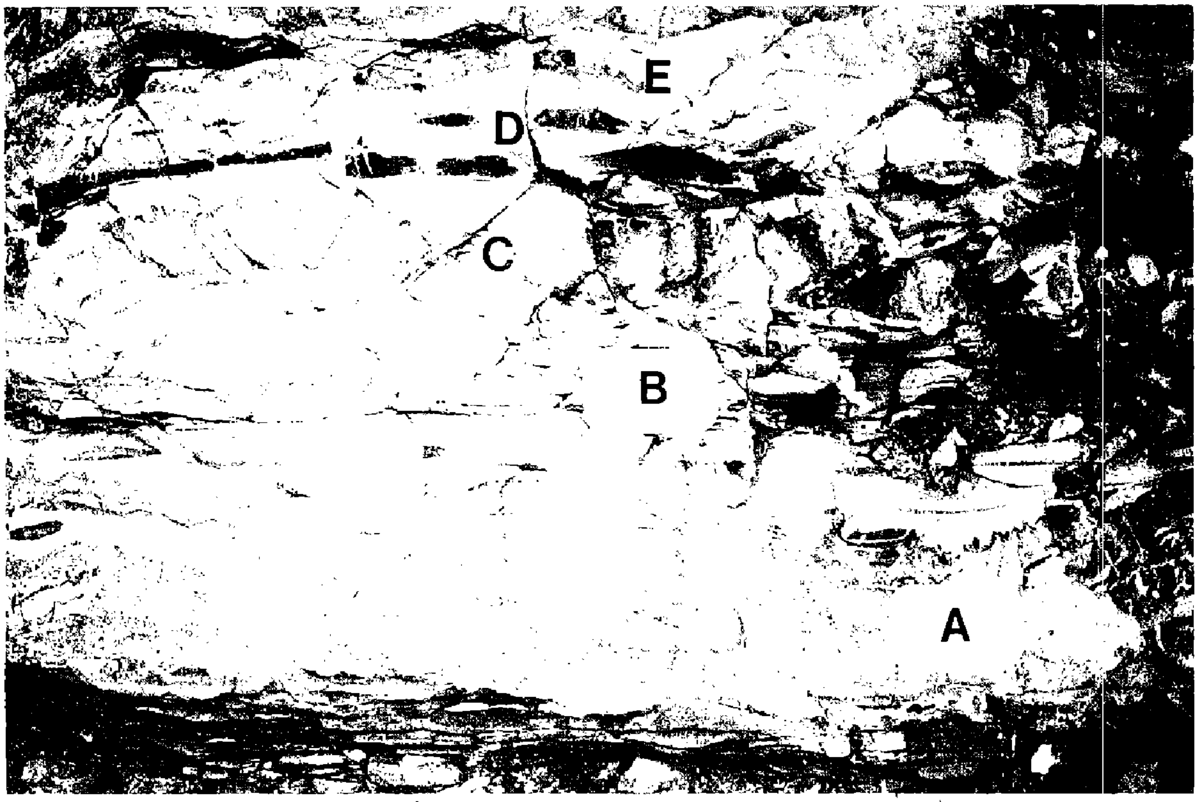

Figure 4. Part of section measured along U.S. Highway 77, across from Turner Falls overlook. Base of unit is marked by a "storm deposit" composed of intraformational clasts, minor quartz sand, and fragments of algal boundstone (*A*). The storm deposit is overlain by a heterolithic unit (*B*) of interbedded micrite, minor dolomicrite, and quartz silt. Encrusting algae began growth after stabilization of the heterolithic unit and branched upward in a dendritic manner (*C*). A relatively homogeneous micrite overlying the boundstone contains secondary chert nodules (*D*). Another small layer of boundstone (*E*) appears near the top of the unit.

organization into several growth forms of stromatolite and thrombolite is apparent (figs. 4–7).

Approximately 10% of the formation is composed of intraformational conglomerates in erosive-based beds that are rarely more than 12 in. (30 cm) thick. Most clasts are varieties of lime mud but also include fragments of encrusting stromatolites (fig. 4). The clasts are disc- or rod-shaped, resulting in four varieties of packing arrangements: random, flat, imbricate, and vertical (figs. 8–10). Textures observed in the conglomerates vary from mud supported to open framework (now cemented by sparite).

The longer section at Turner Falls displays a spectacular example of a collapse breccia (figs. 2, 11). The breccia consists of angular blocks, some up to a meter across, that appear to be the result of gravity-controlled collapse of well-lithified rock (Ragland and Donovan, 1984). Three zones are present: the lowest shows signs of early liquefaction (including the upward injection of clastic dikes), the middle displays listric normal faulting in a heterolithic unit, and the upper zone comprises an intensively fractured boundstone. The fractures have been infilled by

Figure 5. Algal colony composed of well-laminated digitate and coalescent stromatolites.

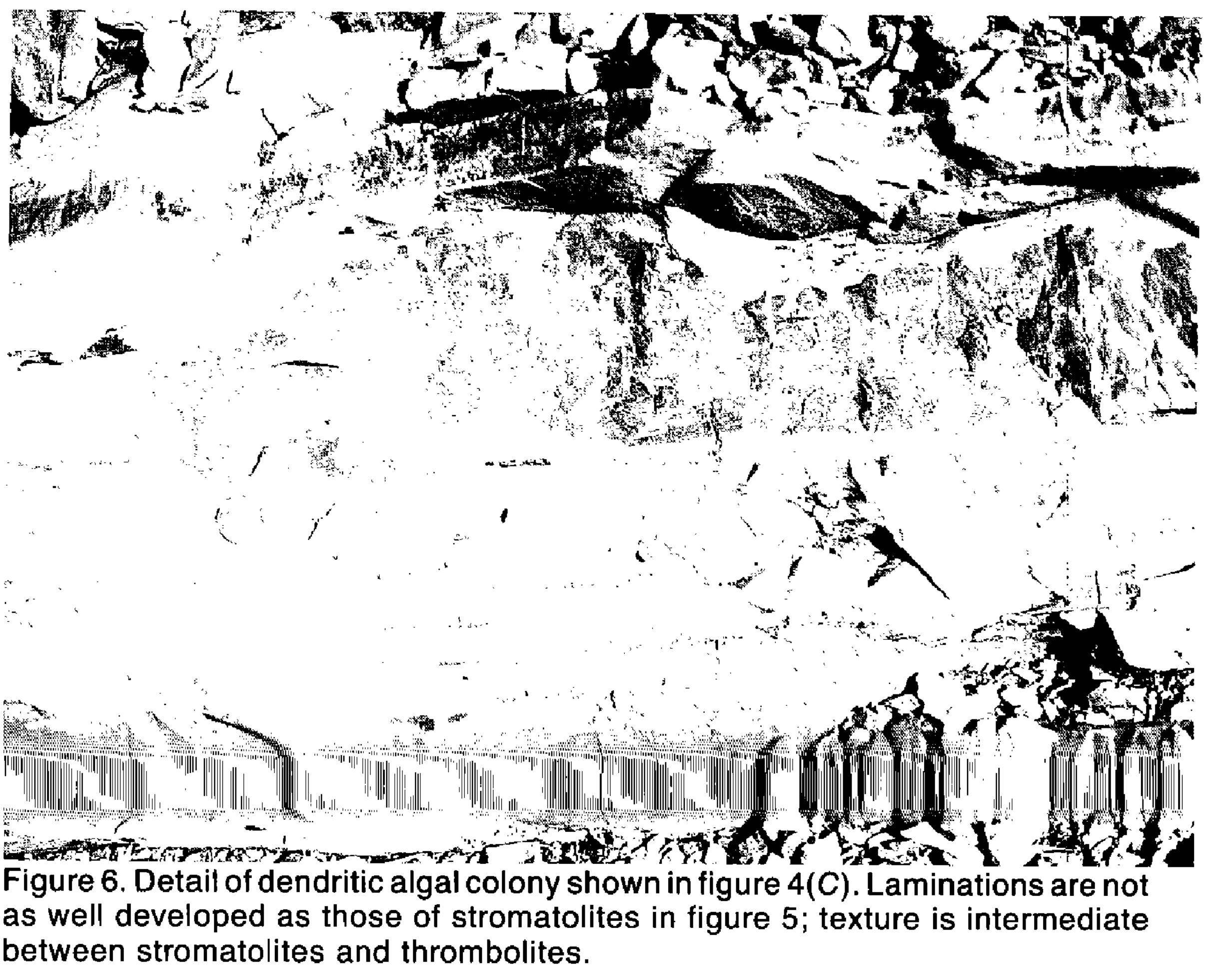

Figure 6. Detail of dendritic algal colony shown in figure 4(*C*). Laminations are not as well developed as those of stromatolites in figure 5; texture is intermediate between stromatolites and thrombolites.

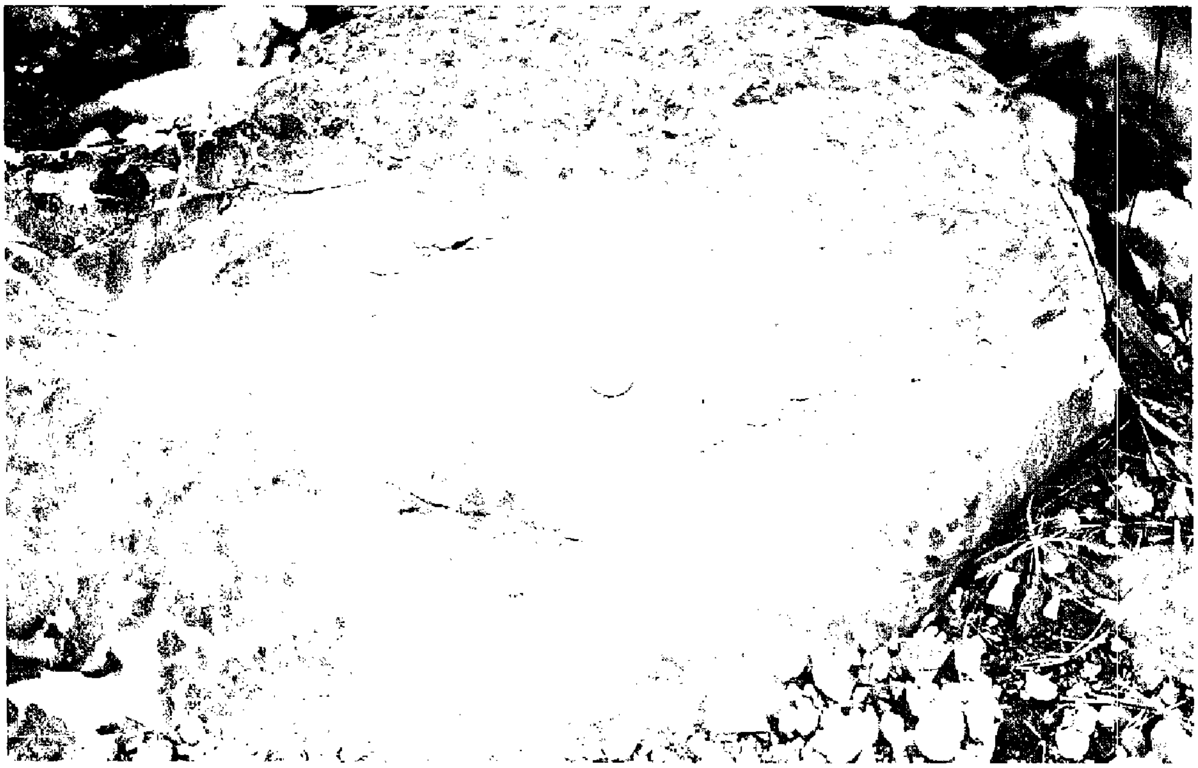

Figure 7. Top view of thrombolite mound, showing typical clotted texture. Thrombolites appear disrupted internally and lack laminated character of stromatolites.

sparite. Fractures and faults have a north-northwest trend, and the overall sense of transport of the faults is to the west-southwest.

Grainstones are a common feature of the formation. The principal allochems present are ooliths and intraclasts. Skeletal fragments, which are uncommon, include trilobites, brachiopods, and gastropods. The latter, particularly *Lecanospira*, are the only fossils apparent on outcrop. All grainstones contain significant amounts (maximally 90%) of quartz grains (plus some microcline) up to very coarse-sand size (fig. 9). Some grainstones form discrete beds up to 15 in. (38 cm) thick. These exhibit small- and medium-scale crossbedding (maximum set thickness is 3 in. (8 cm)). Grainstones also occur as infill between algal mounds and in heterolithic units interbedded with lime-mud layers.

Other clastic carbonate sediments are packstones and wackestones, which, although they contain several types of allochems and quartz grains, are dominated by well-sorted oval peloids (probably fecal pellets). All of these mud-supported textures occur as thin beds (1–3 in., 2–8 cm), with lamination and bioturbation (including both vertical and horizontal burrows) as the principal sedimentary structures.

The heterolithic units are characterized by varieties of flaser bedding. Alternating layers consist of lime mud (some of which is colored pink by disseminated hematite) and quartz-rich calcarenites (fig. 4). The latter are characterized by small-scale crossbedding, some of which can be related to both asymmetrical and symmetrical ripple marks. Units of this type are cut by both subaerial and subaqueous mud cracks. The former may be as deep as 6 in. (15 cm).

Early calcite cementation was generally contemporaneous with the formation of a variety of siliceous cements and replacement nodules. The latter are developed in all of the limestone lithologies. Some of the chert nodules contain preserved molds and pseudomorphs of salts. These have been interpreted as gypsum and anhydrite (St. John and Eby, 1978; Ragland, 1983); SEM studies have confirmed the presence of very small crystals of anhydrite and celestite in the cherts (Ragland and Donovan, 1984).

Environmental Synopsis

Based on their analyses of sedimentary parameters, several authors have suggested that the Cool Creek Formation was deposited under warm, arid to semiarid climatic conditions in the supratidal to subtidal zones of shallow epicontinental seas (St. John and Eby, 1978; Donovan, 1982; Ragland, 1983).

During Early Ordovician time, southern Oklahoma lay approximately 25° south of the equator (Habicht, 1979). Large parts of the vestigal North American craton were covered by vast, shallow seas. These seas were self-evidently a highly productive carbonate factory. The application of

Figure 8. Intraformational conglomerate with two of four types of packing arrangement. Many clasts are flat-lying. Note faint outline of what may be a channel base (*A*). Other clasts, especially those at sides of channel(?), are randomly packed (*B*). Note well-defined erosive base of unit and normal graded bedding at top.

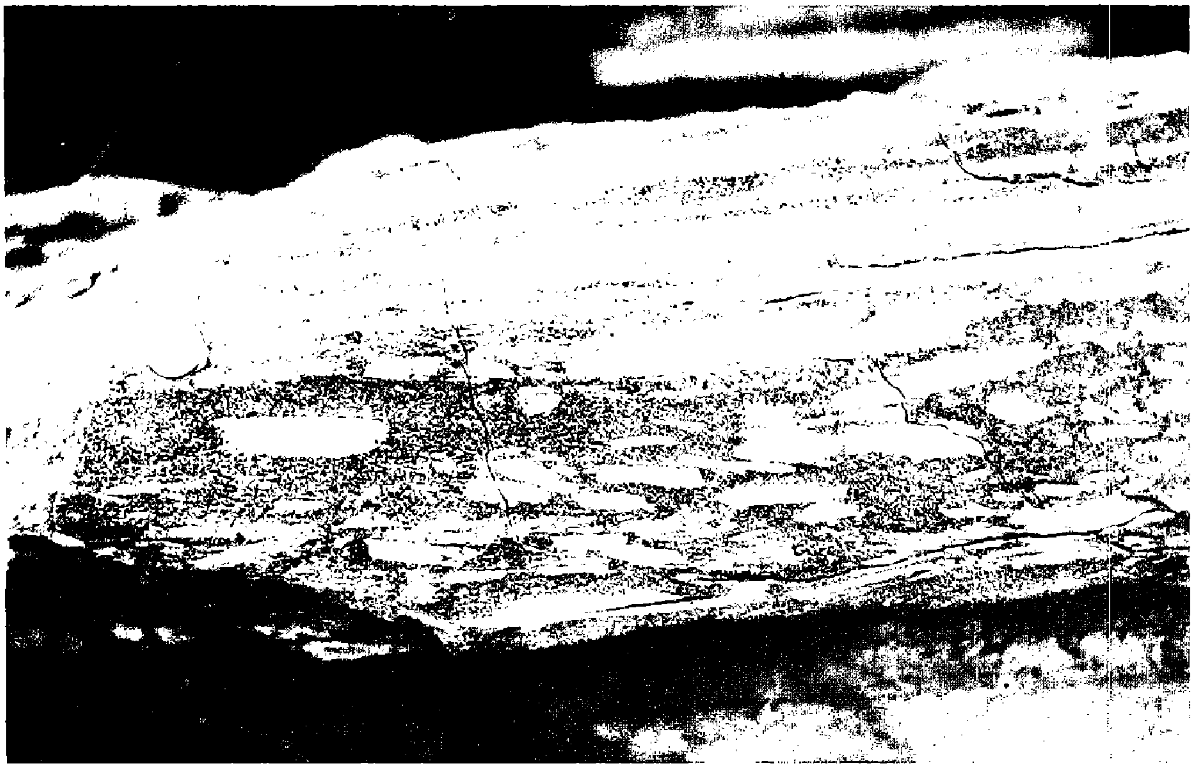

Figure 9. Imbricately packed intraformational conglomerate with micrite clasts set in matrix of coarse quartz sand. Primary direction of flow: right to left(?).

uniformitarian analogy must be tempered by the recognition that the atmosphere contained only 10% of the present level of free oxygen (Windley, 1979). Similarly, the nature and ecology of the Ordovician biota, dominated in the present instance by blue-green algae, were fundamentally different from those that exist today. Furthermore, the salinity of the deeper oceans has been postulated to have been less in Ordovician time than it is now (Levin, 1983). This last discrepancy was apparently offset by the high evaporation rates that prevailed in the warm, shallow epicontinental seas being discussed. The scanty fossil record of the Cool Creek Formation suggests that the animal biota did not readily adapt to saline conditions (as evidenced by evaporite-mineral precipitation). In contrast, the underlying McKenzie Hill and overlying Kindblade Formations of the Arbuckle Group, in which we have found only minor traces of evaporites, contain an abundance of fossils.

Role of Algae

The vacant ecological niche in the relatively hostile Cook Creek environment—and it was a large one—was filled mostly by colonies of blue-green algae (Wray, 1977). The simple life-style of the algae helps to delineate the regional paleoenvironment, while the individual boundstone morphologies help to define more subtle variations (fig. 12).

Most algal forms began their growth on some minor relief of the sea floor (e.g., a stabilized ripple-marked surface, sand shoal, or conglomer-

Figure 10. Vertically packed intraformational conglomerate (IFC). Block has been used as building stone and has been emplaced upside down in gift-shop wall. Top of IFC bed was cleanly eroded to form a planar surface on which laminated micrite and encrusting algae were deposited.

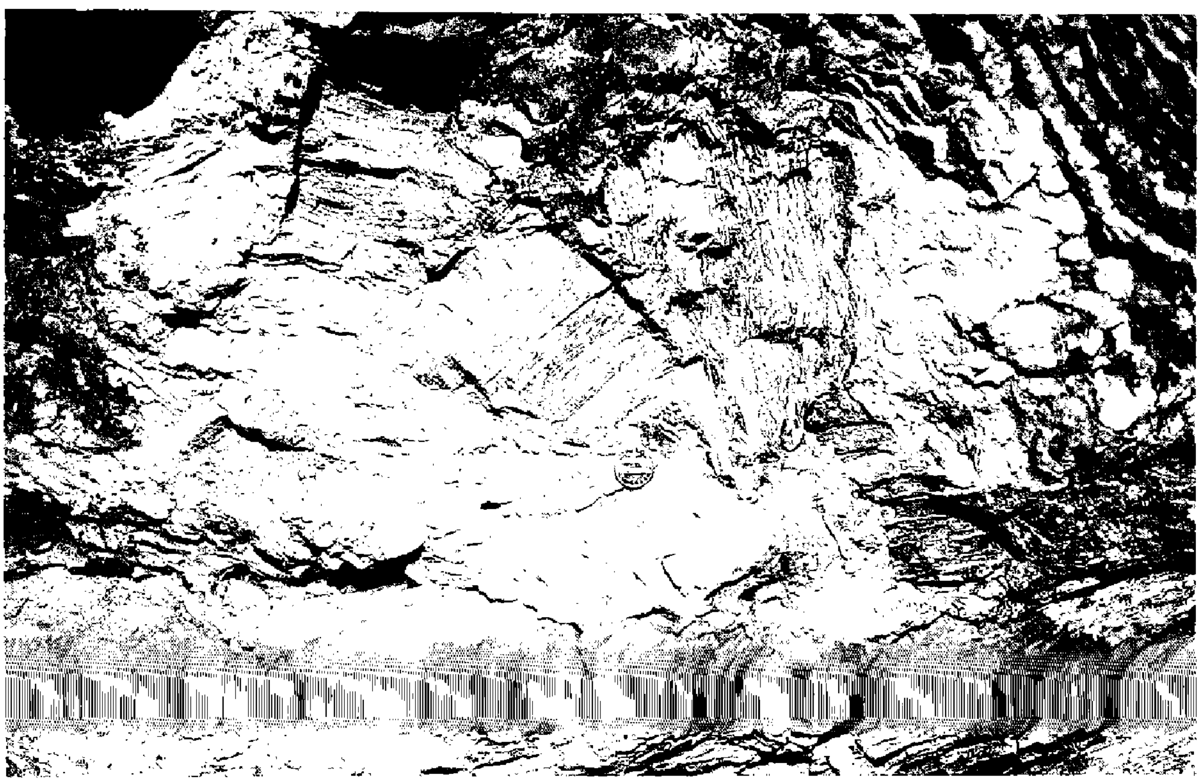

Figure 11. Large blocks of collapse breccia. Deposition of breccia probably resulted from removal of evaporites from underlying unit, with subsequent collapse of overlying laminated micrites.

ate deposit). They started growth as stratiform crusts and continued upward either as parallel laminae or branched out into a variety of algal buildups.

By uniformitarian analogy, most algal mats were restricted either to the supratidal zone or to calm, shallow lagoons. The greatest variety of boundstones developed in the intertidal zone. Given the "damping" effect of the vast carbonate shelf, it is likely that both tidal ranges were small and ocean-wave energy was dissipated. Consequently, laterally persistent algal reefs, unbroken by tidal channels, were common. Indeed, lateral persistence of relatively thin beds is one of the characteristic motifs of the entire Arbuckle Group. At one locality in the Wichita Mountains we have traced an algal reef 15 ft (5 m) thick in unbroken outcrop for more than 1 mi or 1.6 km (it is eventually cut out of the section by faults).

In the intertidal area the cyclic growth of algal laminae led to the development of stromatolitic texture (Gebelein, 1969) (fig. 5). In the subtidal zone, where the mounds were neither subaerially exposed nor subjected to clastic influx as regularly as buildups nearer the shoreline, thrombolitic texture formed (fig. 7). Thrombolites are characterized by a nonlaminated to poorly laminated clotted texture (Pratt and James, 1982). Forms intermediate between thrombolites and stromatolites developed in transitional depth zones.

Algal boundstones are overlain either by heterolithic units, sandstones, or conglomerates. These relationships suggest that periodic algal demise was due to a variety of causes among which can be identified storms (as evidenced by intraformational conglomerates) and the migration of sand shoals. It is also possible that salinity extremes may have killed the algae. This suggestion is supported by the occurrence of sulfate pseudomorphs and subaqueous shrinkage cracks. The latter form where there is a marked increase in salinity (Donovan and Foster, 1972) (fig. 13).

Although body fossils are rarely found, pelmicrites are an abundant rock type. It is thus conceivable that grazing by invertebrates, particularly gastropods, may have inhibited the development of algal colonies (Garrett, 1970).

Interplay of Clastic Sediments

As we have noted, the most common rock type seen in Turner Falls is algal boundstone. Interbedded with the boundstones are clastics, which range in grain size from pebble to mud and in bed thickness from fine laminae to 15 in. (38 cm).

All the conglomerates are intraformational. In some, substantial erosion of existing sediments is suggested by the heterogeneity of clast lithologies; in others, more superficial erosion is indicated by clast homogeneity. In the environmental setting envisaged for the formation, the most likely mechanisms for the formation of these clasts were (1) desiccation, (2) storms, and (3) minor regressions and transgressions. The second and third mechanisms are more likely to have yielded heterogeneous clast types.

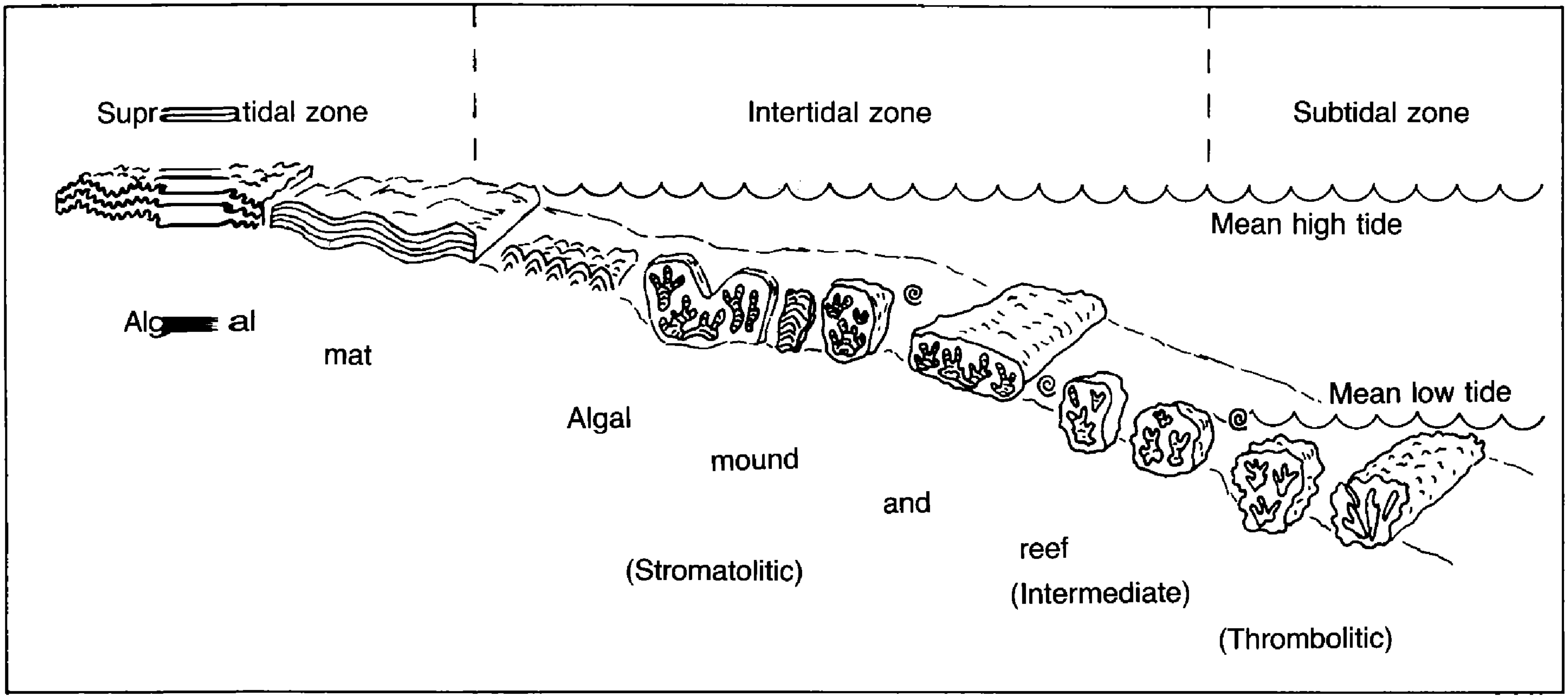

Figure 12. *Ger eralized* environmental relationships between algal morphologies and zones in which they may have formed during depositi on of Cool Creek Formation. Other parameters, including channeling and clastic input, also may have affected morphologies of algal boundstones.

We interpret mud-supported conglomerate textures, which are characterized by random clast packing, to be unreworked storm deposits. On the other hand, many open-framework textures show flat-lying, imbricate, and vertical-packing arrangements (figs. 8–10). We interpret such arrangements as the result of reworking of clasts by waves and tides. This interpretation is supported by uniformitarian analogy. For example, Shinn (1983) noted the imbrication of clasts in tidal channels in the Bahamas, while Sanderson and Donovan (1974) noted that flat pebbles on modern beaches are frequently packed in vertical arrangements by waves of moderate energy. Some channel geometries are present in the Turner Falls section; none of the examples here or elsewhere in the formation is of any great size. In these channels, conglomerate clasts show fining-upward grading, suggesting their origin to have been lag deposits (fig. 8).

The varieties of grainstone mostly record small sand shoals that were moved about by relatively weak currents. This is suggested by the modest dimensions of crossbedding sets.

Some of the thin beds of mudstone and peloidal wackestone that occur throughout the sections are characterized by fine lamination; some are apparently massive, while others show evidence of extensive bioturbation. None of these features is diagnostic, although in the present context they can be used as supporting evidence for deposition in a calm subtidal, low intertidal, or lagoonal environment.

Mudstone laminae are also present as one element of the heterolithic facies; the other is provided by quartz-rich carbonate sandstone and siltstone laminae. Both at Turner Falls and elsewhere this facies is the most likely one to have been dolomitized (fig. 4). Evidence of subaerial exposure and substantial siliciclastic input suggests that the facies was deposited in a high intertidal and (or) supratidal environment.

We have suggested elsewhere (Ragland and Donovan, in press) that the likely source of siliciclastics was to the north and east of Oklahoma. Some grains may have been transported by the wind (Donovan, 1982), but most were probably transported initially into the area by rivers and then gradually reworked across the shelf by waves and tides.

Evaporite Evidence

Clear evidence of evaporite precipitation is provided by the sulfate molds, pseudomorphs, and minute traces of anhydrite that are preserved in cherts. This evidence, together with the dolomitization of certain zones (particularly the high intertidal/supratidal heterolithic facies), suggests the presence of sabkha-like conditions. Certainly Oklahoma was at the appropriate latitude for sabkha development at this time.

Clearly, most of the evaporite imprint was subsequently dissolved unless it was preserved by silicification. Evidence supporting this dissolution is provided by intraformational breccias (fig. 11). The principal disruption in the breccia at Turner Falls is reflected in a pink

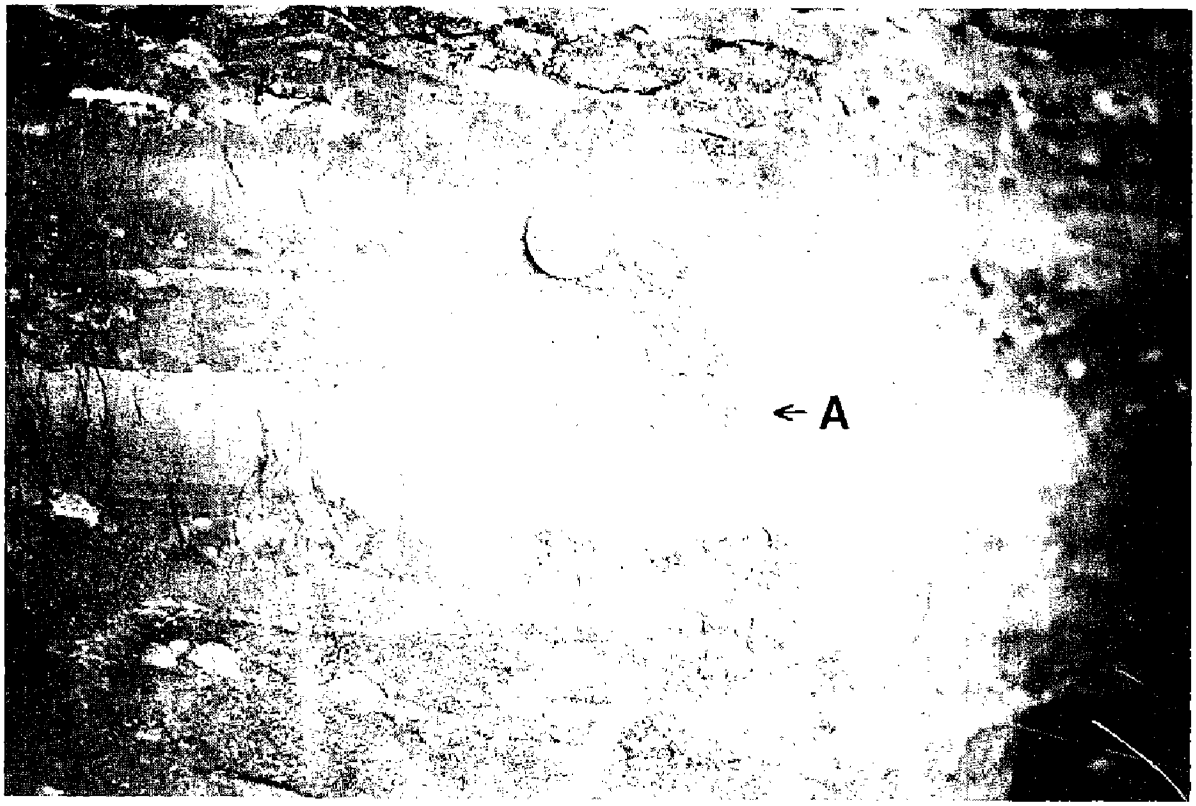

Figure 13. Subaqueous shrinkage cracks (*A*) formed as a result of an increase in water salinity. In this case, a marked change in sediment occurred, with a dark-gray IFC set in a quartz sand and micrite matrix overlying lighter gray silty micrite. Contortion of filled cracks was probably caused by compaction of soft sediments.

heterolithic unit, which is the most likely zone for evaporite precipitation in the sabkha model. Furthermore, cherts in undisturbed strata beneath the breccia contain numerous salt molds. We interpret the breccia to be the result of subsurface dissolution of an evaporite-rich layer at a time when (to judge from the limit of brecciation) at least 12 ft (4 m) of lithified sediment was present above the zone. We suggest that the lowest zone of the breccia indicates the presence of slow-moving brines and that the clastic dikes indicate overpressuring.

Some Conclusions

Exposures of the Cool Creek Formation at Turner Falls are of high quality and exhibit the essential aspects of the formation for easy scrutiny. Algal boundstones constitute the dominant lithologic type; many of the stromatolitic zones are exceptionally well exposed, and a variety of geometries is present. Other limestone rock types are intraformational conglomerates, oolitic grainstones, pellet-rich wackestones, mudstones, and heterolithic alternations of quartz-rich carbonate sandstones and mudstones. Chert and dolomitic zones record diagenetic imprints. Some of the cherts contain traces and pseudomorphs of sulfates. An intraformational breccia in the section may record the subsurface dissolution of an evaporite zone.

Our analysis of the exposures suggests that the formation was deposited in a shallow-marine semiarid or arid setting. Most lithologies bear the imprint of tidal effects; supratidal settings of sabkha type are evidenced by the evaporite relicts.

It is difficult to resolve the concatenation of lithologies present into well-defined progradational cycles such as that recorded in the modern Persian Gulf. The juxtaposition of heterolithic and algal-mound facies, for example, certainly indicates that fluctuations in sea level relative to the sedimentary pile took place. However, we have been unable to establish a statistically significant (Markovian) pattern in these changes. We suggest that the most likely reason for this is that facies belts were relatively poorly defined on the vast, low-energy Cook Creek shelf.

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SYMPOSIA PLANNED IN CONJUNCTION WITH SME–AIME ANNUAL MEETING

The Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers (SME–AIME) has announced two symposia to be held as part of the annual meeting scheduled for March 2–6, 1986, at the Hilton Hotel in New Orleans, Louisiana.

A symposium on "Economics of Internationally Traded Minerals" will examine long-term mineral-industry trends by focusing on supply, consumption, policy, and trade issues of selected internationally important materials.

About 40 papers are scheduled for presentation. Session topics include world trade in metals and minerals and the economics of coal, sulfur, phosphates, copper, aluminum, lead, zinc, and specialty metals.

A four-day symposium to discuss "Design and Installation of Concentration and Dewatering Circuits" is expected to attract operators of mineral-processing plants and specialists in the mining industry.

About 40 papers are scheduled for presentation on flotation, solid–liquid separation, solid–solid separation, auxiliary-unit operations, support information for design, laboratory testwork for design, operating controls and instrumentation, operating metallurgy and support facilities, engineering/procurement/construction, and operation.

The papers for each symposium will be included in a book available at the meeting.

For further information, contact Meetings Dept., Society of Mining Engineers, Caller No. D, Littleton, CO 80127, or call (303) 973-9550.

OVERVIEW OF HYDROLOGIC-DATA COLLECTION BY THE U.S. GEOLOGICAL SURVEY IN OKLAHOMA

L. D. Hauth[1]

Abstract

The U.S. Geological Survey (USGS) collects hydrologic data from 1,332 stream, lake, and ground-water sites in Oklahoma. Information on the quantity of water from a network of 123 streamflow stations, 30 lakes, 42 peak-flow stations, three low-flow stations, and on the quality of water from 40 stream locations is published each year in the USGS publication *Water Resources Data for Oklahoma*. Information on water levels from 1,134 ground-water wells is currently published in cooperation with the State of Oklahoma in the USGS publication *Ground-Water Levels in Observation Wells in Oklahoma*. The data also are made available to the public as printouts from several computerized databases maintained by the USGS.

Introduction

Most hydrologic data in Oklahoma have been collected by the U.S. Geological Survey (USGS) through cooperative programs with state and federal agencies. Through these cooperative programs, state agencies have obtained the hydrologic data necessary for water management by sharing data-collection costs with the USGS on a matching basis. When data are collected for other federal agencies, the entire funding is provided by those agencies.

In Oklahoma, the monitoring of water resources by the USGS began in 1900, when C. N. Gould compiled ground-water information from about 5,000 wells throughout the State. Gould also analyzed the chemical characteristics of 154 water samples from wells, springs, and rivers. The results of Gould's three-year effort are described in USGS Water-Supply Paper 148, *Geology and Water Resources of Oklahoma* (Gould, 1905).

In 1903, streamflow-measuring stations were established at eight locations in the State: Salt Fork at Alva, Cimarron River at Waynoka, North Canadian River at El Reno and Woodward, Washita River at Anadarko and Chickasha, North Fork of Red River at Granite, and Otter Creek at Mountain Park. Although the operation of these stations was brief and fragmentary, between 1936 and 1944 a network of 88 streamflow-

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gaging stations was established. The data-collection program had increased to a total of 123 streamflow-gaging stations during the 1984 water year (October 1, 1983, to September 30, 1984).

The first water-quality information was collected in 1905 at the North Fork of the Red River in Granite. Major increases in the water-quality program did not begin, however, until 1944, when samples for determination of chemical constituents and physical properties were collected at streamflow-gaging stations on Council Creek near Stillwater, Cimarron River at Oilton, and Poteau River at Poteau.

The current data-collection network (1984) consists of 1,332 stream, lake, and ground-water well sites in Oklahoma.

The purpose of this report is to inform the reader of the types and availability of hydrologic data collected by the U.S. Geological Survey in Oklahoma.

Types of Water Data

Surface Water

Water of sufficient quantity and quality for use by the people of Oklahoma is available from both surface and ground waters; however, surface waters supply the needs of most users. Information on streamflow magnitude and lake levels is collected by the USGS from sites throughout the State. The drainage area represented by these sites during the 1984 water year ranged from < 1 to 75,473 mi^2 (fig. 1). The greater part of the stream flow measurements made in the State is from drainage areas with sizes between 100 and 50,000 mi^2.

Together with other State and federal agencies, the U.S. Geological Survey collected continuous water-surface elevations at 123 streamflow stations and at 30 lake-stage stations during the 1984 water year. Streamflow was measured at stations where continuously recorded stages or peak stages were collected. A stage-discharge relationship then was established for those stations, as shown in the example for Horse Creek in figure 2.

Once a sufficient number of streamflow measurements have been obtained to define the stage-discharge relationship, discharge (rate of flow, in cubic feet per second) can be determined from stage. A stage-discharge relationship has been established at all network stations in Oklahoma. Discharge is computed for each day of the water year (table 1) for stations where continuous records are collected; and annual peak discharges are computed for stations where only peak stages are obtained. These data are published annually in the U.S. Geological Survey report *Water Resources Data for Oklahoma* (Hauth and others, 1982). Publication of station data includes pertintent information about each stream-flow gaging staion, extremes measured both during the year and for the total period of record, and annual discharge statistics.

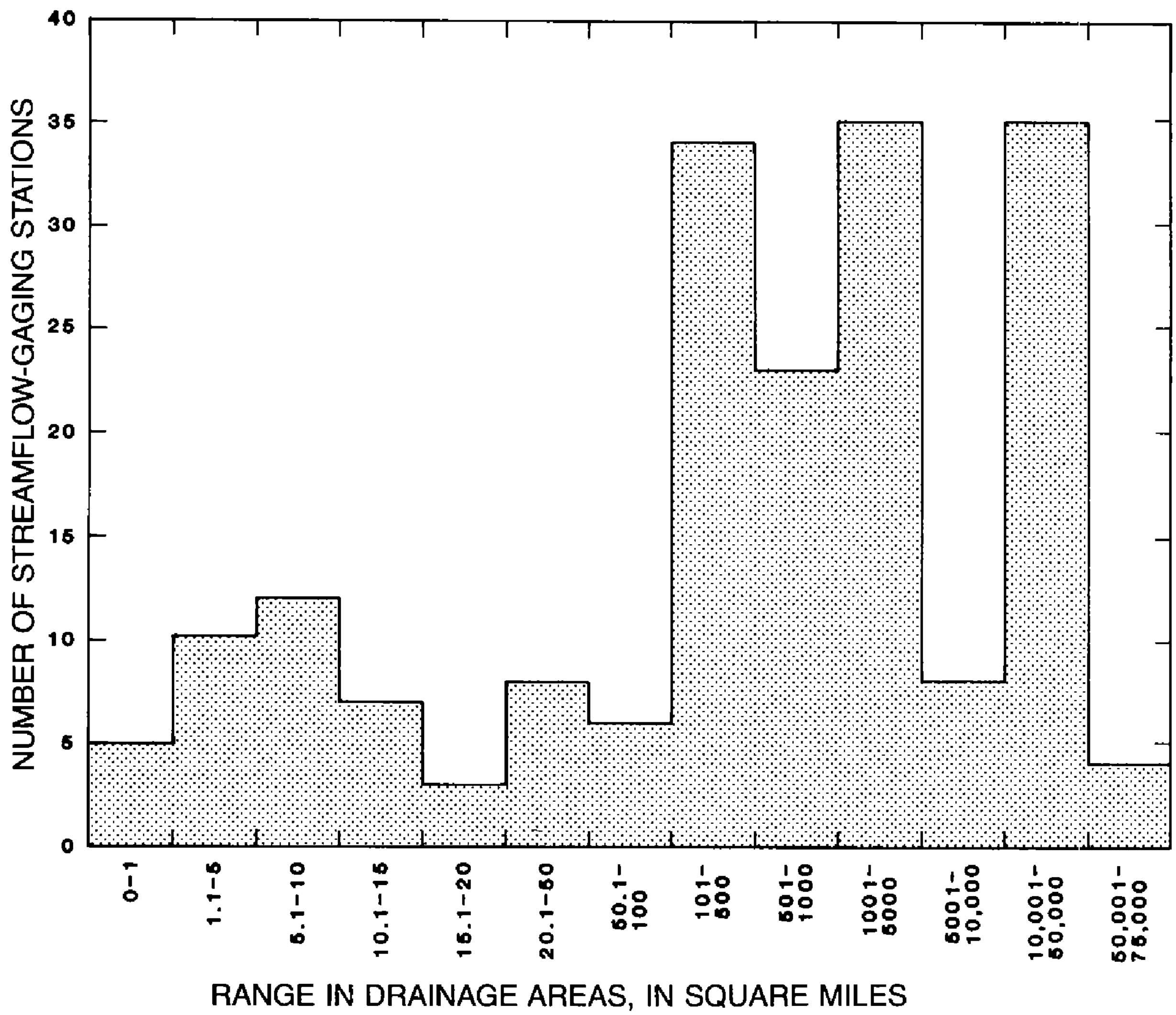


Figure 1. Distribution of streamflow-gaging stations in relation to drainage areas in Oklahoma, water year 1984.

The streamflow data-collection program also includes the annual peak-stage resulting from storm runoff at selected small watersheds in the State. A stage-discharge relationship has been established at 42 stations where only peak stages are collected. This network measures discharges in small drainage areas (100 mi^2 and less). Maximum discharge is published annually for these 42 stations in the report *Water Resources Data for Oklahoma*. Data from specific gaging stations can be obtained when available from computerized printouts.

Stream discharge is intermittently measured at three selected locations as an annual check on the duration and extent of low flow. Stage-discharge relationships are not determined, nor is stage measured. These low-flow data are used in conjunction with information collected at continuous-record stations to establish regional low-flow frequency relationships. Resulting data are published annually in *Water Resources Data for Oklahoma*.

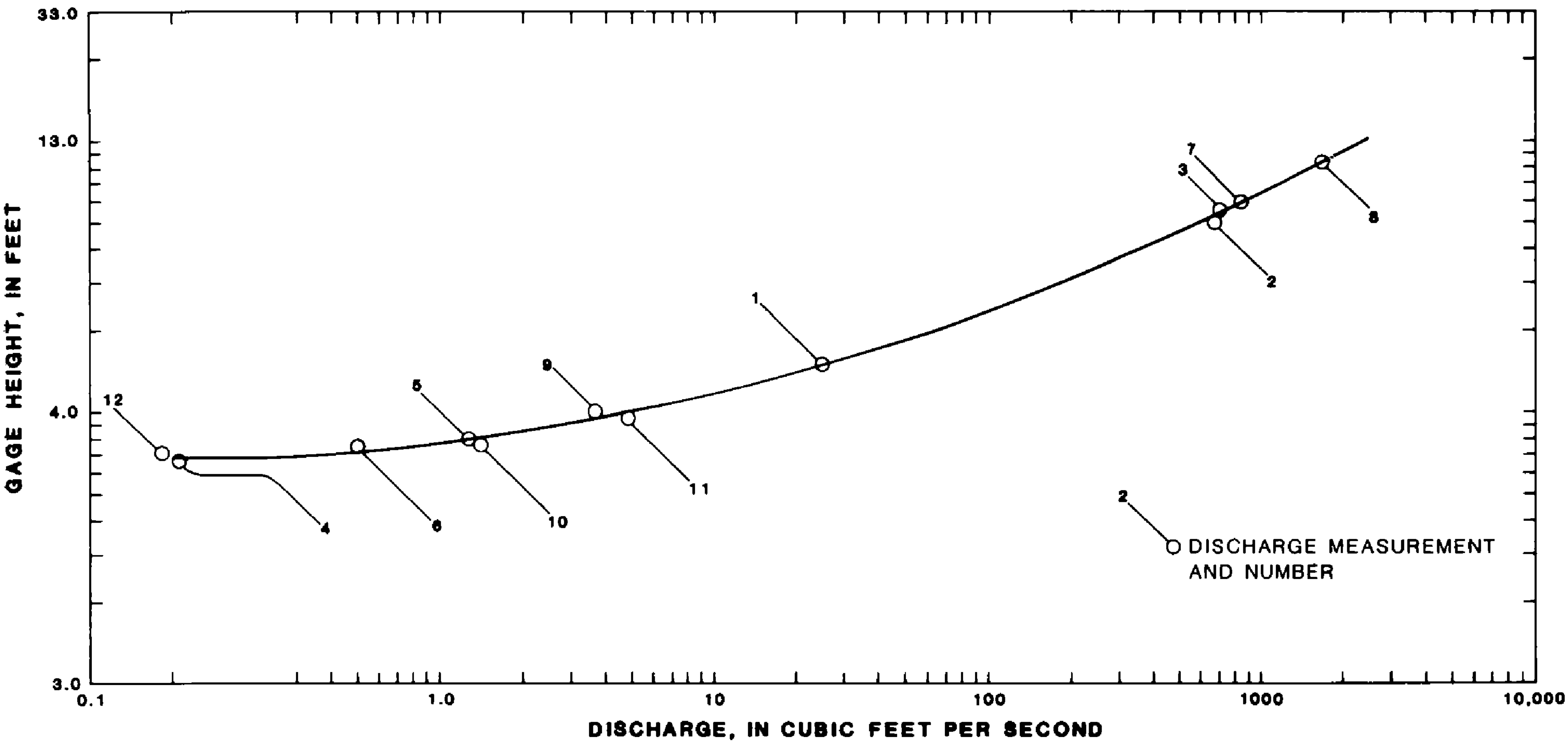


Figure 2. Stage-discharge relation for Horse Creek Canyon at Afton.

TABLE 1.—SURFACE-WATER COLLECTED AT LITTLE RIVER NEAR SASKAWA AS PUBLISHED IN *WATER RESOURCES DATA FOR OKLAHOMA*

LOCATION.--Lat 34°59'02", long 96°33'01", NE 1/4 sec.22, T.6 N., R.7 E., Seminole County, Hydrologic Unit 11090203, near left abutment on downstream side of county road bridge, 2.8 mi (4.5 km) northwest of Sasakwa, 8.7 mi (14.0 km) downstream from Salt Creek, and at mile 24.1 (38.8 km).

DRAINAGE AREA.--865 mi^2 (2,240 km^2).

WATER-DISCHARGE RECORDS

PERIOD OF RECORD.--September 1942 to current year. Monthly discharge only for some periods, published in WSP 1311.

REVISED RECORDS.--WSP 1117: Drainage area.

GAGE.--Water-stage recorder. Datum of gage is 744.34 ft (226.875 m) National Geodetic Vertical Datum of 1929 (levels by Corps of Engineers). Prior to Apr. 11, 1946, nonrecording gage at same site and datum. Prior to Oct. 1, 1979, gage at same site and datum 4.87 ft (1.484 m) higher.

REMARKS.--Records good. Flow regulated by Lake Thunderbird 72.3 mi (116.3 m) upstream since March 1965 (station 07229900).

AVERAGE DISCHARGE.--(Prior to regulation by Lake Thunderbird) 23 years (water years 1943-65), 398 ft^3/s (11.27 m^3/s), 288,400 acre-ft/yr (356 hm^3/yr); (since regulation by Lake Thunderbird) 17 years (water years 1966-82), 242 ft^3/s (6.853 m^3/s), 175,300 acre-ft/yr (216 hm^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 44,600 ft^3/s (1,260 m^3/s) May 11, 1950, gage height, 33.48 ft (10.205 m); no flow at times most years after 1952.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 6,650 ft^3/s (188 m^3/s) May 12, gage height, 21.90 ft (6.675 m); minimum daily discharge, 0.07 ft^3/s (.002 m^3/s) on Sept. 16, 17.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1981 TO SEPTEMBER 1982
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	.84	702	143	8.7	748	31	40	1060	2380	1010	38	1.1
2	.55	238	84	9.4	754	31	38	502	2610	895	31	.80
3	.25	119	47	10	639	31	34	238	3490	735	24	.72
4	.19	88	30	12	310	30	29	153	3140	659	18	.46

TABLE 1.—CONTINUED

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
5	. 10	58	21	12	93	29	27	585	1860	596	14	.40
6	. 15	45	18	11	143	26	25	1920	1000	558	10	.31
7	. 48	34	16	9.4	100	24	21	2060	842	1350	8.4	.27
8	. 27	65	15	7.4	63	24	23	1730	796	891	15	.27
9	. 17	450	14	5.5	12	24	23	991	656	628	26	.24
10	. 09	438	13	4.0	48	24	24	569	954	579	22	.24
11	. 52	172	13	3.0	141	25	26	383	793	564	17	.17
12	18	100	11	2.7	131	26	25	2960	895	504	15	.15
13	1750	68	11	4.7	256	30	25	5830	727	469	12	.17
14	1470	51	13	6.3	193	141	23	4210	623	249	6.3	.15
15	833	43	13	6.6	149	915	21	2580	692	159	5.7	.09
16	1270	36	14	6.0	204	1330	20	1200	2760	145	4.2	.07
17	688	30	13	5.7	189	424	18	2540	1960	114	3.8	.07
18	400	27	10	6.3	146	225	16	2950	1000	98	3.6	23
19	189	22	9.3	6.3	93	159	16	2600	791	84	3.8	12
20	119	19	8.2	11	74	121	16	1750	724	75	3.2	11
21	81	17	8.9	19	63	97	17	880	722	66	2.5	5.2
22	64	15	10	24	55	99	14	621	701	62	2.4	4.8
23	48	14	14	19	48	71	13	900	1330	54	1.8	6.0
24	37	13	13	12	43	60	12	3340	4230	48	1.2	4.0
25	30	13	11	13	37	51	14	4400	4880	43	1.2	2.5
26	25	13	12	10	34	43	17	2860	4540	36	1.1	1.8
27	22	12	10	8.8	33	41	21	1430	2960	34	1.2	1.6
28	19	12	10	9.2	33	52	24	4300	2640	30	2.4	1.4
29	15	12	10	9.2	---	56	34	5250	2260	30	2.2	1.1
30	12	87	10	1140	---	59	198	4050	1450	30	1.9	.88
31	363	---	9.6	1860	---	49	---	3690	---	47	1.3	---
TOTAL	7456. 61	3013	635.0	3272.2	4832	4348	854	68532	54406	10842	300.2	80.96
MEAN	2 41	100	20.5	106	173	140	28.5	2211	1814	350	9.68	2.70
MAX	17 50	702	143	1860	754	1330	198	5830	4880	1350	38	23
MIN	. 09	12	8.2	2.7	12	24	12	153	623	30	1.1	.07
AC-FT	147 90	5980	1260	6490	9580	8620	1690	135900	107900	21510	595	161

CAL YR 1981 TOTAL 17711.49 MEAN 48.5 MAX 1750 MIN .00 AC-FT 35130
WTR YR 1982 TOTAL 158571.97 MEAN 434 MAX 5830 MIN .07 AC-FT 314500

Water Quality

As demand for water increases because of population growth in Oklahoma, more interest has been placed on the quality of surface- and ground-water supplies. In 1944, systematic collection and publication of surface-water-quality records began. The number of surface-water (lakes and streams) stations, by water year, where water-quality data were or are being collected is shown in figure 3.

In addition to the local needs for water-quality information, the USGS has established the National Stream-Quality Accounting Network (NASQAN), a network of stream-sampling stations throughout the United States, to assess the quality of the country's waters. Fifteen of these stations are located in Oklahoma. In addition, water-quality data collected at two stations in the State reflect the quality of surface runoff from areas not likely to be developed. These stations are part of the Hydrologic Bench-Mark Network (HBMN) and are located on Blue Beaver Creek near Cache and the Kiamichi River near Big Cedar.

During the 1984 water year, the U.S. Geological Survey collected and analyzed water samples from 40 stream locations in Oklahoma. Varying types of analyses ranged from the determination of physical properties (specific conductance, temperature, pH, and dissolved oxygen) to complete chemical (including organic and inorganic), biological, and trace-metals analyses. Specific conductance, temperature, pH, and dissolved oxygen are monitored continuously at the Arkansas River at Tulsa and the Salt Fork of the Arkansas River near Jet. Water-quality data are published each year in *Water Resources Data for Oklahoma*, as shown by the example in table 2.

Information on the quality of ground water has been collected at selected sites in the State, but not on a continuing network basis. Data are collected during specific hydrologic investigations and published in final project-data reports.

Ground Water

Ground-water levels are monitored in cooperative effort with the State of Oklahoma at 1,087 wells. The distribution of these wells has been determined on the basis of local water needs. Monitoring frequency at these wells ranges from an annual measurement to continuous recording of ground-water levels. In areas of extensive irrigation, annual measurements are made at 1,087 wells, most of which are located in the Panhandle. Quarterly measurements are made at six wells, and four wells are measured monthly. An additional 37 wells are equipped with recorders that monitor water levels continuously at selected locations statewide, and recorded data are processed by computer. Ground-water-level data are published each in a U.S. Geological Survey Open-File Report entitled *Ground-Water Levels in Observation Wells in Oklahoma*

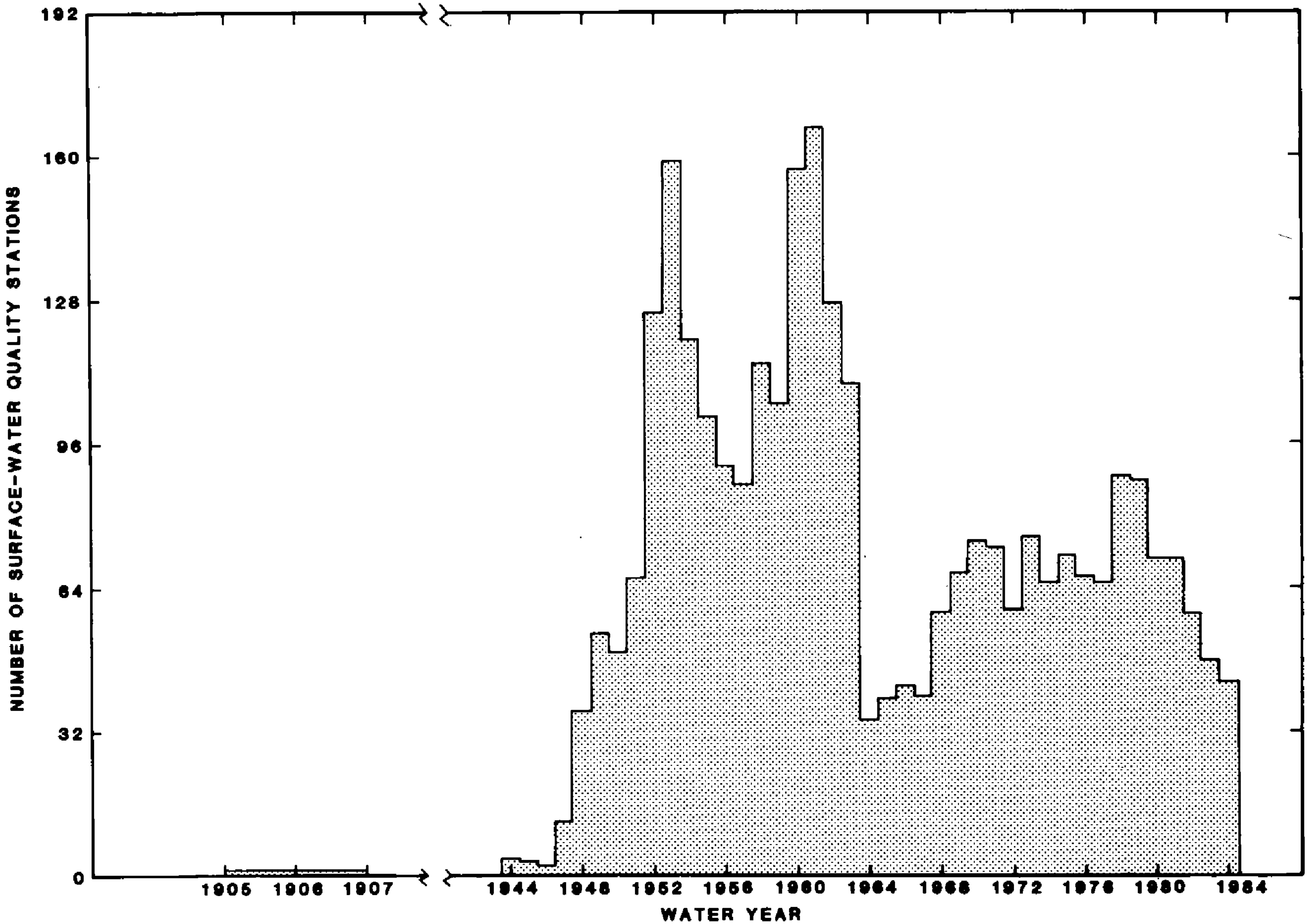


Figure 3. Number of surface-water-quality stations in Oklahoma.

TABLE 2. — WATER QUALITY DATA COLLECTED AT LITTLE RIVER NEAR SASKAWA AS PUBLISHED IN THE ANNUAL REPORT *WATER RESOURCES DATA FOR OKLAHOMA*

PERIOD OF RECORD.--Water years 1951 to current year.

PERIOD OF DAILY RECORD.--
SPECIFIC CONDUCTANCE: October 1955 to April 1982.
WATER TEMPERATURE: October 1955 to April 1982.

REMARKS: Samples were collected by a local observer on a daily basis. Partial analyses were made on those samples at or near the 5th, 15th and 25th from Oct.-Feb. Additional samples were collected at times and specific conductance, pH, water temperature, and dissolved oxygen were determined in the field.

EXTREMES FOR PERIOD OF DAILY RECORD.--
SPECIFIC CONDUCTANCE: Maximum daily, 138,000 micromhos Oct. 31, 1956; minimum daily, 118 micromhos Sept. 11, 1977.
WATER TEMPERATURE: Maximum daily, 38.5°C July 13, 1978; minimum, 0.0°C on several days during winter months.

WATER QUALITY DATA, WATER YEAR OCTOBER 1981 TO SEPTEMBER 1982

DATE	TIME	AGENCY ANA- LYZING SAMPLE (CODE NUMBER)	STREAM- FLOW, INSTAN- TANEOUS (CFS)	SPE- CIFIC CON- DUCT- ANCE (UMHOS)	PH (STAND- ARD UNITS)	TEMPER- ATURE (DEG C)	OXYGEN, DIS- SOLVED (MG/L)	OXYGEN, DIS- SOLVED (PER- CENT SATUR- ATION)	HARD- NESS (MG/L AS CACO3)	HARD- NESS NONCAR- BONATE (MG/L AS CACO3)
OCT										
05...	1545	80020	.10	2690	7.4	27.5	--	--	410	315
15...	1227	80020	435	393	7.7	22.0	--	--	95	19
25...	1205	80020	30	910	7.9	11.0	--	--	200	69
NOV										
05...	1102	80020	58	1200	7.4	13.0	--	--	230	106
15...	1518	80020	43	1310	7.6	14.5	--	--	270	122
25...	1323	80020	13	2030	7.8	15.0	--	--	430	197

TABLE 2.———CONTINUED

DATE	TIME	AGENCY ANALYZING SAMPLE (CODE NUMBER)	STREAMFLOW, INSTANTANEOUS (CFS)	SPECIFIC CONDUCTANCE (UMHOS)	PH (STANDARD UNITS)	TEMPERATURE (DEG C)	OXYGEN, DISSOLVED (MG/L)	OXYGEN, DISSOLVED (PERCENT SATURATION)	HARDNESS (MG/L AS CACO3)	HARDNESS NONCARBONATE (MG/L AS CACO3)
DEC										
05...	1338	80020	20	1560	8.3	8.5	--	--	320	139
15...	1523	80020	13	2540	8.0	9.5	--	--	440	305
25...	1425	80020	9.6	2850	8.0	3.0	--	--	460	304
JAN										
05...	1600	80020	12	3010	8.0	9.0	--	--	510	346
15...	1543	80020	6.6	2640	7.9	2.0	--	--	470	265
25...	1556	80020	13	2830	8.0	7.0	--	--	500	291
FEB										
05...	1513	80020	93	993	8.0	1.0	--	--	230	112
15...	1425	80020	145	1440	8.1	9.0	--	--	330	156
25...	1418	80020	36	2550	8.2	8.0	--	--	530	281
JUL										
15...	1430	80020	156	1540	7.9	30.0	8.2	112	340	118
AUG										
16...	1625	80020	4.2	2070	8.0	34.0	8.4	123	430	--
SEP										
27...	1435	80020	1.6	1200	8.2	25.0	10.7	135	--	--

(Goemaat and others, 1982–83). An example of continuous ground-water-level data published each year is shown in table 3.

Data Collection for Hydrologic Studies

In addition to the regular data-collection network, hydrologic studies are conducted for which data are collected on a temporary basis. The resulting data types and site locations are published in *Oklahoma — A Summary of Activities of the U. S. Geological Survey, Water Resources Division* (Hanson and others, 1983). Data from these locations are published in individual project reports obtainable through:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225.

Water Resources Division
U.S. Geological Survey
215 Dean A. McGee Street
Room 621
Oklahoma City, OK 73102.

Where data are collected continuously, information from specific site locations can be available in computerized printouts.

References Cited

Goemaat, R. L., Mize, L. D., and Spiser, D. E., 1984, Ground-water levels in observation wells in Oklahoma 1982–83 climatic years: U.S. Geological Survey Open-File Report 84–472, 583 p.

Gould, C. N., 1905, Geology and water resources of Oklahoma: U.S. Geological Survey Water-Supply Paper 148, 178 p.

Hanson, R. L., Scott, J. C., and Kurklin, J. K., 1983, Oklahoma: A summary of activities of the U.S. Geological Survey Water Resources Division for 1983: U.S. Geological Survey Open-File Report 83–767, 104 p.

Hauth, L. D., Kurklin, J. K., Walters, D. M., and Ferree, D. M., 1982, Water resources data, Oklahoma, water year 1982: U.S. Geological Survey Water-Data Report OK–82–1, 336 p.

TABLE 3.—DAILY GROUND-WATER LEVELS AT LE FLORE COUNTY WELL AS PUBLISHED IN *GROUND WATER LEVELS IN OBSERV ATION WELLS IN OKLAHOMA*

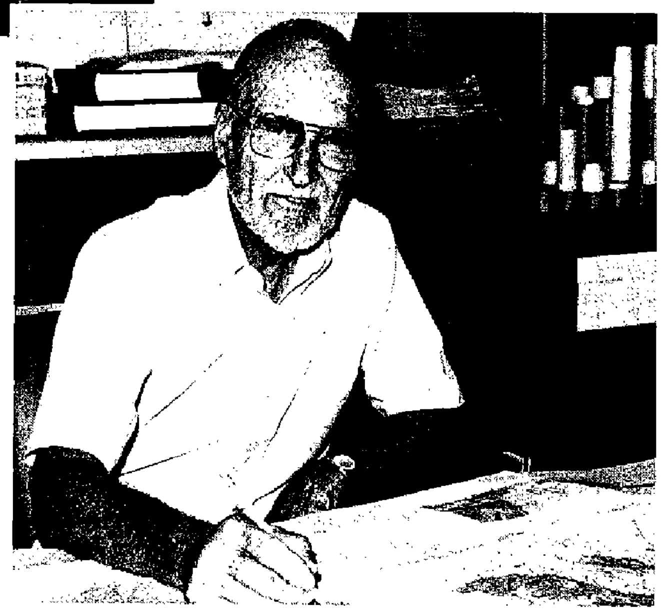
3510020 4314401. LOCAL NUMBER, 08N-26E-14 ACC 1.
LOCATIO N.--LAT 35 10'02", LONG 094 29'15", HYDROLOGIC UNIT 11110105, OWNER: BUREAU OF LAND MANAGEME NT.
AQUIFER --ATOKA FORMATION.
WELL CH RACTERISTICS.--DRILLED TEST HOLE, DIAMETER 6 IN (0.15M), DEPTH 277 FT (84.4M).
DATUM.--MEASURING POINT: TOP OF CASING 1.60 FT (0.48M) ABOVE LAND-SURFACE DATUM.
REMARKS --TEST HOLE NO. 17.
PERIOD F RECORD.--1980 TO CURRENT YEAR.
EXTREMES FOR PERIOD OF RECORD.--HIGHEST WATER LEVEL, -1.53 FT (0.466M) ABOVE LAND-SURFACE DATUM. JUNE 8, 1981; LOWEST WATER LEVEL, 3.43 FT (1.045M) BELOW LAND-SURFACE DATUM, NOV. 16, 1980.

WATER LEVEL, IN FEET BELOW LAND SURFACE DATUM, CLIMATIC YEAR APRIL 1983 TO MARCH 1984
MEAN VALUES

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1	−2.07	3.43	3.45	---	1.21	2.21	2.80	3.14	2.79	2.62	1.94	0.89
2	−2.14	3.44	3.45	---	1.26	2.23	2.79	3.15	2.63	2.63	1.91	0.84
3	−2.15	3.49	---	---	1.32	2.24	2.76	3.15	2.45	2.60	1.92	0.84
4	−2.17	3.60	---	---	1.37	2.23	2.75	3.13	2.42	2.47	1.93	0.69
5	−2.16	3.65	---	---	1.43	2.24	2.85	3.17	2.40	2.40	1.95	0.53
6	−2.14	3.66	---	---	1.47	2.28	2.95	3.17	2.51	2.33	2.06	0.51
7	−2.14	3.69	---	---	1.48	2.37	2.97	3.16	2.55	2.38	2.06	0.51
8	−2.15	3.83	---	---	1.46	2.42	2.96	3.17	2.53	2.39	2.06	0.54
9	−2.15	3.88	---	---	1.46	2.47	3.01	3.15	2.51	2.35	2.01	0.57
10	−2.15	3.93	---	---	1.49	2.50	3.01	3.17	2.50	2.33	1.95	0.51
11	−2.17	3.95	---	---	1.51	2.50	2.93	3.22	2.33	2.24	1.92	0.41
12	−1.86	3.93	---	---	1.52	2.50	2.93	3.21	2.34	2.14	1.82	0.18

13	3.66	3.95	---	0.35	1.57	2.56	3.02	3.18	2.22	2.19	1.73	-0.03
14	3.59	3.87	---	0.37	1.63	2.63	3.04	3.12	2.12	2.26	1.72	-0.04
15	3.67	3.56	---	0.38	1.67	2.61	3.05	3.19	2.15	2.24	1.70	-0.06
16	3.72	3.46	---	0.39	1.71	2.58	3.07	3.32	2.28	2.16	1.59	-0.12
17	3.68	3.45	---	0.43	1.73	2.60	3.09	3.28	2.34	2.14	1.49	-0.31
18	3.62	3.43	---	0.49	1.76	2.61	3.10	3.18	2.35	2.16	1.40	-0.46
19	3.63	3.43	---	0.56	1.80	2.65	3.08	3.08	2.34	2.22	1.45	-0.62
20	3.59	3.43	---	0.63	1.86	2.67	3.02	3.03	2.30	2.24	1.53	-0.61
21	3.53	3.43	---	0.67	1.90	2.74	2.98	3.07	2.27	2.27	1.50	-0.60
22	3.46	3.43	---	0.72	1.92	2.68	3.02	3.10	2.36	2.24	1.44	-0.59
23	3.44	3.43	---	0.76	1.96	2.70	3.04	2.94	2.40	2.14	1.40	-0.56
24	3.44	3.43	---	0.79	2.03	2.71	3.06	2.95	2.57	1.94	1.42	-0.72
25	3.43	3.44	---	0.83	2.08	2.69	3.14	2.91	2.64	1.88	1.45	-0.82
26	3.43	3.45	---	0.89	2.09	2.69	3.17	2.83	2.51	1.85	1.33	-0.88
27	3.43	3.45	---	0.96	2.09	2.70	3.15	2.75	2.39	1.86	1.07	-0.96
28	3.43	3.45	---	1.03	2.11	2.72	3.15	2.66	2.41	1.87	0.99	-1.06
29	3.43	3.45	---	1.11	2.15	2.77	3.17	2.71	2.67	1.86	0.99	-1.04
30	3.43	3.45	---	1.19	2.16	2.80	3.18	2.73	2.77	1.92	---	-0.96
31	---	3.45	---	1.20	2.17	---	3.15	---	2.71	1.97	---	-0.92

Elizabeth A. Ham



Thomas W. Amsden

TWO SURVEY STAFF MEMBERS 'RETIRE'

Thomas W. Amsden and Elizabeth A. Ham officially retired from the Oklahoma Geological Survey on June 30 of this year. But the term "retirement" hardly describes their true status, as both will continue to assist with Survey programs on a part-time basis.

Tom Amsden has worked actively for the Survey for almost 30 years. Before coming here in September 1955, he was a member of the geology faculty at Johns Hopkins University in Baltimore.

Tom has been one of the most energetic and productive staff members the Survey has ever had. The author of scores of articles and reports, he is known internationally for his contributions in the fields of paleontology, biostratigraphy, and lithostratigraphy. Since he started working for the Survey, he has concentrated his efforts on middle Paleozoic stratigraphy and is the author of several landmark OGS publications on the geology and paleontology of the Hunton Group of rocks in the Arbuckle Mountains, the Anadarko Basin, the Arkoma Basin, and elsewhere in Oklahoma.

Early in his career, Tom worked as an areal geologist with the U.S. Geological Survey, mapping in such diverse places as New Hampshire, Washington, and Arizona.

Tom left the USGS in 1946 and went to Yale University to complete work on a Ph.D. degree, which he received the following year.

He belongs to a number of scientific and professional organizations, including the Geological Society of America, the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, the American Institute of Professional Geologists, the Paleontological Society, and the Palaeontological Association of Great Britain.

Tom's part-time duties at the Survey for the next several years will focus on an evaluation of the Anadarko Basin in cooperation with the USGS. Tom explains that this work is actually a continuation of research results published 10 years earlier by the OGS as Bulletin 121, *Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko Basin of Oklahoma*. As many more deep cores and samples are now available for study, the utility of the present investigation is obvious.

Now that he's working part time, Tom said that he and his wife, Virginia, are looking forward to doing more traveling and to visiting their many friends in North America and throughout the world.

Betty Ham's career with the Oklahoma Geological Survey began officially in 1970, when she went to work in The University of Oklahoma's Geology and Geophysics Library. In 1971 she transferred to the Survey's editorial section as editorial assistant. In 1977 she was promoted to associate editor, later expanding her activities to include the duties of public-information specialist (the later by default, she says).

The author or coauthor of a number of articles and books, Betty is perhaps best known for her annual editions of the bibliography and index of Oklahoma geology, which she has prepared for more than a decade, and a lucid and eminently readable history of the Oklahoma Geological Survey. Betty's 60-page history was issued by the Survey as Special Publication 83–2, *A History of the Oklahoma Geological Survey, 1908–1983*, on the occasion of a symposium in 1983 celebrating the Survey's 75th anniversary.

Betty Ham's continuing work for the Survey will be directed principally toward preparing the bibliography and index of Oklahoma geology, in responding to requests for geological information, and in writing news releases. She is the envy of her colleagues in the latter endeavor, as she somehow manages to make news announcements interesting as well as informative.

Betty came to Norman, Oklahoma, "temporarily," she thought, after receiving a bachelor's degree in geology from the University of Kansas

City (now the University of Missouri at Kansas City).

Shortly after Betty enrolled in graduate school at The University of Oklahoma in 1937, she met fellow student William E. Ham, her husband-to-be, whom many readers will remember as a distinguished specialist in carbonate rocks and a long-time member of the OGS staff. (Bill was acting director of the Survey from 1952 to 1954.) Thus, after receiving her master's degree in geology in 1939, Betty remained inexorably linked to the Survey, OU, and Norman.

We're glad she stayed.

William D. Rose

ERI STAFF MEMBER ON BOARD TO CONDUCT SPECIAL STUDY BY NATIONAL ACADEMY OF SCIENCES

Mary L. Fleming, director of Information Systems Programs, a branch of The University of Oklahoma's Energy Resources Institute, was named to the Board of Minerals and Energy Resources (BMER) of the National Academy of Sciences. The BMER, under the chairmanship of William L. Fisher, director of the Texas Bureau of Economic Geology, will study methods used by industry, academia, and government to estimate undiscovered, economically recoverable oil and gas resources on the outer continental shelf (OCS).

The study will evaluate existing resource-estimation methods and adequacy of data available for resource assessment, then recommend ways to improve estimation techniques. It will take nearly two years to complete the project, which is supported by a $237,694 contract issued by the Department of the Interior's Minerals Management Service (MMS).

MMS is responsible for developing estimates of undiscovered oil and gas resources. These estimates are used in preparing 5-year OCS-leasing schedules, environmental-impact statements for lease sales, and other policy and decision documents. The BMER provides an overview of science, technology, economics, industrial activity, education programs, and governmental policies related to resources.

NOTES ON NEW PUBLICATIONS

Water Resources Data: Oklahoma, Water Year 1983

Water-resources data for Oklahoma for the 1983 water year are presented in this 286-page volume by L. D. Hauth, J. K. Kurklin, and D. M. Walters. Data consist of records of stage, discharge, and water quality of streams and stage, contents, and water quality of lakes and reservoirs. The report contains discharge records for 117 gaging stations, stage and contents for 27 lakes and reservoirs, and water quality for 39 gaging stations and 3 lakes. Also included are data for 39 crest-stage partial-record stations and 3 low-flow stations.

Order from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. Copies are available free of charge.

Techniques for Estimating Flood Peak Discharges for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma

Robert L. Tortorelli and DeRoy L. Bergman, authors of this 85-page report, describe a technique of estimating peak flows for Oklahoma streams using either graphs or equations. The report states: "Now only two variables, drainage area and mean annual precipitation, are needed to estimate flood discharge for unregulated Oklahoma streams with drainage areas less than 2,500 square miles. Peak discharge for streams with small floodwater retarding structures can also be estimated." The report can be inspected at the U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102.

Order WRI 84–4358 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. Copies are sold at cost.

Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks

Editor James G. Palacas has synthesized data from about 20 different sedimentary basins on several continents in this volume. The book serves as a resource for evaluating petroleum occurrence in carbonate sequences and for locating petroleum resources in unexplored, partially explored, and maturely explored basins where possible carbonate-generated oil and gas may have been overlooked.

Order from: AAPG Bookstore, P.O. Box 979, Tulsa, OK 74101. The price is $16 for AAPG members, $20 for nonmembers; add $3 for shipping and handling in North America, $4.50 elsewhere.

Ground Water Regions of the United States

The nation's ground-water resources, which account for nearly 40% of the fresh water for most uses in the United States each year, are described in this 78-page report by Ralph C. Heath. The report divides the 50 states, plus Puerto Rico and the Virgin Islands, into 15 regions and describes in nontechnical language the geology and physical characteristics of the ground-water system in each region. Each of the sections on the ground-water regions provides a location map, information on the geology and hydrology of the area, specific issues concerning ground water, and additional illustrations to explain different aspects of the regional ground-water system. The report is illustrated with 65 diagrams, sketches, tables, and full-page national maps. A glossary provides 51 basic definitions.

Order W 2242 from: U.S. Geological Survey, Eastern Distribution Branch, 604 S. Pickett St., Alexandria, VA 22304. The price is $4.25.

Use and Availability of Continuous Streamflow Records in Oklahoma

This 23-page open-file report by S. P. Blumer and L. D. Hauth is available for reference at the U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102.

Order OF 84—0747 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $3.50 for microfiche, $3.50 for a paper copy.

Hydrologic Data: North Canadian River from Lake Overholser to Lake Eufaula, Central Oklahoma.

J. S. Havens is the author of this 49-page open-file report, which can be inspected at the U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102.

Order OF 84–0808 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche, $8.50 for a paper copy.

International Strategic Minerals Inventory Summary Report—Chromium

This report identifies 51 major deposits of chromite, a strategic mineral essential to making stainless steel. Almost 95% of the world's known resources of chromium is in two countries in southern Africa—South Africa and Zimbabwe. None of the world's major deposits is in the United States, and the U.S. now relies entirely on imports for the chromium it uses. But the Stillwater complex deposits in Stillwater and Sweetgrass

Counties in Montana are among 11 other deposits and districts in the world that might have regional significance, the report says. Authors of the circular include John H. DeYoung, Jr., Michael Lee, and Bruce Lipin.

Order C 930-B from: U.S. Geological Survey, Eastern Distribution Branch, Text Products Section, 604 S. Pickett St., Alexandria, VA 22304. Single copies are free.

NEW REGIONAL SEISMICITY REPORT SUMMARIZES NEMAHA UPLIFT STUDY

A new publication released by the Oklahoma Geological Survey contains results of a four-state, six-year project to investigate areas of high seismicity in a region extending from central Oklahoma northward through eastern Kansas into eastern Nebraska and western Iowa.

The study was sponsored by the U.S. Nuclear Regulatory Commission (NRC) and was conducted by the geological surveys of Oklahoma, Kansas, Iowa, and Nebraska. The 33-page report, published through permission of NRC, has been issued as OGS Special Publication 85–2, *Seismicity and Tectonic Relationships of the Nemaha Uplift and Midcontinent Geophysical Anomaly (Final Project Summary)*. The authors are R. R. Burchett of the Nebraska Geological Survey, Kenneth V. Luza of the Oklahoma Geological Survey, O. J. Van Eck of the Iowa Geological Survey, and F. W. Wilson of the Kansas Geological Survey.

The program was initiated by NRC to provide information useful in the safe siting of nuclear power plants. Its application was soon expanded to cover determination of insurance rates and siting and design of any large-scale earthquake-prone structures, such as bridges, dams, and high-rise buildings.

Beyond these applications, however, is the knowledge gained of the geologic structure and its possible relation to earthquake sources in the region through seismological, aeromagnetic, gravity, geophysical, and tectonic investigations and evaluations.

For the report, each author has prepared a summary section covering his own state and has provided a list of pertinent references. Also, the publication includes two large plates containing four maps each that incorporate the major data acquired through the study. These maps show bedrock geology, structure, gravity and magnetism, geologic lineaments, earthquake epicenters, and seismological-station locations in the four-state region.

Oklahoma Geological Survey Special Publication 85–2 can be obtained from the Survey at the address given inside the front cover of this issue or by calling (405) 325-3031. The price is $7.

FUNDAMENTALS OF THE PETROLEUM INDUSTRY

Fundamentals of the Petroleum Industry, by Robert O. Anderson, 1984, 390 p. University of Oklahoma Press, 1005 Asp Ave., Norman, OK 73019. $29.95.

Author Robert Anderson is well qualified to report on the petroleum industry, having spent more than 40 years in that industry. From 1965 to 1982 he served as chairman of the board and chief executive officer of Atlantic–Richfield Co. (ARCO); he continues as board chairman.

In a preface Anderson recognizes the public's lack of understanding and appreciation of the complexity and global importance of the petroleum industry and expresses the hope that his book "will provide, in some small way, an insight not only for those on the inside but also for the increasing numbers of individuals in both the private and public sectors who have a growing interest in the affairs of this great and vital industry." He says that an earlier book of the same name, by the distinguished geologist Dorsey Hager, which was published in 1939, largely inspired the present work.

The author has organized his material well and has presented it in a conversational style that makes for easy reading and comprehension.

Overall, the book covers virtually every aspect of the industry from exploration and leasing to production, refining, marketing, and the inevitable role of governmental bodies in levying taxes and enacting regulatory legislation. On the other hand, Anderson's subject is so broad as to preclude detailed treatment of any single topic.

Early chapters cover periods in the historical development of the industry, from wells drilled by the Chinese thousands of years ago through Colonel Drake's well at Titusville (1859) and the discovery of the Spindletop (1901) and East Texas (1930) Fields, through contributions of the industry toward waging World War II, up to the present.

Some of the other chapters touch on oil generation, petroleum geology, completion practices, reservoir engineering, environmental considerations, refining, petrochemicals, and marketing. A concluding chapter, "Energy for Tomorrow," looks at alternate energy sources, such as solar, geothermal, nuclear (fission and fusion), tidal, and wind power, and assesses the extent to which these sources might contribute toward meeting our future energy needs.

The author deserves credit for defining "reserves" and for making a distinction between proved reserves and probable, possible, speculative, and ultimate reserves.

The University of Oklahoma Press has designed and produced the book handsomely in a 9- by 9-in. hardbound edition. The volume is liberally illustrated with photographs, drawings, maps, and graphs, most of which are effective and germane to the text. The text is printed in a easy-to-read double-column format.

The book also contains a glossary, chapter notes for the inquisitive reader, and a reasonably complete index.

I can recommend Anderson's work for the informed general reader as a good overview of a highly complex industry. I suspect that insiders also could benefit from the book's perspective as a whole and from those chapters that treat less familiar topics.

William D. Rose

USGS INCREASES MAP PRICES

A recent 10% increase in map prices by the U.S. Geological Survey is now reflected at the sales counter of the Oklahoma Geological Survey.

The popular *Geologic Map of Oklahoma* now sells for $8.80, and the price of the *Geologic Map of the United States* has increased to $9.90.

The *Topographic Map of Oklahoma*, the Army Map Service 1:250,000-scale quadrangle maps, and the metric topographic (30- by 60-minute) series now cost $4 each. The 7.5- and 15-minute standard topographic maps each sell for $2.50.

Maps published by the USGS as well as those published by the Oklahoma Geological Survey are available for sale at the OGS office during regular business hours: 8 a.m. to 12 noon and 1 to 5 p.m. Monday through Friday, and from 8 a.m. to 12 noon Saturday.

OGS ISSUES PUBLICATION LIST

A new publication released recently by the Oklahoma Geological Survey comprises a listing of the total published output of the Survey since its inception. The 78-page volume, *List of Publications of the Oklahoma Geological Survey, 1902–1984*, issued as OGS Special Publication 85–3, is a revision and updating of the 1979 edition that had gone out of print.

The book contains a bibliographic listing of both available and out-of-print bulletins, circulars, mineral reports, guidebooks, maps, hydrologic atlases, educational publications, special publications, and miscellaneous items, with accompanying indexes to authors, counties, and commodities.

Some of the items included were issued prior to Oklahoma's statehood and therefore actually antedate the Oklahoma Geological Survey. These early reports were published by what has come to be known as the "Territorial Survey," an agency formed under a law introduced into the Territorial Legislature by David R. Boyd, first president of The University of Oklahoma.

An article in the 1907 Constitution of Oklahoma and an enabling act passed by the first legislature put the State's Geological Survey on a firmer basis. The act enjoined the Survey to engage in geological investigations in the new state, with "special reference to its mineral deposits," and to publish the information so acquired.

The 136 bulletins, 86 circulars, 36 mineral reports, and the myriad of other materials listed in the revised compilation represent the results of adherence to the constitutional mandate.

OGS Special Publication 85–3, *List of Publications of the Oklahoma Geological Survey, 1902–1984*, compiled by OGS associate editor Elizabeth A. Ham and OU geology librarian Claren M. Kidd, can be obtained from the address inside the front cover of this issue or by calling (405) 325-3031. The price is $5.

NEW THESES ADDED TO OU GEOLOGY LIBRARY

The following M.S. theses and Ph.D. dissertation have been added to The University of Oklahoma Geology and Geophysics Library:

Magnetization in the Sediments of a Modern Fan Delta, Baja California, Mexico, by Lynn Claire Bryan. 126 p., 56 figs., 1984.

Mixed Clastic to Carbonate Deposition, Falmouth, Jamaica, by Donald G. Burdick. 134 p., 16 figs., 22 maps, 12 tables, 6 appendixes, 1984.

Paleoenvironmental Analysis of the Ralston Creek Formation within the Canon City Embayment, Canon City, Colorado, by Michael Howard Carter. 90 p., 29 figs., 1984.

Paleomagnetic and Petrographic Investigation of the Taum Sauk Limestone, Southeast Missouri, by William J. Dunn. 66 p., 16 figs., 3 tables, 1984.

Relation of Biofacies to Lithofacies in Interpreting Depositional Environments in the Pitkin Limestone (Mississippian) in Northeastern Oklahoma, by Robert S. Fabian. 126 p., 12 figs., 6 pls., 5 tables, 3 appendixes, 1984.

Paleomagnetic and Petrographic Investigation of the Morgan Creek Limestone, Central Texas, by Virginia L. Loucks. 63 p., 15 figs., 1 table, 1984.

A Synergetic Study of Seismic Reflections and Critical Refractions in the Great Salt Lake Desert, Utah, by Donald J. Murray. 94 p., 17 figs., 2 tables, 5 appendixes, 1984.

A Petrographic Investigation of the Windsor Formation, St. Ann's Basin: Implications Concerning the Cretaceous Tectonic History of Northern Jamaica, by Marianne Victoria O'Neal. 224 p., 46 figs., 2 tables, 3 appendixes, 1984.

Lithostratigraphy of Cambro-Ordovician Rocks and Radionuclide Analysis of Associated Waters, Northeastern Oklahoma, by James Martin Reis. 83 p., 46 figs., 3 pls., 2 tables, appendix, 1984.

Field and Laboratory Study of Fracture Characteristics as a Function of Bed Curvature in Folded Dolomites, Sawtooth Mountains, Montana, by Jill A. Spooner. 135 p., 35 figs., 4 tables, appendix, 1984.

Facies Analysis of the Kindblade Formation, Upper Arbuckle Group, Southern Oklahoma, by Christopher M. Tenney. 110 p., 17 figs., 7 tables, 1984.

Geologic Applications of Late Pennsylvanian Ichthyoliths from the Midcontinent Region, by Linda E. Tway. 316 p., 18 figs., 5 pls., 5 tables, 6 appendixes, 1982 (Ph.D. disseration).

Chemical Equilibria Between Holocene and Pleistocene Intertidal/Shallow Subtidal Carbonate Rocks and Associated Interstitial Waters, Discovery Bay, Jamaica, by Nancy Irene Trumbly. 185 p., 50 figs., 4 tables, 3 appendixes, 1984.

Coral Fauna and Carbonate Mound Development, Pitkin Formation (Chesterian), North America, by Gregory Edward Webb. 267 p., 22 figs., 22 pls., 3 tables, 3 appendixes, 1984.

Comparative Sandstone and Mudrock Diagenesis in the Jackfork Group, Northern Flank of the Broken Bow—Benton Anticline, Southeastern Oklahoma, by Jay Arthur Winters. 62 p., 17 figs., 3 appendixes, 1984.

OKLAHOMA ABSTRACTS

AAPG, Rocky Mountain Section, Annual Meeting Denver, Colorado, June 2–5, 1985

The following abstract is reprinted from the *Bulletin* of the American Association of Petroleum Geologists, v. 69, no. 5. The page number is given in brackets below the abstract. Permission of the author and of the AAPG to reproduce the abstract is gratefully acknowledged.

Diagenetic Destruction of Primary Reservoir Porosity in Viola Limestone, South-Central Oklahoma

G. MICHAEL GRAMMER, Texaco, Inc., Denver, CO

The Viola Limestone in south-central Oklahoma is a Middle and Upper Ordovician carbonate unit interpreted as being deposited on a carbonate ramp within and peripheral to the southern Oklahoma aulacogen. Depositional environments within the study area ranged from anaerobic deep ramp through aerobic middle and shallow-ramp environments. Total organic carbon analyses of the lower anaerobic deep-ramp facies suggest that, at least locally, the Viola is a potential hydrocarbon source rock. Detailed petrographic examination of the Viola indicates that primary porosity in the shallow-ramp skeletal packstones and grainstones was initially quite high. This combination of source potential and original porosity should make the Viola an attractive target for hydrocarbons in southern Oklahoma. The Viola, however, has been subjected to a complex sequence of diagenetic events that have extensively altered the sediments and occluded much of the primary porosity. A thorough understanding of the timing and nature of these events can be critical in evaluating the economic potential of the Viola.

Petrographic evidence combined with the use of cathodoluminescence indicates that several generations of calcite cementation occurred within the shallow-ramp packstones and grainstones. An initial phase of very early, possible synsedimentary marine cementation is evidenced by cloudy, inclusion-rich syntaxial cements on echinoderm fragments. This

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OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

early phase of cementation was followed by several generations of clear syntaxial calcite, prismatic calcite, blocky mosaic calcite, and bladed mosaic calcite, all of which indicate changes in the pore-water chemistry from the inclusion-rich cements. This phase of meteoric phreatic cementation occurred soon after the marine cementation and occluded virtually all remaining primary reservoir porosity. [849]

GSA, South-Central Section, Annual Meeting
Fayetteville, Arkansas, April 14–16, 1985

The following abstracts are reprinted from *Abstracts with Programs, 1985* of the Geological Society of America, v. 17, no. 3. Page numbers are given in brackets below the abstracts. Permission of the authors and of the GSA to reproduce the abstracts is gratefully acknowledged.

Chemical Characterization of Cambrian Basaltic Liquids from the Southern Oklahoma Aulacogen

M. CHARLES GILBERT, Dept. of Geology, Texas A&M University, College Station, TX 77843; and SCOTT S. HUGHES, Dept. of Chemistry and Radiation Center, Oregon State University, Corvallis, OR 97331

Within the Wichita Mountains portion of the Southern Oklahoma aulacogen three important stratigraphically distinct units of basaltic bulk chemistry crop out. INAA on representative samples from two of these three, the older Roosevelt Gabbros (RG) and the younger late diabases (LD), yields the following:
1) Incompatible elements, Ba, Rb, LREE are enriched relative to MORB, being similar to continental tholeiites.
2) Trace element patterns for Ba, REE, Sc, Ta, Th, normalized to volatile-free C1 chondrites, are fractionated and have distinctive, common shapes for all samples.
3) Patterns show positive Eu anomalies.
4) The Sandy Creek Gabbro member of the RG has the lowest abundances of REE while Mount Sheridan Gabbro member is similar to the LD.
5) Those LD occurring in a granitic/rhyolitic host show some evidence of contamination.
Conclusions are:
1) Parallelism of all patterns suggests a common source, which also implies a short time interval between them.
2) This "common source" may itself have been emplaced in the upper crust and caused partial melting leading to the granites/rhyolites.
3) The two basaltic units may have segregated from a cumulate pile during various stages of differentiation. Neither unit represents truly primary liquid.

4) Cambrian rifting here has generated basaltic liquids similar to those found in the Proterozoic Keweenawan suite rather than the alkalic types of the southern Rio Grande Rift or East Africa. [159]

Sedimentation, Diagenesis and Deformation of a Pennsylvanian Conglomerate, Arbuckle Mountains, Southern Oklahoma

JEANNE E. GLAHN and ROBERT L. LAURY, Department of Geological Sciences, Southern Methodist University, Dallas, TX 75275

Late Pennsylvanian uplift during the Arbuckle orogeny led to exposure and erosion of Cambro–Ordovician carbonate strata and to coeval deposition of a [predominantly] carbonate-clast conglomerate in a small, fault-bounded basin. The basin is aligned east–west and lies on the northern flank of the northwest-trending Arbuckle Anticline.

Deposition of sediments preserved within the basin appears to have been largely by flashy fluvial processes, with minor debris flows. Channel scour-and-fill deposits are evident, as are sieve deposits composed of moderately-sorted pebble-sized clasts with infiltrating fine sediment and coarse calcite cement filling remaining interstices.

Pressure solution has occurred between carbonate clasts, apparently in response to tectonically-induced, post-depositional stresses applied to the conglomerate. An expected horizontal orientation of stylolites due to burial/compactional stresses exists. However, the greater degree and abundance of vertical pressure solution seams indicates that horizontal principal stresses may have been more significant than vertical loading in the compaction of the conglomerate. Planes of most of the stylolites appear to be oriented north–south, and may be related to the same principal stresses which caused faulting within the unit. Subsequent, possibly shallow burial coarse calcite cement has occluded most of the remaining porosity. Slickensides along numerous small, near-vertical faults show definite left-lateral strike-slip displacement, paralleling the long axis of the basin.

The origin of the basin has not been well established, but postdepositional deformation and cementation were the principal mechanisms of porosity loss in the conglomerate. [159]

Mapping of Surface Joints on Air Photos Helps Understand Waterflood Performance Problems at North Burbank Unit, Osage and Kay Counties, Oklahoma

KURT B. HAGEN, Phillips Petroleum Company, 834 Frank Phillips Building, Bartlesville, OK 74004

A system of parallel joints is well developed in the thin limestones of Permian age exposed in Osage County, Oklahoma. The joints are recognized due to lush vegetation growing in them. Statistical studies using aerial photos supplemented by ground observations showed the direction of the [principal] set is very regular, averaging N70°E. Evidently, a parallel set cuts the oil-producing sand at a depth of 3000 feet. The Burbank Field was discovered in 1920. Secondary recovery by waterflood was started in 1950. Although first results were encouraging, large quantities of water appeared in oil-producing wells, both east and west of the pilot flood area, apparently channeling through open joints. The pattern was changed to a north–south line drive. The amount of bypassing was reduced, and the operation was successful. Future waterflood projects should take the surface joint pattern into account and orient the well pattern to conform. [160]

Structural History of the Ouachita Mountains, Arkansas: Part One—The Big Picture

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The rocks in the Ouachita Mountains may have attained their present structural setting through sequential periods of folding and faulting, with each period of deformation affecting the previous folds and faults to the extent that, in many of the areas, they were backfolded to the point of being overturned southward.

In most previous investigations the deformed Paleozoic rocks of the Ouachita Mountains of Arkansas were divided into three poorly defined structural parts: the "core area," the "frontal zone" or "frontal belt" to the north, and the "southern Ouachitas" or "southern belt" to the south. Through recent studies the area has been divided into seven generally east–west trending structural belts. These belts are named Rover, Aly, Nixon, Avilla, Mt. Ida, Hopper, and Amity. The Mt. Ida, Nixon and Avilla belts include most of the older Paleozoic rocks and these rocks are the most intensely deformed. Each belt is a northward moving imbricately faulted thrust plate with a major sole fault.

It is suggested that the simplified sequential phases in the structural development of the Ouachita Mountains are as follows: (A) extensional faults with minor igneous intrusions; (B) major uplift with folding and faulting of the more competent units; (C) several periods of folding and thrust faulting with related backfolding and cross faulting; and (D) regional uplift and arching. Most of Step A took place from early Mississippian to late Atokan time, Steps B–C during middle Pennsylvanian to early Permian, and Step D from Triassic to Recent.

We conclude that (1) the Ouachita Mountains in Arkansas are allochthonous and formed by northward overriding imbricately faulted thrust plates with major sole faults; (2) some thrust plates involved Precambrian rocks in the subsurface; and (3) the structural deformation may have narrowed the initial width of the Ouachita depositional basin by as much as 200 miles. [160–161]

Correlation of Organic and Inorganic Indicators of Thermal Maturity, Ouachita Mountains

D. HOUSEKNECHT, J. GUTHRIE, L. ROSS, W. KELLER, and R. ETHINGTON, Dept. of Geology, University of Missouri, Columbia, MO 65211

Vitrinite reflectance, illite crystallinity, organic geochemistry, chert crystallinity, and conodont color are independent indicators of thermal maturity that can be correlated in the Ouachita Mountains where strata displaying an extreme range of thermal maturity are juxtaposed. In Carboniferous strata, a statistically significant relationship exists between vitrinite reflectance (Ro) of dispersed organic matter and illite crystallinity determined using either Weaver's sharpness ratio (SR) or Kubler's crystallinity index (CI): $Log(SR) = 0.28 + 0.08(Ro)$; $Log(CI) = 1.01 - 0.07(Ro)$. Plots of bitumen/organic carbon vs. Ro, SR, and CI reveal hydrocarbon generation–preservation curves that define submature, mature, and supermature zones with regard to an "oil window."

Chert crystallinity correlates well with Ro, especially in areas of high thermal maturity. Cryptocrystalline chert occurs throughout areas of Ro <2.0%, chert with triple point texture and mean crystal size <10 microns occurs in areas of Ro 2.0-3.0%, and chert with triple point texture and mean crystal size >10 microns occurs in areas of Ro >3.0%. Data on color alteration index (CAI) of conodonts, limited to lower Paleozoic strata of the Ouachita core, confirm the high thermal maturity of these strata (CAI = 5), whose Ro values are generally >3.0%.

As an example of the applicability of these correlations, illite crystallinity was determined for Cambrian shales from two wells in the northern Mississippi embayment (Mississippi Co., AR). Numerous samples yielded SR values that equate with a Ro of 1.38%, a value within the "oil window." Conodonts from Ordovician strata in a nearby well (Lauderdale Co., TN) yielded CAI values of 2–2.5, thereby corroborating a moderate thermal maturity for these prospective strata. Although such data must be evaluated cautiously, they demonstrate the potential utility of a regional correlation among thermal maturity indicators. [162]

Influence of Syndepositional Normal Faulting on Morrow and Atoka Sedimentation, Arkoma Basin

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Morrow and Atoka sedimentation in the Arkoma basin was significantly influenced by syndepositional normal faulting related to the tectonic evolution of the Mississippi embayment and Ouachita orogenic belt.

Following its earliest Paleozoic formation as a NE–SW oriented system of grabens, the Mississippi embayment remained an axis of subsidence until the late Paleozoic. Subsurface correlations in the easternmost Arkoma basin reveal that Morrowan strata thicken into the embayment in discrete steps, suggesting that subsidence continued to be localized along faults bordering the buried graben system. This area of active subsidence funnelled detrital sediment southward from the Illinois basin toward the deep Ouachita basin. Morrow strata in the embayment represent marine shelf through deltaic facies that are distal equivalents of deltaic and fluvial facies in the Illinois basin. West of the embayment, Morrow strata in the Arkoma basin reflect a less abundant supply of detrital sediment and are indicative of marine shelf through fluvial depositional environments.

During the Atokan, syndepositional normal faults formed parallel to the evolving Ouachita orogenic belt, apparently in response to tectonic loading of the Ouachita subduction complex onto North American continental or transitional crust. These faults induced longitudinal dispersion of detrital sediment from east to west within the Arkoma basin, thereby delivering sand to the basin from the evolving orogenic belt and accounting for the observed increase in metamorphic lithic fragments in the Atoka section. Moreover, many of the syndepositional faults localized sediment dispersal patterns in deltaic, shallow marine, and deep marine depositional environments, resulting in sand body geometries that closely parallel the strike of faults. [162]

Comparison of Chert/Novaculite Textures from the Ouachita Mountains, U.S. Virgin Islands, Scotland and Other Localities

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The textures of chert/novaculite heated by geothermal processes are remarkably similar whether the chert is from a folded sedimentary belt region in the Ouachita Mountains, Arkansas–Oklahoma, from a volcanic arc province in the U.S. Virgin Islands, or from a contact metamorphic aureole, Isle of Skye, Scotland.

Scanning electron micrographs (SEMs) of all those rocks show a complete range of textures from cryptocrystalline, anhedral quartz in nonmetamorphosed chert/novaculite to coarse, polygonal triple-point quartz over 30 μm in diameter in metamorphosed counterparts. Additional examples of triple-point texture in chart collected from overseas localities, and ranging in age from Precambrian to Tertiary further show that such rocks and metamorphic effects are world-wide in occurrence. Our studies indicate that triple-point texture is related to the thermal history of these rocks.

Temperature estimates from limited studies of mineral-chemical phase relationship in associated rocks, fluid inclusions, and stable isotope ratios suggest that maximum temperatures as high as approximately 760°C have been reached by small portions of the chert/novaculite. Other variables, such as geologic time, crystal deformation and mineralizing compounds, have not been evaluated for possible effects on recrystallization. Chemical compounds other than silica in the chert that may possibly inhibit recrystallization, or somewhat modify the morphology, are under study.

Nonetheless, small samples of chert/novaculite can yield evidence of a history of high temperature resulting from deep burial by sedimentation, tectonism, volcanogenic events, and/or from exposed or concealed intrusions. Such evidence may be used in determining maturation or degradation of hydrocarbons in the rocks, and to furnish clues during exploration for thermally related metallic and non-metallic minerals.

[163]

The U.S. Geological Survey's Program to Acquire Side-Looking Airborne Radar Data: A Progress Report

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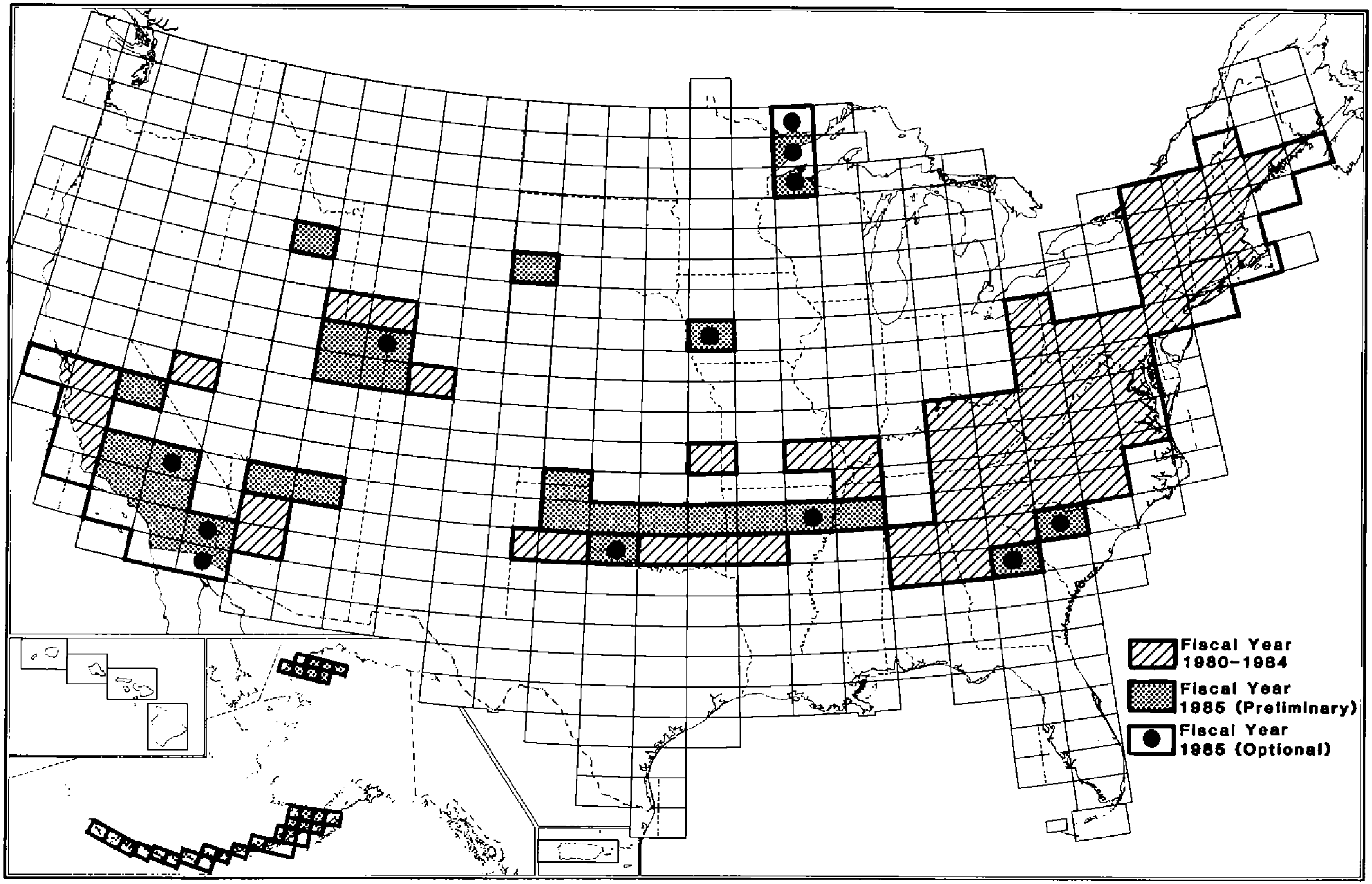
This is a progress report on the U.S. Geological Survey's (USGS') program to acquire side-looking airborne radar (SLAR) data. Since its inception in 1980, over 1.4 million km^2 of SLAR imagery has been compiled into map-controlled mosaics at 1:250,000 of 1° × 2° quads in the conterminous U.S. and Alaska. Within the last 6 months, the USGS has contracted to acquire radar imagery for 20 quads to be collected with the GEMS-1000 X-band synthetic aperture system. They are the following: *Little Rock, McAlester*, and *Ardmore* (the Ouachita Mountains), AR & OK; *Plainview* and the eastern half of *Clovis* (Palo Duro basin), TX; *Joplin* (a Conterminous U.S. Mineral Assessment Program, CUSMAP, quad), MO & IL; *Rolla, Paducah*, and *Dyersburg* (lead–zinc mineralization and active faulting), MO, IL, KY, & TN; *Cleveland* and *Canton*, OH & PA; *San Francisco, San Jose, Monterey, San Luis Obispo*, and *Santa Maria*, CA; *Leadville* (a CUSMAP quad), CO; *Prescott* and *Phoenix*, AZ; and *Rock Springs* and *Ogden*, UT & WY.

Also received during the past year were radar mosaics of 38 Appalachian quads from AL to ME prepared using data from the STAR-1 system, an X-band, synthetic-aperture, digitally correlated radar. Near- and far-range mosaics are available at 1:250,000 and 1:100,000. Other new material [includes] X-, C-, and L-band, like- and cross-polarized data of central NC, 12 lithographed image maps of the Aleutians, and several demonstration products. Earlier acquisitions include imagery for mosaics of these areas: Alaska Peninsula (16), western Alaskan North Slope (16), Tonopah, NV (1), central [Appalachians] (5), and northern New England (3).

All radar data and products from this program are available from the



The U.S. Geological Survey Radar Acquisition Program: Side-looking airborne-radar image mosaics at 1:250,000. [Map supplied by Kover and Jones for abstract on facing page.]

EROS Data Center, USGS, Sioux Falls, SD 57198, telephone (605) 594-6151. Price lists and order forms will be provided on request. [163]

An Anomalous Geothermal Gradient in the Mid-Continent and Its Possible Relationship to the Late Pennsylvanian–Early Permian Ouachita Orogeny

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Studies of fluid inclusions in sphalerite and hydrothermal dolomite from mining districts and unmineralized areas in Missouri, Arkansas, and parts of Oklahoma and Kansas show that an anomalously high regional geothermal gradient (80° to 100°C/km) prevailed during or after Late Pennsylvanian time north of the Ouachita fold belt. Neither "normal" heat flow by conduction from basement rocks nor localized magmatic activity provides an adequate explanation for the observed gradient. Rather, migration of heated brines out of the 12 to 18 km thick sedimentary section in the southern portion of the Ouachita–Arkoma basin system is believed responsible for the high heat flow. Flow of hot basin fluids onto the southern flank of the North American craton was driven by some combination of compaction, uplift and gravity draining, and geopressuring in response to tectonic stresses during the Late Pennsylvanian–Early Permian Ouachita orogeny.

The migration of hot brines from the Ouachita–Arkoma basin may also have been responsible for widespread Mississippi Valley type Pb–Zn mineralization. Inclusions in Northern Arkansas zinc district dolomite and sphalerite record the passage of hot (110°–130°C), highly saline (>22 wt.% NaCl equiv.) fluids. Volatiles in these inclusions consist primarily of thermally refractory, light, chain hydrocarbons (methane, ethane, and propane), and relatively high proportions (3 mile %) of CO_2. These compositions are consistent with those expected for basin fluids evolved under low-grade metamorphic conditions such as prevailed during the Ouachita orogeny in the southern portion of the Ouachita–Arkoma basin system. [164]

Pennsylvanian Hyolitha (Mollusca) from the Southern Midcontinent and Their Paleoecologic Significance

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Hyoliths are more common in the Midcontinent Pennsylvanian than has been previously recognized. Formerly, seven occurrences were recorded from the Late Paleozoic of North America; now, approximately 20 new localities in southern Oklahoma and north-central Texas have

yielded over 800 specimens. The hyoliths occur in strata ranging in age from Morrowan to Virgilian, although most occur in the Virgilian. All hyoliths represent the order Hyolithida. These are conical shells with sub-triangular transverse sections and a shelf or ligula along the ventral margin of the aperture. Most specimens are too poorly preserved for identification at the generic level; however, the variable array of morphologies among specimens indicates that several taxa are present. The occurrence of hyoliths in the Midcontinent Pennsylvanian fills a geographic and stratigraphic gap in the distribution of these organisms in North America.

Strata yielding the hyoliths are part of cyclic sequences (cyclothems) which include a basal fluvial/deltaic package usually overlain by a fossiliferous mudstone or shale, followed by a marine limestone. The hyoliths are part of the *Sinuitina*-juvenile ammonoid "community," confined to the dark gray portion of the fossiliferous mudstone/shale. This interval is the most offshore facies of the cyclothem, correlative to "core" shales in cyclothems of the northern Midcontinent. The apparent restriction of [hyoliths] to this interval may reflect a preference for slightly oxygen-poor, offshore environments, and may aid in recognition and correlation of similar facies elsewhere in the North American Pennsylvanian. [165]

Polyphase Deformation of the Lynn Mountain Formation, Frontal Ouachitas of Oklahoma

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Two distinctive structural styles are evident within the Frontal Ouachita Mountains of Oklahoma. Some disruption of turbidite sequences within the Lynn Mountain Formation (equivalent to the lower Atoka Formation of Arkansas) can be attributed to folding and thrusting along the Ti Valley, Pine Mountain, and related faults. The asymmetric folds associated with these north-verging thrusts are also north-verging or upright. Other structures, however, occur on the limbs of such folds and clearly record a phase of deformation which preceded the foreland thrusting event. Early-phase structures include: (1) isoclinal folds and tight, asymmetric folds with steeply plunging fold axes, (2) folds which are completely overturned (e.g., antiformal synclines), (3) pinch-and-swell, boudinage, and necking of sandstone layers, (4) zones of shale injection, (5) incipient scaly argillite, and (6) web structure, which is defined by an anastomosing network of cataclastic surfaces within sandstone. Significantly, all of these structural features are characteristic of circum-Pacific subduction zones.

We believe the early-phase structural fabrics are accretionary in origin and resulted from tectonic deformation of poorly indurated sediments. The deformation probably occurred during the final phase of closure of the Ouachita trough, and the collisional event which followed then superimposed a foreland style of thrusting and folding on the primary accretionary fabrics. It is interesting to note that the accretionary deformation affected younger strata in Oklahoma, as compared to the Ouachitas of Arkansas. Similar fabrics are evident in Jackfork/Johns Valley strata within the Maumelle chaotic zone of Arkansas, but they are absent in the lower Atoka Formation. [166]

Phylogenetic Importance of Hydrodynamic Structures of Carboniferous Nautiloids

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Mineralized structures produced by Paleozoic nautiloid cephalopods to counter the inevitable excess positive buoyancy of long, chambered shells serve as one of the primary criteria for ordinal classification within this group. In terms of structural details, method of production, and morphological complexity, cameral and siphuncular deposits of Carboniferous orthoconic nautiloids represent one of the most complex and sensitive hydrodynamic systems used by either extinct or extant cephalopods to regulate the orientation of the shell. Comparisons of traditional taxonomic characters of extremely well preserved phragmocones from the Boggy Formation (Desmoinesian/Westphalian C) of southern Oklahoma with details of cameral and siphuncular deposits [reveal] that the collective morphology of cameral deposits throughout all or a portion of the ontogeny of individuals is a better and much more consistent expression of the true phylogenetic relationships among species, genera, and families than similar relationships based on external morphology, indices of expansion, etc. Under normal conditions of diagenesis, the critical characteristics of cameral deposits are well enough preserved to be observed in hand specimen or thin section. The already established connection between the genetically controlled physiochemical system of the nautiloid animal and production and function of cameral deposits based on empirical observations from more than 500 protoconchs, early chambers, and phragmocones, reveals that cameral deposits reflect phylogenetic relationships at least at the superspecific level. [166–167]

Deep-Water Atoka Depositional System, Frontal Ouachita Mountains

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The Atoka Formation is a key unit to interpreting the sedimentary and tectonic behavior along the Arkoma–Ouachita boundary because it crops out over both provinces. Two differing kinds of deep-sea fan systems provide a basic depositional model. The bulk of the clastics were

emplaced as part of a west-flowing axial fan system. These rocks consist mostly of interbedded turbidite sandstones and black shales that were developed as elongated, non-channelized lobes along topographic lows. In Arkansas, the lower lithic Atoka succession consists of 16,000′ of predominantly axial-fan clastics in the Fourche Mountain block whereas the same unit in the Dutch Creek Mountain block is around 7,000′, suggesting that growth-fault activity may have been active during the early Atokan.

Some thickly bedded sandstones appear to have been emplaced as grain and [liquefied] flows from marginal positions upon much higher slopes, thus are called slope fans. They are coarser grained, non-graded, and practically free of bedded shale but may contain shale or other clasts within sandstone beds. Petrographically, the two kinds of sandstones are perplexingly similar except that slope fans have higher SRF/MRF ratios. Outcrops of marginal fans form resistant, linear mountains such as [Horseshoe] Mountain (Ark.) and Blue Mountain (Okla.). The Red Oak sandstone produces gas from a slope fan located in the subsurface. Additional slope-fan sandstones probably remain to be discovered along the Arkoma basin–Frontal Ouachita boundary. [185]

Integrated Structural Model for the Broken Bow Uplift, Southeastern Oklahoma

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Recent structural studies within the Broken Bow Uplift suggest a unified polyphase evolution. This large northeast-trending structure is subdivided into four structural domains: Hochatown Dome, Carter Mountain Anticlinorium, Linson Creek Synclinorium, and Cross Mountain Anticlinorium. The lowest structural levels are exposed in the Hochatown Dome. Here and throughout the uplift, the earliest deformation is characterized by slaty cleavage and overturned folds. Within the lowest shale sequences large thrust sheets of Crystal Mountain Sandstone form a complex stack. Extension directions varied during thrust emplacement, with initial southeast extension giving way to southerly extension. The flanks of the Hochatown Dome reveal early deformation dominated by tight, southerly verging folds which have been coaxially refolded. This refolding is characterized by southerly directed faults, rotation of slaty cleavage, and flattening of the early fold limbs. In the Carter Mountain Anticlinorium, deformation is characterized by faulted folds. These northerly dipping faults are closely spaced and thought to be related to the coaxial refolding to the south. In the Linson Creek Synclinorium and Cross Mountains, an early cleavage is cut by high angle faults which change from northerly dipping in the south to southerly dipping in the north. This pattern forms a "fan" and is believed to be related to the Boktukola fault. Young northeast trending folds are characterized by crenulation cleavage in the southeast and by discrete kinks in the northwest. Late folding appears to include Basement uplift and to reactivate the northerly dipping faults of the Carter Mountain Anticlinorium, resulting in the observed normal separation. This structural model suggests that earliest deformation predates Central Zone thrust emplacement and that late deformation deforms these thrust sheets. [186]