

OKLAHOMA GEOLOGY

Oklahoma Geological Survey Vol. 49, No. 6 December 1989



On the cover—

Grooved Granites of the Western Wichita Mountains, Oklahoma

Horizontal grooves are developed at the bases of granitic hills, knobs, and boulders in the Lake Altus and Cooperton areas of the western Wichita Mountains, Oklahoma. The granite is Middle to Late Cambrian in age and belongs to the Wichita Granite Group. Lying with nonconformity on the granite surfaces are nearshore marine "red bed" shales and siltstones, with subordinate sandstones and conglomerates, of the Lower Permian Hennessey Formation.

The areal distribution of the grooved granites has been plotted by Merritt (1958) and Harrell and Twidale (in press). Most are found within a 15-km radius of Lake Altus; they are especially well developed on the north sides of Bird and King Mountains, and just east of Buzzard Roost Mountain (cover photo). The grooves occur in vertical flights that together extend through an elevation range of 50 m. With the exception of Bird Mountain, where the grooved surface originally had a 30-m vertical range, 10 m is about the maximum range of grooves at any one locality. Most of the grooves are horizontally disposed, the only exceptions being boulders and blocks that have been displaced through undermining and slumping. Many of the grooves are concave in section, but they also take the form of narrow benches or breaks of slope in the granite surface. The concave grooves vary in width from 0.02 to 1.5 m, and have depths of up to one half their width. Individual grooves can seldom be followed laterally for more than 10–15 m, because of poor preservation or burial beneath talus deposits. When the granite surfaces are broken by joint-controlled clefts the grooves penetrate to the full depths of the openings. The grooves frequently encircle granite boulders and knobs, but in only one instance completely encircle a hill.

(continued on p. 246)

OKLAHOMA GEOLOGICAL SURVEY

CHARLES J. MANKIN
Director

KENNETH S. JOHNSON
Associate Director

OKLAHOMA GEOLOGY NOTES

Editor

Christie Cooper

Geologist/Editor

Larry N. Stout

Publications Clerk

Diana Gilstrap

Cartography

T. Wayne Furr, *Manager*

James H. Anderson

Adam P. Radzinski

Charlotte Lloyd

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, \$1.50; yearly subscription, \$6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231–238. 1,800 copies have been prepared for distribution at a cost of \$1,474.70 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

OKLAHOMA GEOLOGY

C O N T E N T S

198

Grooved Granites of the Western Wichita Mountains, Oklahoma

200

**Geochemistry of Near-Surface Groundwater,
Great Salt Plains, Alfalfa County, Oklahoma**

C. B. Slaughter and R. D. Cody

224

New Underground Coal Mine Opens in Okmulgee County

LeRoy A. Hemish

228

**GSA South-Central Section Meeting
Stillwater, Oklahoma, March 4–6, 1990**

229

Upcoming Meetings

229

**New OGS Publications:
Geology of the Southern Midcontinent
Map of Oklahoma Oil and Gas Fields**

230

**Southern Midcontinent Hydrocarbons Workshop
Norman, Oklahoma, February 6–7, 1990**

233

Notes on New Publications

234

Oklahoma Abstracts

238

Index

OKLAHOMA
GEOLOGICAL
SURVEY

VOL. 49, NO. 6

DECEMBER 1989

GEOCHEMISTRY OF NEAR-SURFACE GROUND WATER, GREAT SALT PLAINS, ALFALFA COUNTY, OKLAHOMA

C. B. Slaughter¹ and R. D. Cody²

Abstract

Shallow ground water of the delta sediments adjacent to the western edge of the Great Salt Plains Reservoir of Alfalfa County, Oklahoma, is highly mineralized and contains chloride, sulfate, sodium, and calcium ions at concentrations that approach or temporarily exceed saturation. Lower Permian salt- and anhydrite-bearing sediments in the subsurface are thought to be sources of dissolved ions which are brought upward by artesian ground-water flow. Capillary draw raises these shallow brines to the surface, where halite and selenite gypsum are precipitated within the upper 1 m of the delta sediments.

Water samples and selenite crystals were collected over the southern two-thirds of the Great Salt Plains during early August and late December. The brine surface was encountered between ~0.5 m and 1.2 m below the ground surface. Water chemistry was highly variable and dependent on location, yearly season, and other, less obvious factors. Maximum chlorinity was ~190,000 ppm, and sulfate concentration maximum was ~6,000 ppm. The controlling factors causing abundant gypsum precipitation in the southern area and relatively sparse precipitation in the central and northern areas of the Great Salt Plains seem to be higher calcium and sulfate concentrations in the south. Sodium- and chloride-ion concentrations might also have an important effect on gypsum precipitation. The reason for higher calcium sulfate and lower sodium chloride in the south is unclear; there may be different ground-water sources for the three Great Salt Plains areas.

Introduction

The near-surface ground water of the Great Salt Plains (GSP) is highly mineralized and contains chloride, sulfate, sodium, and calcium ions at concentrations that approach and temporarily exceed saturation. Halite is precipitated on the ground surface, and gypsum crystals are precipitated just below the surface of the plains. The selenite gypsum precipitating below the surface of the salt plains possesses an unusual crystal morphology that differs in a number of ways from normal selenite. The most obvious difference is shortening parallel to the crystallographic *c* axis of the GSP crystals, which results in a bladed or hemibipyramidal habit (Cody and Cody, 1988; Naff, 1977) rather than the more typical prismatic habit. Second, pronounced hourglass-shaped patterns of sand and clay inclusions are visible in the selenite when viewed along the *c* axis (Naff, 1977). Each year

¹Iowa State University. Present address: U.S. Geological Survey, Salt Lake City.

²Dept. of Geological and Atmospheric Sciences, Iowa State University.

numerous mineral enthusiasts come to the GSP to collect these unusual selenite crystals. Equipped only with shovels, they dig shallow holes in a designated crystal-collecting area in their search for the crystals located approximately 2 cm to 60 cm below the surface (Fig. 1). During the winter, access to the GSP is limited because of wet and muddy conditions on the salt plains (Fig. 2). The objective of the present study was to gain a better understanding of the conditions leading to selenite crystallization in sediments of the Great Salt Plains, Alfalfa County, Oklahoma. This was accomplished by investigating the relationship between the occurrence of gypsum and the shallow ground-water chemistry within which the gypsum crystallizes.

Previous Work

Very little detailed work has been done on the relationship between ground-water chemistry and gypsum occurrence and morphology. Merritt (1935) was first to describe the crystallography of the GSP gypsum, but it was not until the late 1960s that the relationship between gypsum occurrence and near-surface ground-water chemistry was investigated. The first study was by Davis (1968), who conducted a study of environmental conditions affecting the occurrence of the bladed selenite crystals on the GSP. The near-surface ground water was sampled in June 1968; temperature, pH, salinity, and chlorinity were measured. Temperatures ranged from 30°C to 34°C, and pH (measured with Hydrion pH paper) was 5 for all samples. Salinities averaged 208,000 ppm where gypsum hourglass crystals were found.

In the early 1970s, concern over salt pollution in the Arkansas River and how salt control might affect selenite crystal growth prompted a study of the near-



Figure 1. Officially designated selenite-collecting area on the Great Salt Plains, August 1987. The surface is covered with white NaCl crust approximately 2–5 cm thick. The dark mounds result from holes dug by crystal-collectors.



Figure 2. The Great Salt Plains, December 1987. The light-colored areas are shallow-water pools with some unmelted snow. Salt crusts are absent over the plains during most of the winter months.

surface ground water of the GSP by Naff (1977). A grid of 16 test holes in the NE $\frac{1}{4}$ sec. 22, T. 26 N., R. 10 W., was laid out in September 1976 on the GSP. Chloride and sulfate averaged $\sim 130,000$ ppm and 5,900 ppm, respectively. The temperature of the water averaged $\sim 22^{\circ}\text{C}$. Naff (1977) believed that selenite crystallization resulted from the interaction of strong sodium chloride brines and calcium-sulfate-rich surface waters.

The Great Salt Plains

Geology

Western Oklahoma and the eastern part of the Texas Panhandle encompass 51,800 km² within the Anadarko basin (Gould, 1924). The northern element of the Anadarko basin has been called the Northern Oklahoma shelf by Arbenz (1956); this is the area in which the GSP are located.

The study area is underlain by Permian and Quaternary sediments. Permian strata of the Anadarko basin comprise Lower Permian (Wolfcampian) through the middle Permian (Leonardian and Guadalupian) beds, and possibly Upper Permian (Ochoan) beds (Jordan and Vosburg, 1963). In western Oklahoma, subsurface Lower Permian beds do not contain evaporites, but rather marine carbonates and shales, whereas in central Oklahoma the rocks are red shales and sandstones. Pre-Quaternary strata in the vicinity of the GSP dip regionally to the southwest and south into the Anadarko basin at 2–4 m/km (U.S. Army Corps of Engineers, 1981).

Three principal evaporite units overlie the Lower Permian beds (Jordan and Vosburg, 1963). The oldest evaporites are in the middle Permian Wellington Formation. The Wellington evaporites are overlain by the Cimarron and Beckham Formations, which both contain middle Permian evaporites. The Lower Cimarron Salt is the predominant evaporite below the surface in the vicinity of the GSP; the Lower Cimarron Salt occurs at depths ranging from 71 m to 244 m below the surface (U.S. Army Corps of Engineers, 1981). The evaporite units consist primarily of halite and anhydrite, the anhydrite being associated with thin beds of dolomite (Jordan and Vosburg, 1963). Shales and siltstones separate the Permian evaporites in the Anadarko basin. The combined thickness of the Wellington, Cimarron, and Beckham evaporites is 760 m, within a Permian sequence that is 1,200 m thick (Jordan and Vosburg, 1963). The Permian rocks are overlain by a thin covering of Quaternary alluvium and terrace deposits (Jordan and Vosburg, 1963).

Hydrogeology

The GSP encompasses an area of ~5,700 hectares in T. 26,27 N., R. 9,10 W., south of the Salt Fork of the Arkansas River in Alfalfa County, Oklahoma (Fig. 3). The GSP are formed by Quaternary sediments resting upon the Permian (Fig. 4); the sediments are a delta of varied and intertonguing beds of clay, sand, and gravel having a maximum thickness of 7.5 m (U.S. Army Corps of Engineers, 1981). East of the GSP is the Great Salt Plains Reservoir, which is impounded by a dam on the Salt Fork River in sec. 11, T. 26 N., R. 9 W. The surface of the salt plains slopes downward from west to east, with a gradient of 2–4 m/km (U.S. Army Corps of Engineers, 1981).

Meteoric water seeps into the ground west of the GSP and travels downward and laterally through Permian strata. In the path of the ground water, the evaporite deposits, chiefly halite and anhydrite, are dissolved and carried to the surface at the GSP by artesian flow (Johnson, 1981). The most probable source of the salt brine is the Lower Cimarron Salt, because of its proximity to the GSP (U.S. Army Corps of Engineers, 1981). The brine is discharged into the base of the Quaternary sediments under artesian conditions (Fig. 4).

In Alfalfa County, the lower Cimarron Salt consists of red-brown to gray shale and siltstone. The salt occurs mainly in veins, nodules, and isolated crystals or masses within these clastic rocks. The amount of halite in the formation varies from 40% west of the GSP to 10% at the eastern limit of the GSP. West of the GSP the halite occurs as discrete beds of rock salt 0.5–2.5 thick (U.S. Army Corps of Engineers, 1981).

Climate

Average annual precipitation is ~66 cm, most of which occurs between March and October. The mean annual temperature is 15°C. Winds generally are from a southerly or northerly direction in the region. Potential annual evaporation is ~239 cm. The greatest evaporation occurs between March and October, and the least amount of evaporation occurs during the winter months (Oklahoma Climatological Survey, 1988).

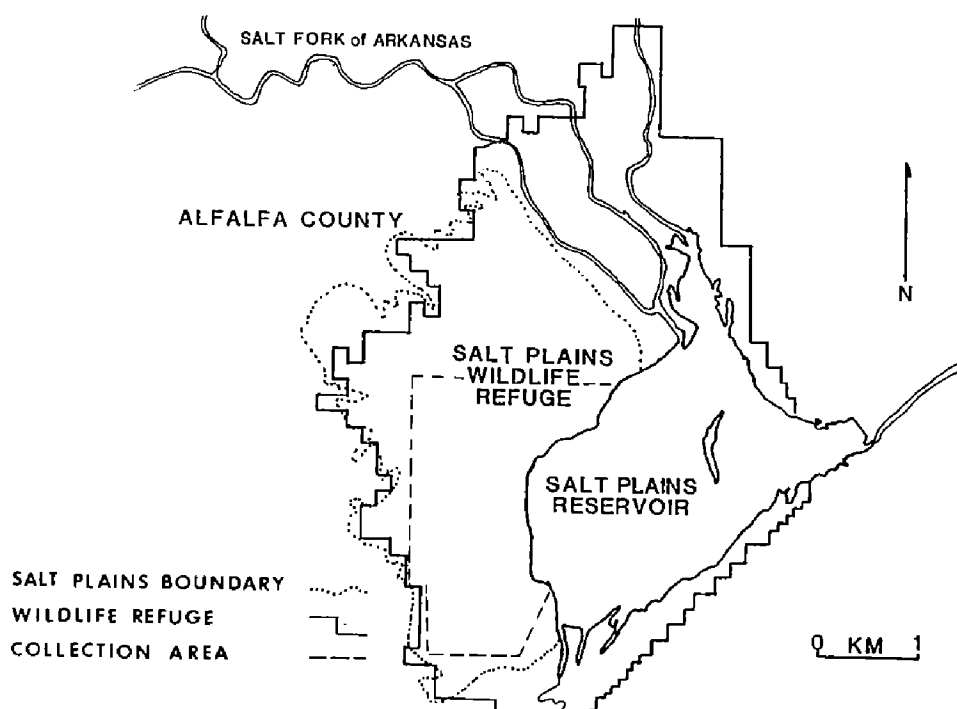
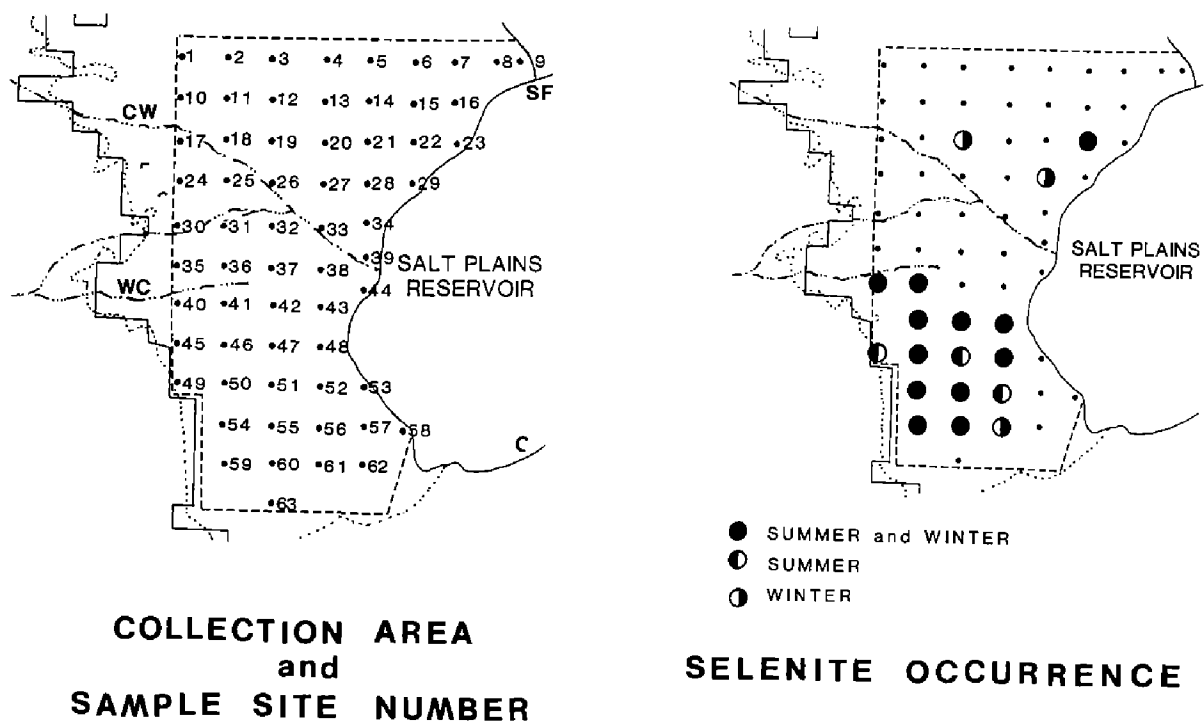


Figure 3. Index maps of the Great Salt Plains, showing the location of the Great Salt Plains, U.S. Department of the Interior Wildlife Refuge, sample-collection area with locations of numbered sample sites, and observed occurrences of gypsum crystals at each sample site. The general index map is modified from Davis (1968). On the collection-area/sample-site map, CW = Cottonwood Creek, WC = West Clay Creek.

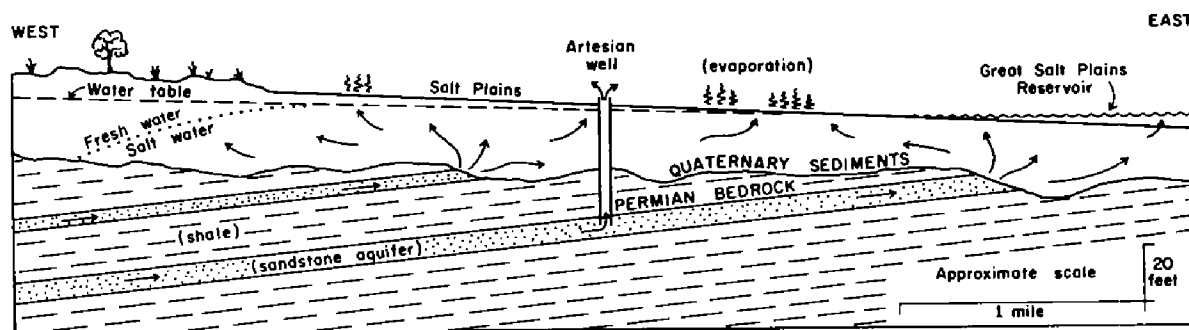


Figure 4. Schematic cross section of the Great Salt Plains area. Artesian water movement from the deeper subsurface is shown by arrows. From Johnson (1972).

Methods

Field Methods

Sampling of the near-surface ground water on the GSP was conducted first in early August and again in late December 1987. With the aid of a Brunton compass, a grid consisting of 63 sampling sites was laid out on the plains in August (Fig. 3). The sampling sites were marked with orange flagging to facilitate resampling of the grid in December. Streams crossing the salt plains, such as West Clay Creek and Cottonwood Creek, along with the Great Salt Plains Reservoir and Salt Fork of the Arkansas River, also were sampled during the summer and winter.

At each grid node, a hole was dug with a shovel until the water table was reached. Temperature, pH, and alkalinity were measured in situ. Alkalinity was determined volumetrically by titration, but only two analyses could be performed at the GSP because of adverse field conditions during the summer and winter. Water samples were collected in 250 ml plastic polyethylene bottles and stored under refrigeration to prevent post-collection changes in sulfate until later analysis at Iowa State University (ISU). Depth to the water table in the hole was measured after approximately 30 min to determine the water table surface of the ground water. Gypsum crystals encountered in the hole were collected and brought to ISU for further study. One potentially important factor not investigated in this study is the phosphorous concentration of the brines. Large numbers of bird guano mounds were seen in the water along the western edge of the GSP Reservoir in the winter, where they protruded above the water surface in water 3–4 cm deep. Similar mounds occur in other locations, but were not as noticeable. These mounds of phosphate-rich organic substances occur because large numbers of birds occupy the bird refuge at various times during the year.

Prior to field work in August, the GSP had received 72 cm of precipitation in 1987. Field work commenced on August 8 and continued through August 17. Trace amounts of rainfall occurred on August 10 and 13. Temperatures reached a high of 41°C; highs averaged 36°C during summer field work (Oklahoma Climatological Survey, 1988).

The winter resampling began on 30 December 1987 and continued through 4 January 1988. The GSP had received 114 cm of precipitation in 1987; no precipitation fell during the winter field work. Snow had fallen earlier in December; some snow cover was still present when winter field work commenced. The northern portion of the GSP was covered with 1–2 cm of water derived from snow melt upon our arrival on 29 December 1987. When field work commenced on 30 December, most of the water had disappeared, either by infiltration into the sediments or by surface runoff into the reservoir. Temperatures reached a low of -11°C ; lows averaged -7°C during the 6-day field period (Oklahoma Climatological Survey, 1988). The reservoir water level was slightly higher than during the August sampling period, so that 7 of the sites on the eastern edge of the summer grid were under water and could not be sampled.

Laboratory Methods

Hach Chemical analytical procedures were used in the laboratory to determine calcium, magnesium, sulfate, and chloride concentrations in the brine. Hach adapted these procedures from *Standard Methods for the Examination of Water and Waste Water* (Franson, 1980). The procedure used to determine sulfate concentration was a modification of the barium sulfate turbidimetric method. A mercuric nitrate method was used to analyze for chloride. Calcium and magnesium were determined with the EDTA Titrimetric method, and sodium was determined using a Perkins-Elmer Atomic Absorption Spectrophotometer.

Results

General

Gypsum crystals occurred primarily in the southern portion of the field area (Fig. 3). The gypsum exhibited three morphologies. In the southern part of the GSP, gypsum occurred either as massive layers or bladed crystals. In the northern and central portions of the GSP, the gypsum was either bladed with hourglass inclusions, similar to that described by Merritt (1935), or lenticular, as described by Naff (1977) and Davis (1968). The gypsum was located primarily in clay beds 2 cm to 0.5 m below the surface of the GSP. The clay beds are above the water table.

Surface-Water Chemistry

The composition of surface waters on the GSP was highly variable (Table 1). Cottonwood Creek, in the northern portion of the GSP, contained low concentrations of calcium, magnesium, sodium, and chloride but had high levels of sulfate in the summer and winter (1,025 ppm and 1,525 ppm, respectively). West Clay Creek contained chloride concentrations of 181,700 ppm in the summer and 73,900 ppm in the winter, similar to the ground water found on the GSP. Neither creek was sampled west of the GSP. The high ion concentrations of these creeks result from dissolution of surface salts on the GSP, and perhaps from inflow of shallow subsurface brines. The Great Salt Plains Reservoir during the summer con-

**TABLE 1.—SURFACE-WATER ANALYSES: RIVER AND CREEK SAMPLES
COLLECTED NEAR POINT OF ENTRY ONTO GREAT SALT PLAINS**

Sample ^a	Temperature (°C)	pH	Alkalinity (ppm)	Chloride (ppm)	Sulfate (ppm)	Calcium (ppm)	Magnesium (ppm)	Sodium (ppm)
SF-S	28	8.60	*	700	437	152	29	450
SF-W	1	8.30	*	2,200	255	176	58	1,275
SPR-S	26	8.33	*	2,700	420	128	63	1,750
SPR-W	1	8.16	*	17,700	1,062	280	156	11,400
CW-S	33	8.68	*	2,400	1,025	114	68	1,800
CW-W	0	8.03	*	8,200	1,525	408	204	5,200
WC-S	32	7.00	*	181,700	1,400	1,168	841	118,000
WC-W	3	7.51	*	73,900	2,700	672	321	47,000

^aS = summer; W = winter; SF = Salt Fork of Arkansas River; SPR = Salt Plains Reservoir; CW = Cottonwood Creek; WC = West Clay Creek.

tained low concentrations of chloride, sulfate, calcium, magnesium, and sodium; in the winter, chloride, sodium, and sulfate concentrations were substantially higher. Ephemeral surface streams flowing onto the GSP are highly migratory due to large and variable discharges during flooding season; for this reason, the precise locations of surface streams depicted on the maps in this study vary seasonally and annually. Because precise locations of the ephemeral streams are not known, ion concentration maps (Figs. 5–7) ignore any influence that these streams might have on ground-water composition.

Ground-Water Chemistry

Ground water was encountered 0.5 m to 1.2 m below the surface of the GSP. The piezometric surface slopes to the east (Fig. 6). Brine temperatures averaged 32°C during the summer and 5°C during the winter. During the summer, the pH of the brine ranged from 6.00 to 6.90, averaging 6.50. During the winter, brine pH varied between 6.25 and 7.54, averaging 6.80. Alkalinity was measured at 60 ppm during the summer and winter.

Analytical results are tabulated in Appendix 1; these data are shown in Figures 5–7 to depict lateral variation in ion concentrations over the GSP. The dominant ions in the ground water during both summer and winter are sodium and chloride (Fig. 5). Calcium, magnesium, and sulfate occur at comparatively lower concentrations in the GSP (Figs. 6, 7).

The GSP field area was divided into three parts to facilitate discussion of ion concentrations during the summer and winter. These areas are (1) north (sample sites 1–29); (2) central (sample site 30–44); and (3) south (sample sites 45–63). These areas were chosen because each is distinctly different in several features from the others.

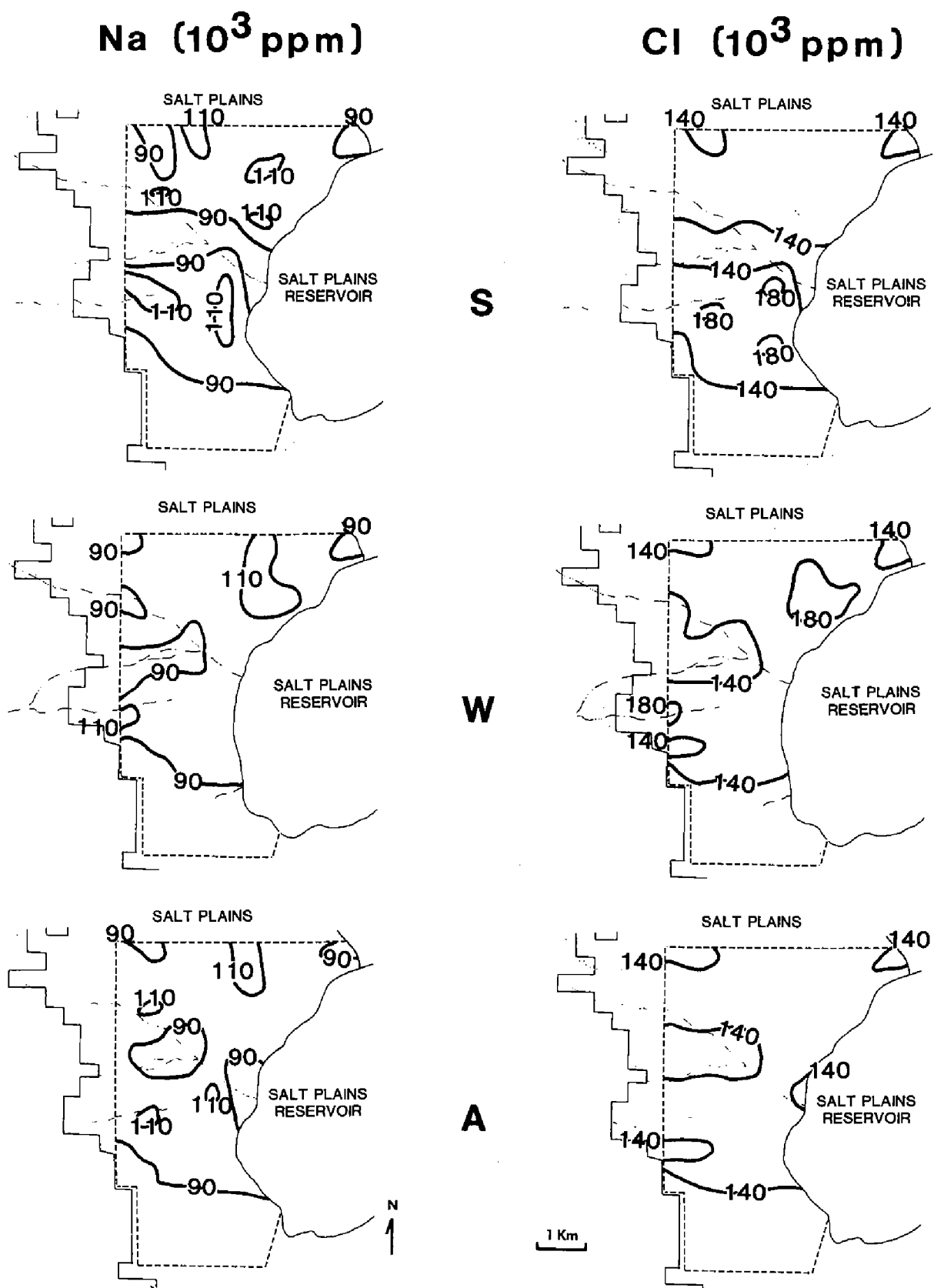


Figure 5. Sodium- and chloride-ion concentration in shallow ground water over the sample-collection area of the Great Salt Plains. The heavy solid lines represent equal ion concentrations. Concentrations in parts per million.

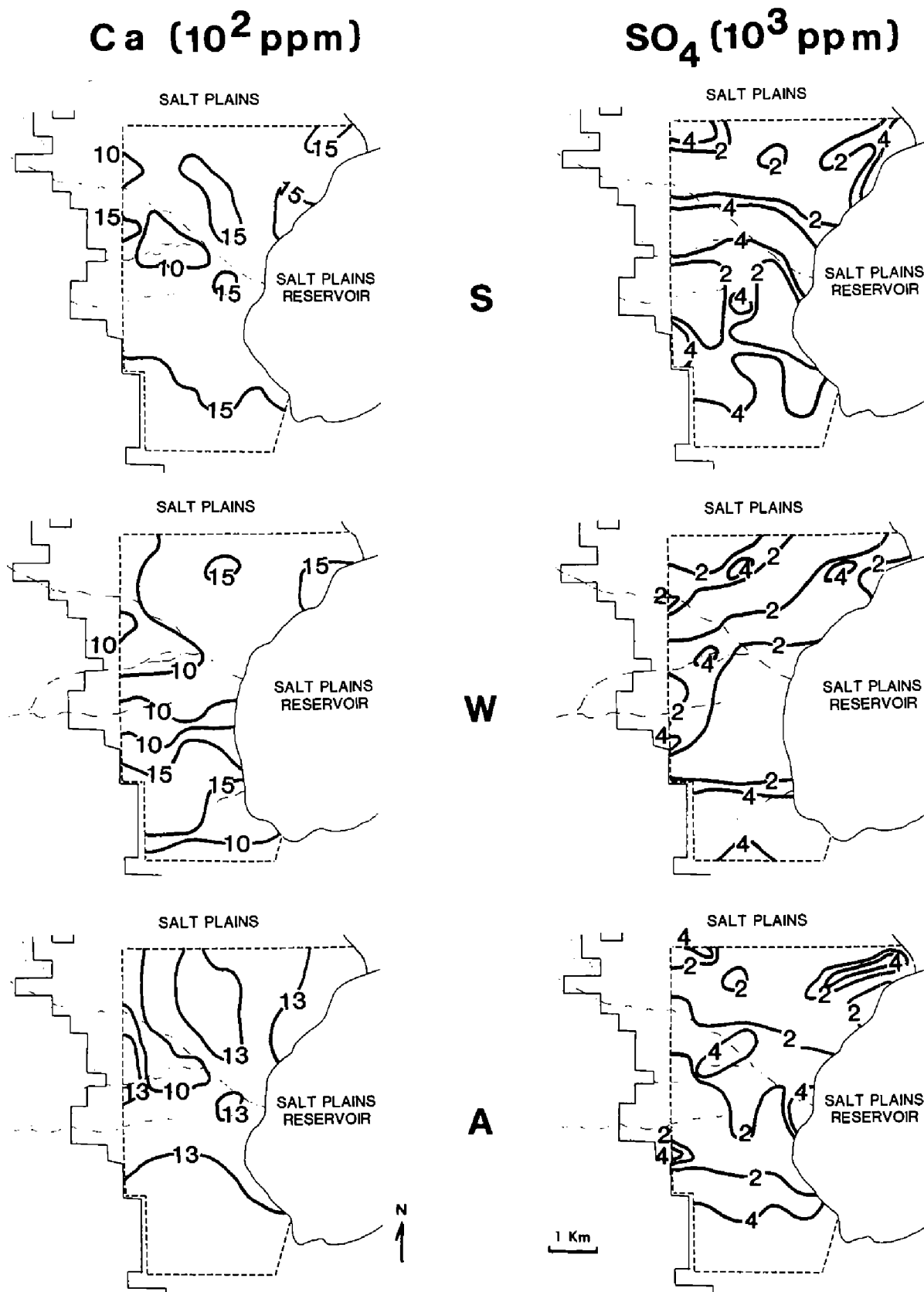


Figure 6. Calcium- and sulfate-ion concentration in shallow ground water over the sample-collection area of the Great Salt Plains. The heavy solid lines represent equal ion concentrations. Concentrations in parts per million.

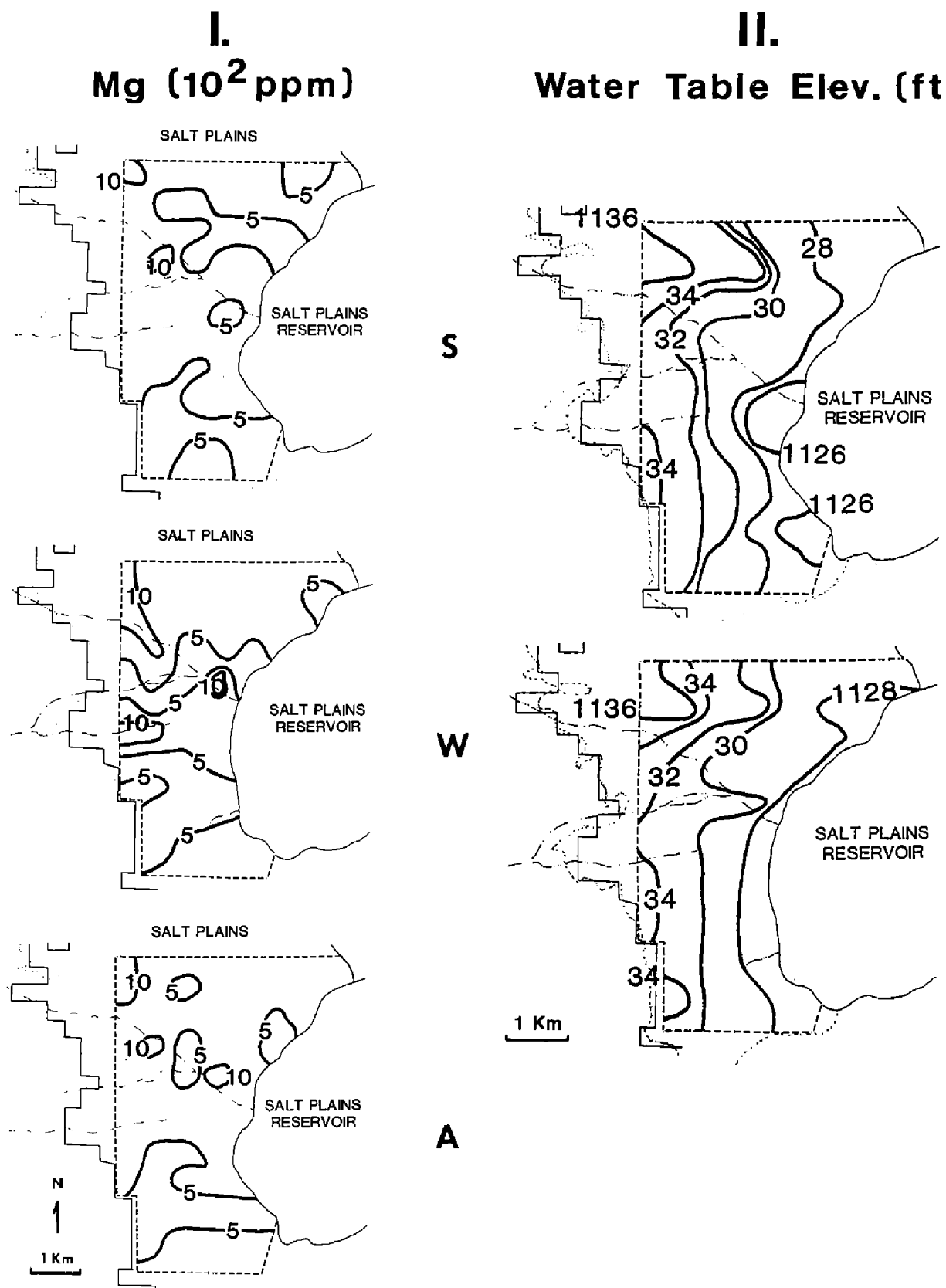


Figure 7. I—Magnesium-ion concentration in shallow ground water over the sample collection area of the Great Salt Plains. The heavy solid lines represent equal ion concentrations. Concentrations in parts per million. II—Elevation of the water table over the sample-collection area of the Great Salt Plains (in feet above sea level).

Summer Geographic Distribution of Ions

South Section

Gypsum was found at 13 of 19 sampling sites. Generally, low chloride concentrations were found in the south section. The average chloride concentration was 132,000 ppm, with a standard deviation (s.d.) of 23,500 ppm; the chloride concentration ranged from 185,000 ppm to 96,000 ppm. Sodium-ion concentrations were found to average 84,000 ppm, with a s.d. of 27,000 ppm; the sodium-ion concentrations ranged from 116,000 ppm to 62,000 ppm. Calcium concentrations were high in the south section. The average calcium concentration was 1,470 ppm, with a s.d. of 300 ppm; maximum and minimum calcium concentrations were 2,100 ppm and 1,040 ppm, respectively. Approximately 50% of the sites had magnesium concentrations of <450 ppm; the remainder had <750 ppm but >530 ppm. Magnesium averaged 520 ppm, with a s.d. of 160 ppm; the high magnesium concentration was 730 ppm, and the low was 240 ppm. Sulfate concentrations were high in the south section. Sulfates averaged 3,700 ppm, with a s.d. of 1,300 ppm; the sulfate concentrations ranged between a high of 6,200 ppm and a low of 1,300 ppm.

Central Section

Gypsum was found in 2 of 15 sampling sites. Chloride concentrations varied greatly, from a high of 182,000 ppm to a low of 61,000 ppm. The chloride concentrations averaged 142,000 ppm, with a s.d. of 35,000 ppm. Sodium concentrations averaged 93,000 ppm, with a s.d. of 23,000 ppm, ranging between 125,000 ppm and 39,000 ppm. Calcium concentrations showed little variation in the central section, with the exception of two isolated areas, one containing the section's low of 480 ppm and the other containing the section's high of 1,520 ppm. The mean concentration of calcium was 1,120 ppm, with a s.d. of 220 ppm. Magnesium concentrations ranged from a low of 440 ppm to a high of 920 ppm. The average magnesium concentration was 650 ppm, with a s.d. of 190 ppm. Sulfate concentrations varied greatly throughout the central region, ranging between 5,700 ppm and 1,200 ppm. The average sulfate concentration was 3,300 ppm, with a s.d. of 1,600 ppm.

North Section

Gypsum was found in 1 of 20 sampling sites. Chloride concentrations were high throughout the north section. The average chloride concentration was 155,000 ppm, with a s.d. of 32,000 ppm; chloride concentrations ranged from a high of 178,000 ppm to a low of 120,000 ppm. Sodium concentrations in this section averaged 98,000 ppm, with a s.d. of 11,000 ppm, ranging from a high of 117,000 ppm to a low of 75,000 ppm. Calcium concentrations ranged between 880 ppm and 1,920 ppm in the north region. The average calcium concentration was 1,300 ppm, with a s.d. of 240 ppm. Magnesium concentrations varied greatly throughout the north section. The average magnesium concentration was 660 ppm, with a s.d. of 260 ppm. Magnesium concentrations ranged between 1,360 ppm and 190 ppm. Sulfate concentrations were found to vary throughout the north section. The aver-

age sulfate concentration was 2,500 ppm, with a s.d. of 1,450 ppm, ranging between 5,500 ppm and 1,100 ppm.

Winter Geographic Distribution of Ions

South Section

Gypsum was found in 10 of 15 sampling sites. The chloride concentrations were low in the region. Chloride concentrations ranged between a high of 154,000 ppm and a low of 56,000 ppm. The average chloride concentration was 123,000 ppm, with a s.d. of 26,000 ppm. Sodium concentrations were low in the south section. The average sodium concentration was 78,000 ppm, with a s.d. of 13,000 ppm. The high and low sodium concentrations were 98,000 ppm and 56,000 ppm, respectively. Calcium concentrations were high in the region. The average concentration was 1,430 ppm, with a s.d. of 390 ppm, ranging between 1,920 ppm and 320 ppm. Approximately 50% of the sampling sites yielded magnesium concentrations <490 ppm; the remainder had >530 ppm but <830 ppm. The average magnesium concentration was 520 ppm, with a s.d. of 200 ppm, ranging between 880 ppm and 140 ppm. Average sulfate concentration was 3,000 ppm, with a s.d. of 1,700 ppm, ranging between a high of 5,200 ppm and a low of 1,100 ppm.

Central Section

Gypsum was found in 2 of 12 sampling sites. Chloride concentrations were found to have a high variability in this section. The average chloride concentration was 146,000 ppm, with a s.d. of 45,000 ppm; chloride concentrations ranged between a high of 180,000 ppm and a low of 133,000 ppm. Sodium concentrations had a high variability in the section. The average sodium concentration was 92,000 ppm, with a s.d. of 29,000 ppm; sodium concentrations ranged between 116,000 ppm and 21,000 ppm. The average calcium concentration was 1,000 ppm, with a s.d. of 240 ppm. Calcium concentrations ranged between a high of 1,400 ppm and a low of 400 ppm. Magnesium concentrations were found to vary greatly throughout this region. The average magnesium concentration was 730 ppm, with a s.d. of 290 ppm, ranging between 1,200 ppm and 200 ppm. Sulfate concentrations varied moderately in the region. The average sulfate concentration was 1,800 ppm, with a s.d. of 870 ppm; sulfate concentration ranged between a high of 4,400 ppm and a low of 1,100 ppm.

North Section

Gypsum was found in 3 of 28 sampling sites. Chloride concentrations were high and varied moderately throughout the region. The average chloride concentration was 160,000 ppm, with a s.d. of 18,000 ppm, ranging between a high of 187,000 ppm and a low of 114,000 ppm. Sodium concentrations were moderately variable in the region. The average sodium concentration was 99,000 ppm, with a s.d. of 10,000 ppm, ranging between 116,000 ppm and 76,000 ppm. Calcium concentrations showed little variation in the section. The average calcium concentration was 1,230 ppm, with a s.d. of 240 ppm, ranging between a high of 1,840 ppm and a low of 800 ppm. Magnesium concentrations varied moderately in the region.

The average magnesium concentration was 790 ppm, with a s.d. of 280 ppm, ranging between 1,460 ppm and 490 ppm. Sulfate concentration varied substantially in the region. The average sulfate concentration was 2,300 ppm, with a s.d. of 1,060 ppm, ranging between a high of 5,050 ppm and a low of 1,400 ppm.

Discussion

Geographic Distribution

Statistical analyses of the ground-water-chemistry data base (Appendix) were conducted to determine whether the ground-water compositions of the three sections of the GSP differ significantly. To determine this, a test for significance was run on the means given in Table 2; the F-statistics were used to test for differences. The program used, "Statistical Analysis Systems" (SAS, 1986), was compiled on a NAS 9000 computer at Iowa State University.

The regional climate of extremely high evaporation and very low precipitation favors gypsum precipitation, but seasonal effects on gypsum precipitation are uncertain. In order to gain a better understanding of these effects, summer, winter, and annual analyses were compared by area. A summary of the statistical analysis is given in Tables 2 and 3; the results are discussed in the following sections.

Summer

Calcium concentrations differ significantly in each area during the summer. No other significant difference in ion concentrations exists between the central and north areas. Between the south and central areas, no significant differences occur for sulfate, sodium, chloride, or magnesium. Significant summer differences also exist between the south and north areas in sodium, chloride, sulfate, and magnesium concentrations, in addition to calcium.

Winter

During the winter, differences in the ground-water chemistry between the south and other areas of the GSP are far more pronounced than during the summer. Significant differences in the ground-water chemistry for all variables except pH and temperature occur between the south and central areas. Differences occur in sodium, chloride, and magnesium between the south and the north. There were no differences in sulfate, pH, and temperature between the south and north. No differences exist between the north and central areas during the winter, except for pH.

During both summer and winter, the south section contained the lowest mean chloride, sodium, and magnesium concentrations and the highest mean calcium and sulfate concentrations in the GSP. Chemical differences between the south and other areas are more evident during winter than during summer. The effects of the seasons on gypsum precipitation are unclear. It seems that both summer and winter might be important in precipitation and potential growth of gypsum below the GSP because differences in ground-water chemistry, in particularly calcium, are maintained throughout the year among the three areas.

TABLE 2.—SUMMARY OF GROUND-WATER ANALYSES

Geographic areas	Ground-water chemistry (ion concentrations in ppm)						Temp. (°C)
	Na	Ca	Mg	Cl	SO ₄	pH	
<i>South</i>							
Summer							
mean	83,631	1,469	520	131,579	3,665	6.55	31
s.d.	27,257	297	156	23,459	1,312	0.23	1.0
Winter							
mean	77,600	1,434	522	122,767	3,046	6.85	5
s.d.	13,388	391	202	25,975	1,653	0.38	1.6
Annual							
mean	80,970	1,454	521	127,691	3,392	6.68	19
s.d.	14,511	254	124	23,947	1,243	0.25	0.8
<i>Central</i>							
Summer							
mean	93,400	1,120	648	142,373	3,326	6.61	32
s.d.	23,303	222	193	34,903	1,565	0.30	1.3
Winter							
mean	91,846	1,034	728	145,538	1,842	7.01	4
s.d.	28,557	241	285	45,431	872	0.43	2.0
Annual							
mean	92,679	1,080	685	143,842	2,588	6.79	19
s.d.	23,266	314	151	36,096	1,211	0.40	1.2
<i>North</i>							
Summer							
mean	98,678	1,296	656	155,053	2,509	6.50	32
s.d.	10,860	239	259	32,444	1,467	0.14	1.4
Winter							
mean	99,148	1,232	793	157,574	2,297	6.77	5
s.d.	10,204	241	278	18,278	1,065	0.22	1.8
Annual							
mean	98,909	1,265	723	156,290	2,400	6.63	19
s.d.	9,044	188	243	14,492	1,042	0.15	0.9

Annual

Ground-water composition in the three areas varies between summer and winter. However, gypsum crystals persist during the entire year, so that averaging summer and winter seasonal data might yield more information about gypsum precipitation in a given section. Annual means found indicate that the south section ground-water chemistry is different from that of both the north and central sections in all aspects, except for pH and temperature. The central and north areas differ only in calcium, chloride, and pH. Ground waters in the south are low in chloride, sodium, and magnesium and high in calcium and sulfate. The north and central areas contain high concentrations of sodium, chloride, and magnesium in conjunction with low levels of calcium and sulfate.

TABLE 3.—CORRELATIONS BETWEEN SEASONS AND GROUND-WATER CHEMISTRY

Geographic areas	Ground-water chemistry						Temp. (°C)
	Na	Ca	Mg	Cl	SO ₄	pH	
<i>Annual</i>							
South—central	**	**	**	**	**		
South—north	**	**	**	**	**		
Central—north		**		**		**	
<i>Summer</i>							
South—central		**					
South—north	**	**	**	**	**		
Central—north		**					
<i>Winter</i>							
South—central	**	**	**	**	**		
South—north	**	**	**	**			
Central—north						**	

**Comparisons significant using F-statistics at the 0.05 level; confidence = 0.95.

Ground-Water Variability

The composition of the near-surface ground water at the GSP varies laterally throughout the salt plains (Figures 5–7). Heterogeneity of the ground water suggests that the geohydrology of the GSP is far more complex than previously thought. Because little is known about the GSP, highly tentative hypotheses will be proposed with the understanding that these hypotheses are based almost entirely on the ground-water-composition data gathered in this study.

Surface waters on the GSP might have an effect on the near-surface ground-water chemistry. Dilute surface water may enter the GSP sediments by flooding from the adjacent reservoir, by runoff from small creeks flowing from the south or west onto the GSP, and by rainfall and snowfall on the GSP surface. Even minor increases in the water level of the reservoir may flood large areas of the salt plains because of the subdued topography and minor elevation differences between the flats and normal reservoir water levels. Small creeks flowing onto the GSP will certainly affect more localized areas than reservoir flooding, but significant amounts of dilute water may reach large areas of the plains during times of heavy rainfall and snow melt. Water derived from snow and rain on the GSP will cover the largest areas, and should result in the least-localized dilution of the subsurface brines compared to the other sources of dilute water.

The effects of dilute surface waters on the near-surface ground-water concentrations will be influenced both by GSP topography and by sediment character, since the sediments are the conduit into the subsurface. Topographic lows will be loca-

tions where dilute waters tend to accumulate, so that infiltration will be most likely if the sediments are permeable.

The sediments of the GSP are complexly varied, intertonguing, and discontinuous beds of clay, sand, and gravel with varying permeability and porosity (U.S. Army Corps of Engineers, 1981). Because the ionic strength of the surface waters at the GSP is substantially lower than that of the ground water, the surface waters should mainly serve to dilute ground water. However, only at a single sampling site (#32) on the GSP was dilution by surface streams evident from the analytical data. Thus, surface waters at the GSP do not seem to be a major influence on ground-water composition in the area.

In addition to surface-water infiltration and sediment character, another factor that may be important in controlling lateral variations of ground-water composition is mineral precipitation, which acts as an ion sink. Gypsum precipitation will remove calcium and sulfate; calcite or aragonite precipitation will remove calcium and carbonate; iron sulfide will remove sulfate (although reducing conditions are necessary); and halite precipitation will remove sodium and chloride from the ground water. No mineral studies on the sediments were performed; thus, mineral precipitation from ground water cannot be evaluated, although it may be important.

Variations in ground-water composition in the GSP also might result from multiple ground-water sources with different chemical signatures. Many samples—especially in the south section, but also at other locations—exhibit an inverse relationship between calcium sulfate and sodium chloride concentrations. Jordan and Vosburg (1963) found from data obtained by drilling that subsurface evaporite sequences vary laterally in their relative proportions of gypsum and halite. Artesian subsystems flowing through strata with different relative amount of gypsum and halite might produce the observed ion-concentration differences in the GSP brines if these subsystems are not completely mixed and homogenized in the very shallow Great Salt Plains ground-water environment.

Gypsum Occurrence

Based on the seasonal averages, it appears that gypsum precipitation occurs primarily in the south section and only sporadically in the central and north sections of the GSP, because of higher calcium and sulfate concentrations in the south. Sodium and chloride ions may also have an important effect on gypsum precipitation on the salt plains. Higher concentrations of sodium chloride could either prevent or enhance gypsum growth because of its effect on calcium- and sulfate-ion activity coefficients. As sodium chloride concentrations increase at low ionic strength, calcium- and sulfate-ion activity coefficients become >1 , so that gypsum solubility increases. However, at very large sodium chloride concentrations the activity coefficients should become >1 , so that gypsum solubility will decrease. Fluctuations of sodium and chloride ions would obviously have an effect on gypsum by lowering and raising solubility of gypsum. Even though calcium and sulfate ions might remain relatively constant throughout the year, variation in sodium- and chloride-ion concentrations might influence gypsum formation.

It has been proposed (Naff, 1977) that gypsum precipitation in the GSP results from the interaction of sodium chloride brines (ground water) and calcium-sulfate-

rich surface waters. Our results do not support this hypothesis. The primary source of calcium and sulfate ions in West Clay Creek is probably the ground water, not dissolution of surface gypsum to the west as proposed by Naff (1977). Naff (1977) did not sample surface streams flowing on the GSP; he obtained water samples at sites near West Clay Creek and Cottonwood Creek. Our analysis of water from West Clay Creek during the summer shows that the stream water contained a chloride concentration of 182,000 ppm. Near-surface ground water sampled within 10 m of the stream had a chloride concentration of 162,000 ppm. Ion concentrations of calcium, magnesium, and sulfate also were similar to each other in both the stream and ground water. Because of the similarity in ion concentrations between the ground water and the stream, and because both waters are similar in overall character to other ground waters in the GSP, it appears that ground water flows into West Clay Creek, rather than the reverse. Halite crystals were growing on the floor of this stream, submerged under ~2 cm of stream-water brine for a distance of ~30 m upstream and downstream from the sampling site. The high ion concentrations are not believed to be from outside the GSP because halite crystal growth was localized and not found farther than 30 m upstream of the sampling site. If the high concentrations were from outside the GSP, halite crystals likely would have precipitated farther than 30 m upstream.

Halite crystals on the surface of the GSP are another possible source which may be contributing sodium and chloride ions to the streams. Halite crystals precipitated on the surfaces of salt plains frequently are windblown. Falling into a stream, a halite crystal dissolves, contributing sodium and chloride ions to the stream. It is unlikely that windblown halite contributes sufficient sodium and chloride ions to account for the high concentrations seen in West Clay Creek. Such a close similarity would not be expected between West Clay Creek waters and the general ground-water composition at the GSP if windblown halite was the primary source of sodium chloride in West Clay Creek. Also, an explanation of why only 60 m of the stream channel contains high enough levels of sodium and chloride for halite precipitation would be required. In addition, the low sodium and chloride concentrations of other local creeks seem to contradict a general windblown source of sodium chloride for the surface streams.

Cottonwood Creek was found to contain low concentrations of chloride, sodium, calcium, and magnesium but sulfate concentrations of 1,025 ppm and 1,525 ppm in summer and winter, respectively. The origin of elevated sulfate-ion concentrations in Cottonwood Creek is uncertain. Ground water 10 m south of Cottonwood Creek has sulfate concentrations that are 455 ppm and 3,275 ppm higher than that of the stream during both summer and winter, respectively; thus, significant contamination from ground water can be ruled out. The high sulfate concentration in Cottonwood Creek may result from dissolution of surface gypsum crystals located west of the GSP, but this hypothesis requires an explanation for low calcium in the stream. Low calcium could result from calcite precipitation in the stream. Although calcite precipitation was not evident through visual inspection of the stream sediment, it cannot be ruled out, because no detailed mineral analysis was performed on these sediments.

Contrary to Naff's (1977) hypothesis, in the few documented instances where surface streams have mixed with the ground water, the mixing does not result in the formation of selenite crystals in the shallow subsurface environment. Gypsum oc-

curs primarily in the southern area of the salt plains where no surface streams are present. The cause of the unusual gypsum habit is not yet clear, because the ion concentrations determined in this study are not particularly different from these in other areas of more common gypsum habits (Cody, 1988).

Conclusion

Before this study was undertaken, the consensus of those familiar with the GSP was that gypsum crystals occurred only in the south. This study confirms that gypsum precipitation is more abundant and widespread in the south section, but demonstrates that gypsum precipitation also occurs in the central and north sections of the GSP; the controlling factors seem to be higher calcium and sulfate concentrations in the south. Sodium- and chloride-ion concentrations might also have an important effect on gypsum precipitation. The explanation for the higher calcium and sulfate and lower sodium and chloride concentrations in the south is uncertain; the differences may be due to different ground-water sources for the three GSP areas. Streams flowing eastward onto the GSP do not seem to be important in gypsum precipitation, because these streams are not calcium- or sulfate-rich, as suggested by Naff (1977). Causes of the unusual GSP gypsum habit are not yet clear, because the ion concentrations in the area are not much different from those of areas where more-common gypsum habits occur (Cody, 1988).

Acknowledgments

We thank Brian Gedlinski and David Hamilton for invaluable assistance in the field. The work benefited from comments of Drs. Robert Stewart, Charles Oulman, and Steven Richardson, Iowa State University. We especially thank Dr. David Bohlen, Department of Chemistry, Northwest Oklahoma State University, for kindly providing use of laboratory facilities during summer field work. M. Dale Streigle, Ken McFadden, John Knightly, Keith Kutz, Sheryl Howe, and Xiaoyun Cau, graduate students at Iowa State University, provided helpful comments and assistance at various stages of the study. We thank the U.S. Fish and Wildlife Service, and Rod Krey, Refuge Manager at the Salt Plains National Wildlife Refuge, for the opportunity to conduct the study and for the use of a field vehicle during the summer work.

References Cited

- Arbenz, J. K., 1956, Tectonic map of Oklahoma: Oklahoma Geological Survey Map GM-3, scale: 1:750,000.
- Cody, R. D.; and Cody, A. M., 1988, Gypsum nucleation and crystal morphology in analogy in analog terrestrial environments: *Journal of Sedimentary Petrology*, v. 58, p. 247–255.
- Davis, J. L., 1968, Meteorologic and hydrologic relationships on the Great Salt Plains of Oklahoma: *Oklahoma Geology Notes*, v. 28, p. 163–168.
- Franson, M. A., 1980, Standard methods for the examination of water and wastewater: American Public Health Association, Washington, D.C.

- Gould, C. N., 1924, A new classification of the Permian redbeds of southwestern Oklahoma: American Association of Petroleum Geologists Bulletin, v. 8, p. 144–153.
- Johnson, K. S., 1981, Dissolution of salt on the west flank of the Permian basin in the southwestern U.S.A.: Journal of Hydrology, v. 54, p. 75–93.
- Jordan, Louise; and Vosburg, D. L., 1963, Permian salt and associated evaporites in the Anadarko basin of the western Oklahoma–Texas Panhandle region: Oklahoma Geological Survey Bulletin 102, 76 p.
- Merritt, C. A., 1935, Gypsum crystals from Alfalfa County, Oklahoma: American Mineralogist, v. 20, p. 674.
- Naff, J. D., 1977, Selenite crystal effects assessment, Ark–Red River basin chloride control, Ark River basin: Unpublished report, Dept. of Geology, Oklahoma State University, 55 p.
- Oklahoma Climatological Survey, 1988, Unpublished data: Oklahoma Climatological Survey, University of Oklahoma.
- Statistical Analysis Systems, 1986, SAS Institute Inc., Cary, North Carolina.
- U.S. Army Corps of Engineers, 1981, Arkansas–Red River basin chloride control: U.S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma, v. 1–4.

APPENDIX: GREAT SALT PLAINS BRINE ANALYSES

SAMPLE NUMBER	TEMPERATURE (degrees C)	pH	ALKALINITY (ppm)	CHLORIDE (ppm)	SULFATE (ppm)	CALCIUM (ppm)	MAGNESIUM (ppm)	SODIUM (ppm)	GYPSUM (yes/no)
1-S	32	6.50	*	141,000	4,900	1,120	1,021	95,000	NO
1-W	3	7.25	*	137,000	1,790	800	1,459	89,000	NO
2-S	31	6.51	*	134,000	4,550	1,021	535	86,000	NO
3-S	32	6.50	*	178,000	1,400	1,360	583	117,000	NO
3-W	7	6.72	*	162,000	1,280	1,280	729	98,000	NO
4-S	33	6.32	*	174,000	1,350	1,040	972	106,000	NO
4-W	7	6.73	*	143,000	2,600	1,120	875	93,000	NO
5-S	33	6.45	*	165,000	1,400	1,040	923	105,000	NO
5-W	6	6.74	*	178,000	1,900	1,040	972	116,000	NO
6-W	6	6.50	*	159,000	1,500	1,200	826	105,000	NO
7-S	34	6.40	*	164,000	1,330	1,520	340	107,000	NO
7-W	5	6.67	65	157,000	1,290	1,120	681	95,000	NO
8-S	31	6.50	*	132,000	4,150	1,440	729	80,000	NO
8-W	7	6.25	60	115,000	3,900	1,440	826	77,000	NO
9-S	27	6.40	*	127,000	4,600	1,520	729	84,000	NO
SF-S	28	8.60	*	700	437	152	29	450	NO
SF-W	1	8.30	*	2,200	255	176	58	1,275	NO
10-S	32	6.40	60	145,000	1,100	960	972	93,000	NO
10-W	6	6.53	*	172,000	2,030	880	1,439	106,000	NO
11-S	30	6.50	60	145,000	1,290	1,360	389	88,000	NO
11-W	7	7.03	*	157,000	1,900	1,200	681	95,000	NO
12-S	32	6.10	*	165,000	1,550	1,520	340	105,000	NO
12-W	5	6.77	*	151,000	4,100	1,280	632	95,000	NO
13-S	32	6.50	*	169,000	2,290	1,200	681	106,000	NO
13-W	3	6.80	*	164,000	1,590	1,600	778	107,000	NO
14-S	32	6.50	*	171,000	1,320	1,040	826	112,000	NO
14-W	5	7.04	*	187,000	1,450	1,200	826	116,000	NO
15-S	31	6.30	*	158,000	3,000	1,280	729	107,000	NO
15-W	7	6.50	*	158,000	5,050	1,200	729	98,000	NO
16-S	32	6.50	*	155,000	1,220	1,200	729	101,000	NO

16-W	7	6.55	*	178,500	1,400	1,840	340	109,000	NO
SPR-S	26	8.33	*	2,700	420	128	63	1,750	NO
SPR-W	1	8.16	*	17,700	1,062	280	156	11,400	NO
17-S	34	6.80	*	157,000	1,480	1,280	778	105,000	NO
17-W	-1	6.80	*	136,500	4,800	880	1,070	83,000	NO
CW-S	33	8.68	*	2,400	1,025	114	68	1,800	NO
CW-W	0	8.03	*	8,200	1,525	408	204	5,200	NO
18-S	33	6.40	*	176,000	1,680	1,360	535	114,000	NO
18-W	3	6.55	*	175,500	1,350	1,040	924	107,000	NO
19-S	31	6.80	*	173,000	1,310	1,200	729	109,000	NO
19-W	5	6.95	*	161,000	1,520	1,200	681	98,000	YES
20-S	32	6.60	*	176,000	1,400	1,520	340	109,000	NO
20-W	5	7.08	*	156,000	1,500	1,360	681	98,000	NO
21-S	34	6.51	*	147,000	1,310	1,280	487	91,000	NO
21-W	3	6.95	*	186,000	2,195	1,040	924	112,000	NO
22-S	31	6.50	*	163,000	1,570	1,920	292	97,000	YES
22-W	6	7.06	*	181,000	2,180	1,360	535	114,000	YES
23-S	31	6.50	*	153,400	4,400	1,200	729	97,000	NO
23-W	6	6.82	*	165,000	2,300	1,760	525	103,000	NO
24-S	32	6.50	*	139,000	5,500	1,520	583	86,000	NO
24-W	4	6.98	*	138,000	1,700	1,360	583	93,000	NO
25-S	32	6.60	*	141,000	4,440	880	1,361	86,000	NO
25-W	3	6.71	*	150,000	1,800	960	1,410	96,000	NO
26-S	31	6.50	*	120,100	4,400	1,200	438	75,000	NO
26-W	3	6.50	*	114,000	3,950	1,200	486	76,000	NO
27-S	32	6.60	*	144,000	4,500	1,520	681	89,000	NO
27-W	6	6.75	*	161,000	2,400	1,360	681	100,000	NO
28-S	34	6.65	*	173,000	1,340	1,120	729	115,000	NO
28-W	4	6.88	*	154,000	2,100	1,440	486	97,000	NO
29-S	34	6.60	*	156,000	1,480	1,680	194	98,000	NO
29-W	3	6.83	*	158,000	2,180	1,120	632	101,000	NO
30-S	31	6.80	*	135,200	4,600	1,360	632	90,000	NO
31-S	29	7.40	*	60,700	4,100	480	535	39,000	NO
31-W	1	7.54	*	60,000	4,400	720	729	39,000	NO
32-S	31	7.20	*	75,000	3,800	960	632	49,000	NO
32-W	3	7.56	*	33,000	1,770	400	195	21,000	NO
33-S	32	6.40	*	138,000	4,400	1,120	923	91,000	NO

APPENDIX: Continued

SAMPLE NUMBER	TEMPERATURE (degrees C)	pH	ALKALINITY (ppm)	CHLORIDE (ppm)	SULFATE (ppm)	CALCIUM (ppm)	MAGNESIUM (ppm)	SODIUM (ppm)	GYPSUM (yes/no)
33-W	7	6.37	*	157,000	1,180	1,120	1,118	100,000	NO
34-S	32	6.50	*	128,000	4,100	1,120	632	86,000	NO
34-W	7	7.70	*	182,000	1,580	1,360	389	115,000	NO
35-S	31	6.40	*	173,000	1,310	1,040	632	116,000	NO
35-W	2	6.80	*	142,000	1,110	1,120	535	90,000	NO
36-S	31	6.55	*	166,000	1,450	1,200	729	109,000	NO
36-W	3	7.09	*	162,500	2,050	1,120	486	105,000	NO
37-S	31	6.50	*	159,000	3,800	1,120	729	104,000	NO
37-W	5	7.05	*	152,000	1,600	1,360	778	97,000	NO
38-S	33	6.35	*	182,000	1,390	1,520	437	118,000	NO
38-W	6	7.04	*	165,000	1,280	1,120	924	103,000	NO
39-S	31	6.40	*	124,000	4,500	1,040	680	81,000	NO
40-S	34	6.70	*	162,000	1,200	1,200	681	103,000	YES
40-W	3	6.76	*	180,000	1,540	880	1,196	116,000	YES
40-S	32	7.00	*	181,700	1,400	1,168	841	118,000	NO
40-W	3	7.51	*	73,900	2,700	672	321	47,000	NO
41-S	33	6.65	*	182,000	1,270	1,120	632	125,000	YES
41-W	3	7.20	*	168,000	2,290	960	1,031	106,000	YES
42-S	31	6.56	*	156,000	5,500	1,360	535	98,000	NO
42-W	3	6.80	*	167,000	1,150	1,040	632	102,000	NO
43-S	31	6.25	*	169,000	1,450	1,120	583	110,000	NO
43-W	4	6.69	*	154,500	1,200	960	875	94,000	NO
44-S	32	6.50	*	125,700	5,700	1,040	729	82,000	NO
44-W	7	6.48	*	169,000	2,800	1,280	583	106,000	NO
45-S	33	6.70	*	128,000	4,500	1,040	534	82,000	NO
45-W	3	7.00	*	121,000	4,600	1,280	486	82,000	NO
46-S	32	6.65	*	151,000	1,290	1,040	682	99,000	YES
46-W	6	6.83	*	154,000	1,210	1,920	145	94,000	YES
47-S	32	6.24	*	158,000	1,350	1,200	437	98,000	YES
47-W	5	6.70	*	154,000	1,550	1,520	340	91,000	YES

48-S	32	6.64	*	185,000	1,420	1,120	535	116,000	YES
48-W	3	7.03	*	154,000	1,400	1,040	632	98,000	YES
49-S	32	6.64	*	134,000	4,100	1,360	739	87,000	YES
49-W	6	6.80	*	133,000	1,480	1,520	826	84,000	NO
50-S	33	6.04	*	141,000	3,700	1,520	243	90,000	YES
50-W	3	6.00	*	137,000	1,390	1,280	729	87,000	YES
51-S	32	6.60	*	149,000	4,800	1,360	681	94,000	YES
51-W	6	6.50	*	145,000	1,110	1,520	340	93,000	NO
52-S	32	6.72	*	148,000	4,350	1,280	681	95,000	YES
52-W	7	7.02	*	146,000	1,200	1,840	389	93,000	YES
53-S	31	6.62	*	169,500	1,340	1,120	632	107,000	NO
54-S	29	6.70	*	120,000	3,800	1,840	438	77,000	YES
54-W	6	6.50	*	118,000	4,900	1,680	437	71,000	YES
55-S	31	6.40	*	137,000	3,700	1,600	437	84,000	YES
56-S	30	6.70	*	122,000	4,100	1,360	340	79,000	YES
56-W	4	6.84	*	93,000	4,300	1,280	389	58,000	NO
57-S	31	6.70	*	118,000	3,800	1,760	389	73,000	YES
58-S	30	6.20	*	114,200	4,200	1,360	438	74,000	NO
59-S	31	6.90	*	96,200	6,100	2,080	292	62,000	YES
59-W	6	7.24	*	100,500	5,150	1,920	340	64,000	YES
60-S	30	6.81	*	106,000	4,000	1,584	583	65,000	YES
60-W	7	7.28	*	113,000	4,600	1,760	535	71,000	YES
61-S	31	6.50	*	117,000	4,600	1,840	729	76,000	NO
61-W	3	6.68	*	115,000	4,800	1,440	729	74,000	YES
62-S	31	6.40	*	99,100	3,980	1,840	340	62,000	NO
62-W	3	6.82	*	102,000	4,400	1,280	875	68,000	NO
63-S	31	6.30	*	107,000	4,500	1,600	729	69,000	NO
63-W	3	7.58	*	56,000	3,600	320	632	36,000	NO

Notes:

Hach Chemical analytical procedures used in this study had the following standard deviations: chloride 2,332 ppm; sulfate 8 ppm; calcium 27 ppm; magnesium 14 ppm.

The detection limit on the Perkins-Elmer Atomic Absorption Spectrophotometer was 2,100 ppm for sodium. To prevent ionization of sodium, a 1,000 ppm solution of potassium chloride was used when analyzing samples with the Perkins-Elmer Absorption Spectrophotometer. Abbreviations in sample identifications are as follows: S, summer; W, winter; WC, West Clay Creek; SF, Salt Fork of Arkansas River; CW, Cottonwood Creek; SPR, Great Salt Plains Reservoir.

NEW UNDERGROUND COAL MINE OPENS IN OKMULGEE COUNTY

LeRoy A. Hemish¹

The Oklahoma/West Virginia Mining Co. began producing coal from a new underground mine in Oklahoma about September 1, 1989. It is the only underground mine currently producing coal in the state. The mine is a slope mine, named Pollyanna No. 4, and is located in sec. 13, T. 12 N., R. 12 E., Okmulgee County, ~5 mi north of the city of Henryetta (Fig. 1).

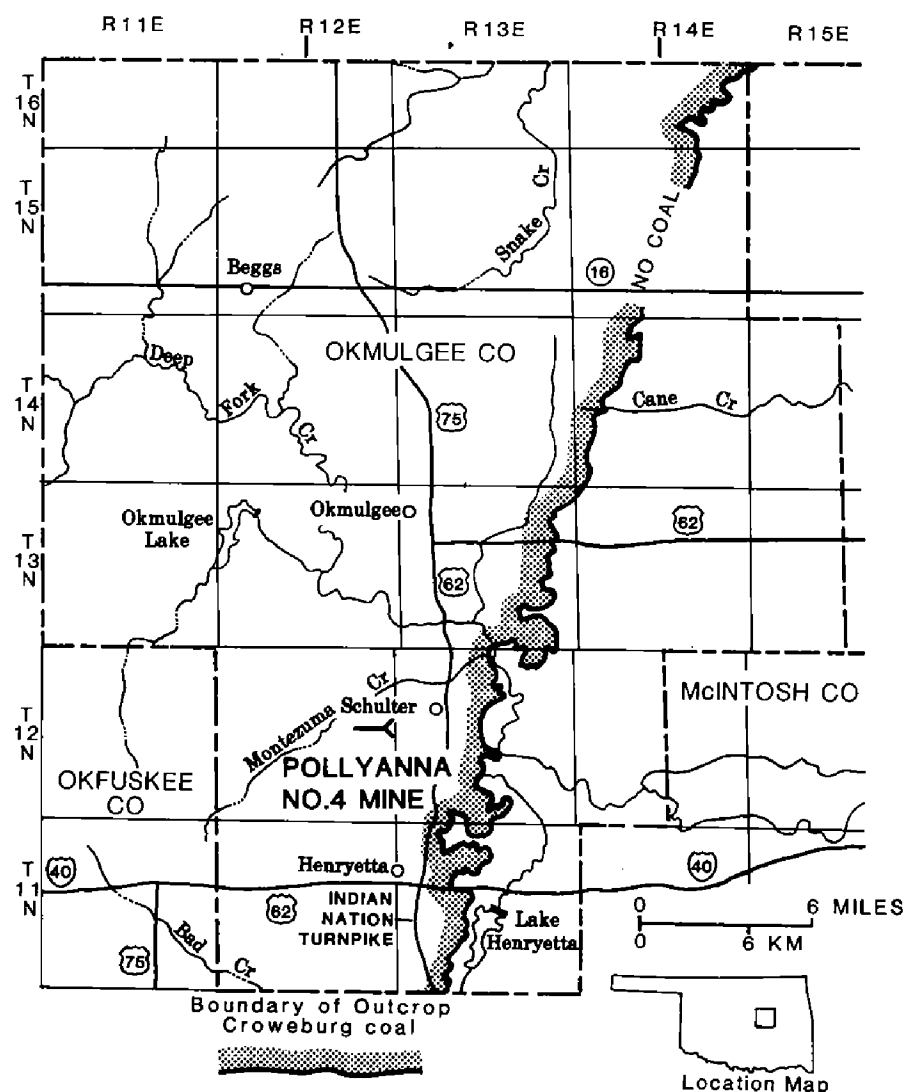


Figure 1. Map of Okmulgee and eastern Okfuskee County, showing the location of the Pollyanna No. 4 Mine and the outcrop boundary of the Croweburg coal. The inset map shows the location of the eastern Oklahoma coalfield and the positions of Okmulgee and eastern Okfuskee Counties.

¹Oklahoma Geological Survey.

The coal being mined is the Croweburg (Henryetta) bed, which averages ~38 in. thick in the immediate area of mining. The bed dips gently to the west at ~1.5°, which makes it particularly amenable to mining. The coal is underlain by ~6 in. of underclay and overlain by several feet of competent, well-indurated, silty shale, which has a tested strength of 6,000 lb/in.². In places, a thin, coaly shale overlies the coal bed, which creates minor problems, owing to its tendency to fall after the coal has been removed. Another minor problem arises from water seepage through the underclay after it has been crushed by the heavy mining equipment. However, pumping quickly alleviates the problem, and mining is progressing normally. No methane gas has been encountered in the mine to date.



Figure 2. Highwall of the pit excavated prior to digging the entry tunnels for the slope mine. The conveyor system used to bring coal from the mine is shown emerging from the center entry.



Figure 3. Continuous miner used to dig tunnels.

Before the mine came into production, a pit was dug through unconsolidated surficial material and weathered shale down to solid bedrock. The maximum depth at the highwall side of the pit is ~30 ft (Fig. 2). Three 6.5-ft-high, 16-ft-wide entry tunnels were then dug, using a continuous miner (Fig. 3). The tunnels have a 25% slope and extend for ~920 ft down to the coal bed. The coal was initially inter-



Figure 4. Diesel pickup entering the mine at the entry to the No. 1 tunnel.

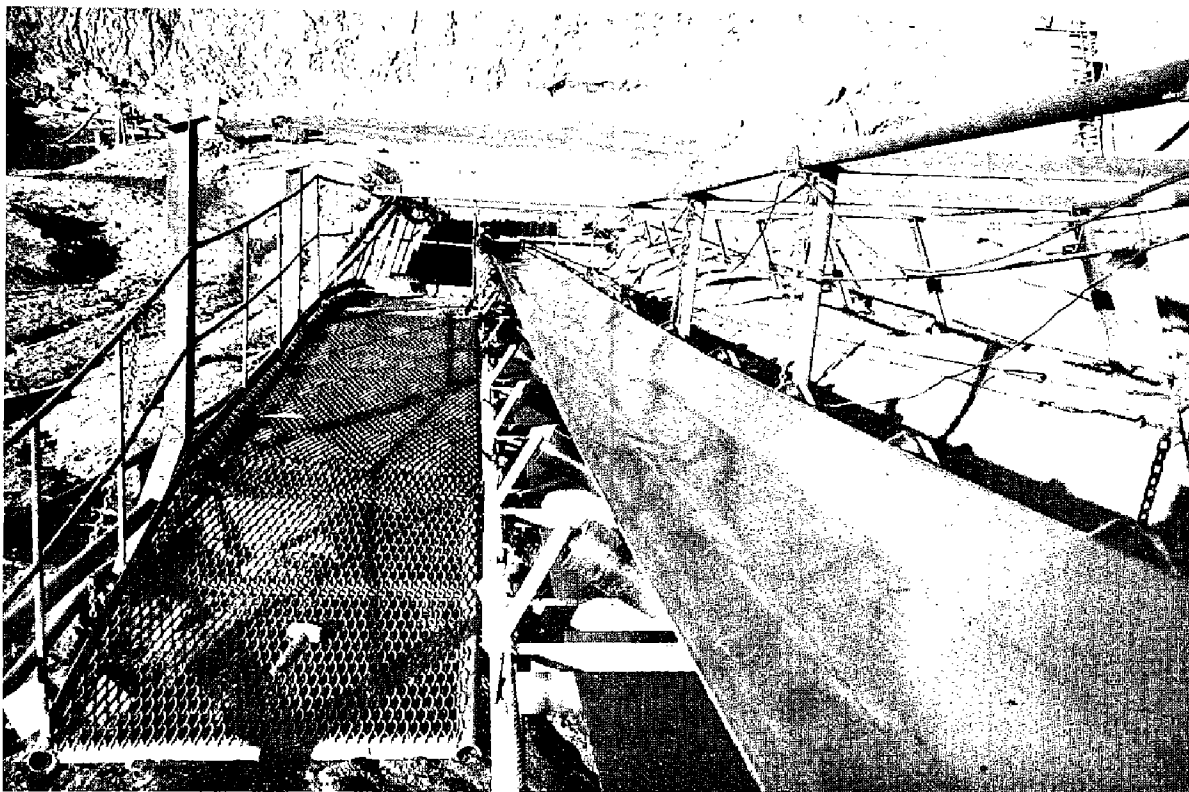


Figure 5. Upper end of the conveyor system used to transport coal from the working face underground.

sected at ~375 ft below surface. One entry tunnel serves as an intake for air for the circulation system; and it is also used to transport men and maintenance equipment into the mine via pickup (Fig. 4).

The center entry tunnel houses the conveyor system, and the third entry tunnel serves as an exhaust vent for the circulating air. Temperatures in the mine are variable, dependent to some degree on surface temperatures, but the average temperature is ~68° F.

The room-and-pillar method of mining is used, and the working height at the face is governed by the thickness of the coal bed. Because the thickness of the coal is only ~3 ft, miners cannot work in an upright position. The coal is mined with a continuous miner, Model 14CM-4, and a continuous conveyor-belt system moves the coal to the surface (Figs. 2,5). The coal is washed at the mine mouth, using a flotation system (Fig. 6). During washing, many of the heavier impurities, such as pyrite and ash, are removed. The processed coal averages just below 2% sulfur, and it has a heat value of ~12,500 Btu/lb. The processed coal initially was hauled by truck to the power plant at Muskogee, Oklahoma, but in the future will be hauled to the new Applied Energy Services power plant at Shady Point, Oklahoma.

Thirty-five men are employed at the mine. Production from the mine averages ~25,000 tons/month. Reserves are plentiful, and coal is available for mining into the foreseeable future.



Figure 6. Preparation plant where the coal is washed at the mine mouth prior to shipment.

GSA SOUTH-CENTRAL SECTION MEETING

Stillwater, Oklahoma, March 4–6, 1990

Hosted by the School of Geology of Oklahoma State University, the 24th Annual Meeting of the GSA South-Central Section will be held jointly with the Midcontinent Section of the National Association of Geology Teachers, Pander Society, and South-Central Section of the Paleontological Society. The following meetings and field trips are planned.

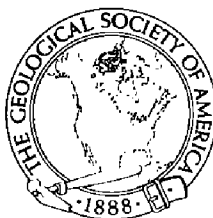
Symposia

Conodont Biofacies—Recent Advances
Tectonic Habitat and Structural Styles in the Midcontinent and Southern Oklahoma: Implications for Hydrocarbon Accumulations
Recent Advances in Middle Carboniferous Biostratigraphy, *Paleontological Society Symposium*
Petroleum Migration: From Organic Matter to the Reservoir
Applied Hydrogeology
Computer Applications in Geological Education, *National Association of Geology Teachers Symposium*
Southern Midcontinent–Texas Craton Transect, International Lithosphere Program

Field Trips

Middle Carboniferous Lithofacies and Biostratigraphy of the Southern Ozarks
Paleozoic Stratigraphy and Conodont Biostratigraphy of the Arbuckle Mountains, Oklahoma

For further information about the meeting, contact Scott M. Ritter, School of Geology, Oklahoma State University, 105 Noble Research Center, Stillwater, OK 74078-0451; (405) 744-6358. The pre-registration deadline is February 9.



UPCOMING MEETINGS

American Association for the Advancement of Science, Annual Meeting, February 15–20, 1990, New Orleans, Louisiana. Information: AAAS Meetings Office, 1333 H St., N.W., Washington, DC 20005; (202) 326-6448.

Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 12–15, 1990, Golden, Colorado. Information: SAGEEP '90, 133 S. Van Gordon, Suite 200, Lakewood, CO 80228; (303) 980-1648.

AAPG–SEPM–EMD, Annual Meeting, June 3–6, 1990, San Francisco, California. Information: Harry E. Cook III, U.S. Geological Survey, 345 Middlefield Road, MS 999, Menlo Park, CA 94025.

NEW OGS PUBLICATIONS

SPECIAL PUBLICATION 89-2. *Geology of the Southern Midcontinent*, by Kenneth S. Johnson and others.
53 pages. Price: \$12.

SP89-2 is reprinted from one of the volumes prepared for the Decade of North American Geology (DNAG) Project that marks the Centennial of the Geological Society of America. Specifically, it is a reprint of chapter 12 in Sloss, L. L. (ed.), *Sedimentary cover—North American craton; U.S.*: Boulder, Colorado, Geological Society of America, *The Geology of North America*, v. D-2, p. 307–359.

The report discusses the regional geology of the southern Midcontinent, embracing all parts of Oklahoma except the Ouachita Mountains. Following a brief review of basement-rock geology for the region, each of the principal episodes of sedimentation and related epeirogenic movement from Cambrian through Mississippian time is discussed for the entire southern Midcontinent. This approach is practical inasmuch as pre-Pennsylvanian strata of the region are remarkably widespread and laterally persistent, reflecting the stability of this part of the craton and the importance of epeirogenic movements during early and middle Paleozoic time.

Pennsylvanian orogenic activity divided the region into a series of sharply uplifted crustal blocks and well-defined marine basins. Inasmuch as the geologic history during Pennsylvanian and Permian times was markedly different in the various tectonic provinces, discussion of this subject was dealt with basin-by-basin. And the final chapter discusses post-Permian rocks for the entire region, because their sedimentation was not influenced by the various tectonic provinces.

The report contains 34 text figures and two 4-color plates consisting of 25 maps (scale 1:5,000,000) showing geologic provinces, basement rocks, and thickness and dominant lithologies of sedimentary rocks in the southern Midcontinent.

Authors of the report are Kenneth S. Johnson (project coordinator and editor), Thomas W. Amsden, Rodger E. Denison, Shirley P. Dutton, Arthur G. Goldstein, Bailey Rascoe, Jr., Patrick K. Sutherland, and Diana Morton Thompson.

GEOLOGIC MAP GM-28. *Map of Oklahoma Oil and Gas Fields*, by Margaret R. Burchfield. 1 sheet, scale 1:500,000, with field supplement. Price: \$6.

The recently sold-out 1985 *Map of Oklahoma Oil and Gas Fields* has been reprinted, and a supplement was added to list the new fields, revised field locations, consolidated fields, and abandoned fields. The supplement, prepared by Michelle J. Summers, updates the data presented on the original map, which was prepared by Margaret R. Burchfield.

The map has been reprinted without change from the original version. It is a 63- by 40-in. colored map that delineates and gives the type of production for Oklahoma's 3,083 active fields and 35 abandoned fields, as of October 1, 1984. The supplement is an 18-page pamphlet that documents changes in delineation of new, old, and abandoned fields between October 1, 1984, and December 31, 1988.

Special Publication 89-2 and Geologic Map GM-28 can be obtained over the counter or postpaid from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73109; phone (405) 325-3031.

SOUTHERN MIDCONTINENT HYDROCARBONS WORKSHOP

Norman, Oklahoma, February 6–7, 1990

The Oklahoma Geological Survey is sponsoring a workshop on Source Rocks, Generation, and Migration of Hydrocarbons and Other Fluids in the Southern Midcontinent. The meeting will be held February 6–7, 1990, at the Oklahoma Center for Continuing Education (OCCE) of the University of Oklahoma in Norman.

The workshop will present current and ongoing research and studies dealing with the Woodford Shale, oil characterization, organic geochemistry, thermal maturation, and carbonates as source rocks.

Provisional titles and speakers are listed below:

February 6

The Role of Source-Rock Studies in Petroleum Exploration, by William E. Harrison, Idaho National Engineering Laboratory, Idaho Falls, ID

Geologic Framework and Hydrocarbon Source Rocks in Oklahoma, by Kenneth S. Johnson and Brian J. Cardott, Oklahoma Geological Survey, Norman, OK

Geology and Organic Geochemistry of the Woodford Shale in the Criner Hills and Western Arbuckle Mountains, by D. W. Kirkland, R. E. Denison, D. M. Summers, and J. R. Gormly, Mobil Research and Development Corp., Dallas, TX

- Organic Geochemistry, Diagenesis, and Depositional Setting of Upper Devonian Formations in Oklahoma and Western Arkansas, by John Comer, Indiana Geological Survey, Bloomington, IN
- Internal Stratigraphy and Biostratigraphy of the Chattanooga Shale in Kansas, by Michael W. Lambert, Kansas Geological Survey, Lawrence, KS; and Jed E. Day, Illinois State University, Normal, IL
- The Effects of Weathering and Maturity on the Geochemical Characteristics of the Woodford Shale, by R. P. Philp, J. Chen, A. Galvez-Sinibaldi, and H. Wang, University of Oklahoma, Norman, OK
- Thermal Maturity of Atokan and Desmoinesian Strata in the Arkoma Basin, by Lori A. Hathon and David W. Houseknecht, University of Missouri, Columbia, MO
- Evidence for Expulsion of Hydrothermal Fluids and Hydrocarbons in the Midcontinent during the Pennsylvanian, by Raymond M. Coveney, Jr., University of Missouri, Kansas City, MO
- Diagenesis and Fluid Migration in Pennsylvanian Rocks of Southeastern Kansas, by Robert Goldstein, Anthony Walton, and Chris Wojcik, University of Kansas, Lawrence, KS
- Geochemistry of Oil-Field Waters and Associated Reservoir Rocks in the Morrowan Formation in Western Kansas, by Sam Chaudhuri and R. Robinson, Kansas State University, Manhattan, KS; and N. Clauer, Centre de Sédimentologie et Géochimie de la Surface, Strasbourg, France

February 7

- The Source-Rock Potential of the Arbuckle Group: A New Approach to an Old Problem, by Stephen W. Brown, Core Labs, Houston, TX; Paul J. Swetland, Core Labs, Irving, TX; and Alan R. Daly, Chevron Overseas, San Ramon, CA
- Vitrinite Reflectance and Deep Arbuckle Maturation, Wilburton Field, Latimer County, Oklahoma, by Steven J. Hendrick, ARCO Oil and Gas Co., Midland, TX
- Organic-Rich Facies of Ordovician Viola Limestone and Bigfork Chert, Southern Oklahoma, by Robert L. Laury, Southern Methodist University, Dallas, TX; and Jackie D. Reed, ARCO Oil and Gas Co., Plano, TX
- Characterization of Oil Types Reservoired in the Arbuckle, Simpson, and Viola Groups, Southern Oklahoma Aulacogen, by David A. Wavrek, University of Tulsa, Tulsa, OK
- Panel Discussion: Can Carbonates be Source Rocks for Commercial Petroleum Deposits? Panelists are Lloyd E. Gatewood, Independent Geologist, Oklahoma City, OK; William E. Harrison, Idaho National Engineering Laboratory, Idaho Falls, ID; James G. Palacas, U.S. Geological Survey, Denver, CO; and Jack A. Williams, Amoco Production Co. Retiree, Tulsa, OK
- Hydrocarbon-Induced Diagenetic Aureoles in Southwestern and Southern Oklahoma, by Zuhair Al-Shaieb, Oklahoma State University, Stillwater, OK; Janet L. Cairns, Amoco Production Co., Tulsa, OK; and Anthony R. Lilburn, Union Oil of California, Oklahoma City, OK
- Geochemistry of Pennsylvanian Oils and Hydrocarbon Source Rocks, Greater Anadarko Basin, Oklahoma, Kansas, and Texas, by Robert C. Burruss and Joseph R. Hatch, U.S. Geological Survey, Denver, CO

- Oil in Permian Karst, Slick Hills, Southern Oklahoma, by R. Nowell Donovan, Texas Christian University, Fort Worth, TX
- Deep Pressure Compartments and Seals in the Anadarko Basin, by Zuhair Al-Shaieb, Vanessa Tigert, James O. Puckette, and Rick Ely, Oklahoma State University, Stillwater, OK
- The Relationships between Primary and Secondary Liptinite Fluorescence and Hydrocarbon Generation and Migration in the Permian Basin, by Charles R. Landis, Texas Tech University, Lubbock, TX

Poster Session, February 6

- Numerical Simulation of Light Hydrocarbon Diffusion from Petroleum Reservoirs, by Ken Wohletz, Los Alamos National Laboratory, Los Alamos, NM
- Structural Controls on Sediment Distribution and Thermal Maturation of the Woodford Shale, Anadarko Basin, Oklahoma, by Timothy C. Hester, James W. Schmoker, and Howard L. Sahl, U.S. Geological Survey, Denver, CO
- New Organic Geochemical Data of the Bertha Rogers No. 1 as Related to Hydrocarbon Generation in the Anadarko Basin, by Leigh Price, U.S. Geological Survey, Denver, CO
- Thermal Maturation of the Eastern Anadarko Basin, Oklahoma, by Mark Pawlewicz, U.S. Geological Survey, Denver, CO
- A Reexamination of the Geochemical Characteristics of Solid Bitumens from the Ouachita Mountains, by T. Ruble and R. P. Philp, University of Oklahoma, Norman, OK
- Laminated Black Shale-Chert Cyclicity in the Woodford Formation, Southern Oklahoma, by Charles T. Roberts, ARCO Oil and Gas Co., Plano, TX; and Richard M. Mitterer, U.S. Department of Energy, Washington, D.C.
- Investigation of the Pyrolysis Process from Pyrolyzing the Woodford Shale and the Excella Shale, by Longjiang Wang, University of Tulsa, Tulsa, OK
- Source-Rock Maturity and Geochemistry, Cherokee Group, Southeast Kansas, by Charles Barker, U.S. Geological Survey, Denver, CO; Robert Goldstein and Anthony Walton, University of Kansas, Lawrence, KS
- Hydrodynamics of Deep Basin Flow: Constraints on Timing of Midcontinent MVT Deposits, by Lori H. Filipek, U.S. Geological Survey, Denver, CO
- Rock Heterogeneity and Geostatistical Methods in Reservoirs and Source Rocks, by Ahmad Junaid Sultan and John P. Heller, New Mexico Petroleum Recovery Research Center, Socorro, NM
- Paleomagnetic Dating of Basinal Fluid Migration and Hydrocarbon Maturation in the Arbuckle Mountains, Oklahoma, by David J. Fruit, Donald S. Bagley, Douglas R. Elmore, M. H. Engel, David London, and K. Cates, University of Oklahoma, Norman, OK
- Geochemical Fluid Inclusion and Petrographic Evidence for Regional Late-Diagenetic Alteration of Upper Cambrian Carbonates by Basinal Fluids, Southern Missouri, by J. M. Gregg, University of Missouri, Rolla, MO; Kevin L. Shelton and Rita M. Bauer, University of Missouri, Columbia, MO

Advance registration (prior to January 15) is \$50, which includes two lunches and a copy of the proceedings. On-site registration will be \$60 per person. Lodging will be available on the OU campus or at local motels.

Contact Kenneth S. Johnson or Brian J. Cardott, General Co-Chairs, Oklahoma Geological Survey, University of Oklahoma, 100 E. Boyd, Room N-131, Norman, OK 73019, phone (405) 325-3031, for registration forms and/or more information.



NOTES ON NEW PUBLICATIONS

Major Geohydrologic Units in and Adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma; Basement Confining Unit

A brief description of the major structural features of the basement confining unit is presented with a map of the altitude of the top of the unit. J. L. Lines prepared this hydrologic investigations atlas at a scale of 1:750,000 (1 in. = ~12 mi). Latitude 34°30' to 40°, longitude 89° to 96°. The sheet measures 35 × 40 in. Although, regionally, the geohydrologic unit is confining, fracture systems in the basement confining unit in a small area within the St. Francois Mountains can yield water sufficient for domestic water supplies. Wells can yield up to 70 gal/min, but they seldom yield >10 gal/min.

Order HA 0711-B from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is \$2.40. (A \$1 postage and handling charge is applicable on orders of less than \$10.)

Review of the Geology of the Southern Oklahoma Fold Belt Province as a Basis for Estimates of Undiscovered Hydrocarbon Resources

This 21-page USGS open-file report was written by M. E. Henry.

Order OF 87-0450-W from: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225. The price is \$4 for microfiche and \$3.25 for a paper copy; add 25% to the price for shipment outside North America.

Bibliography of Oklahoma Hydrology—Reports Prepared by the U.S. Geological Survey and Principal Cooperating Agencies, 1901–88

Of the nearly 350 reports issued by the USGS from 1901 through 1988, about 200 have been concerned primarily with ground water; the remainder have dealt with some aspect of surface water, water quality, or geology. In addition to reports issued by the USGS, this open-file report lists selected journal articles and reports issued by the principal state cooperators, the Oklahoma Water Resources Board, and the Oklahoma Geological Survey. Compiled by John S. Havens, this 59-page bibliography first lists reports by publishing agency, then by type of report, and, last, by author and date of publication.

Order OF 89-33 from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. A limited number of copies are available free of charge.

OKLAHOMA ABSTRACTS

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

Horizontal Grooves in Granite, Western Wichita Mountains, Oklahoma, U.S.A.

J. A. HARRELL, University of Toledo, Toledo, OH; and
C. R. TWIDALE, Adelaide, SA

Horizontal grooves developed at the bases of granitic hills, blocks and boulders in the western Wichita Mountains, Oklahoma, have been ascribed by earlier workers to wave erosion in Permian times. In these terms they were buried by Permian marine sediments and then exhumed. Evidence and argument are adduced to suggest that the grooves were developed by groundwater weathering at the contact between granitic and sedimentary rocks, and that they are congeners of the flared slope and other forms of basal steepening described from other parts of the world.

Subsurface moisture attack in the vadose zone opposite water-bearing sandstone and conglomerate beds, and also perhaps at the level of the water table are responsible for the formation of the grooves. A middle to late Pleistocene, or Holocene age for the grooves is likely.

Reprinted as published in *Zeitschrift für Geomorphologie*, v. 33, no. 2, p. 165.

Red Fork Sandstone of Oklahoma: Depositional History and Reservoir Distribution

JOHN W. SHELTON, ERICO Companies, Tulsa, OK;
RICHARD D. FRITZ and CHRIS JOHNSON, MASERA
Corp., Tulsa, OK

The Middle Pennsylvanian Red Fork sandstone formed as a result of progradation across eastern Kansas and most of Oklahoma. The Red Fork is one of several transgressive-regressive sequences (cyclothems) developed within the Desmoinesian "Cherokee" Group. Sea level changes, together with varying subsidence, were dominant factors controlling the general stratigraphic (correlative) characteristics of the Red Fork interval. Progradation was episodic, with sand deposition in the more active part of the basin during lower sea level stands and valley-fill deposition in the more stable areas during sea level rises.

A map of Red Fork sand trends reveals an alluvial-deltaic complex covering most of Oklahoma. The Red Fork consists primarily of alluvial-valley and plain (fluvial) bodies in the northernmost part of northeastern Oklahoma, alluvial-deltaic bodies

in most of the remaining parts of the shelf area, and off-shelf submarine-fan and slope basal-floor complexes within the deeper part of the Anadarko basin.

Determination of reservoir trend and genesis requires integration of rock and log data. Logs need to be calibrated to cores in order to estimate depositional environments accurately and to make a reasonable assessment of diagenetic overprints.

Much of the oil and gas has been trapped in stratigraphic traps, and a significant amount of oil is in channel sandstones with trends at high angles to the structural grain. In some areas, secondary clay, in particular chloritic clay, has resulted in microporosity, high water saturation, and correspondingly low resistivities in oil reserves.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 73, p. 412.

Thermal Maturation by Vitrinite Reflectance of Woodford Shale, Arbuckle Mountains, Oklahoma

BRIAN J. CARDOTT, Oklahoma Geological Survey, Norman, OK; WILLIAM J. METCALF III, Shell Offshore Inc., New Orleans, LA; and JUDSON L. AHERN, School of Geology and Geophysics, University of Oklahoma, Norman, OK

.....

Vitrinite reflectance was measured on 40 grab samples from outcrops of the Woodford Shale (Upper Devonian–Lower Mississippian) collected near the Washita Valley fault in the Arbuckle Mountains in south-central Oklahoma. Samples are widely distributed along 40 km. Sample localities range from 60 m to 7.63 km from the Washita Valley fault. Well-indurated shale samples were collected from below the outcrop surface to reduce the effect of weathering on vitrinite reflectance. Vitrinite reflectance values were measured from standard kerogen concentrate pellets.

Mean random (plane-polarized light, stationary stage) reflectance values from low-gray vitrinite are 0.35–0.77% R_o with a weighted average of 0.54% R_o based on 14 to 98 measurements per sample with an average of 46. Weathering effects on vitrinite (e.g., oxidation rim) were not observed during petrographic examination, suggesting relatively unweathered samples.

Variation in vitrinite reflectance values is attributed to geologic history (e.g., tectonics), organic variables (e.g., geochemical gelification or vitrinitization of huminite; bitumen and/or liptinite maceral impregnation of vitrinite maceral), and analytical error (e.g., kerogen concentration process; number of measurements).

Implications of the data specific to the Arbuckle Mountains include the Woodford Shale is immature to marginally mature with respect to the generation of liquid hydrocarbons; high heat flow associated with the rifting stage of the southern Oklahoma aulacogen was diminished by Late Devonian; the Woodford Shale was never deeply buried; and frictional heating from the Washita Valley fault did not affect the temperature field significantly.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 73, p. 1150.

Glacial-Eustatic Sea-Level Curve for Early Late Pennsylvanian Sequence in North-Central Texas and Biostratigraphic Correlation with Curve for Midcontinent North America

DARWIN R. BOARDMAN II, Dept. of Geosciences, Texas Tech University, Lubbock, TX 79409; and PHILIP H. HECKEL, Dept. of Geology, University of Iowa, Iowa City, IA 52242

.....

At least 30 transgressive-regressive cycles of deposition are recognized from the upper Desmoinesian East Mountain Shale to the mid-Virgilian Wayland Shale in north-central Texas. Maximum regressive deposits are typically paleosol mudstones and fluvial sandstones; maximum transgressive deposits are typically widespread, ammonoid-bearing, conodont-rich, dark phosphatic shales in more major cycles, and persistent fossiliferous shales or limestones overlying terrestrial deposits in more minor cycles. Delta complexes dominate the regressive sequences of many cycles.

Using biostratigraphic criteria of first, last, sole, or acme occurrence of ammonoid, conodont, and fusulinid taxa, we correlate 17 cycles in the Texas sequence directly with 17 glacial-eustatic cycles of similar magnitude in the northern midcontinent. This correlation suggests that glacial eustasy was the basic control over the cyclic sequence in Texas, that tectonic masking of the eustatic signal by nearby orogenic movement in Texas was negligible, and that delta shifting, though conspicuous, was only a secondary control over the cyclicity there. Minor cycles recognized between the correlated cycles also match well enough between Texas and the midcontinent to further discount potential tectonic or deltaic masking of glacial-eustatic cyclicity. This strengthens the likelihood of correlating glacial-eustatic events across larger parts of North America, and perhaps with other parts of the world.

Reprinted as published in *Geology*, v. 17, p. 802.

Determination of Offset across the Northern Margin of the Wichita Uplift, Southwest Oklahoma

DAVID A. McCONNELL, Dept. of Geology, Kansas State University, Manhattan, KS 66506

.....

The Wichita uplift represents a tectonic element within the Ancestral Rocky Mountains, a series of basement-involved uplifts and associated basins within the foreland of the Ouachita orogen. Contrasting tectonic models for the evolution of the Wichita uplift are evaluated by (i) analyzing the suite of structures within the Frontal fault zone, which separates the uplift from the adjoining Anadarko basin, and (ii) undertaking a palinspastic restoration of Hunton Group (Late Ordovician–Devonian) thickness trends between the basin and the Frontal fault zone to estimate the magnitude and sense of offset across the principal uplift-bounding faults.

Cross sections from uplift to basin show basement-involved thrusts and folds similar to those recognized within the Laramide (Late Cretaceous–Tertiary) foreland of the Rocky Mountains. Structural patterns in map view possess elements that have been previously interpreted as resulting from reverse slip and/or left slip on the uplift-bounding faults.

Palinspastic restoration of isopach patterns between the Frontal fault zone and Anadarko basin indicates that offset across the frontal faults may be explained by oblique slip (left reverse slip) on the uplift-bounding faults. The component of left slip is nearly an order of magnitude less than proposed in some previous models of Carboniferous tectonism within the foreland of the Ouachita orogen.

Reprinted as published in the Geological Society of America *Bulletin*, v. 101, p. 1317.

Clay Mineralogy and Diagenetic Evolution of Deeply Buried Rocks of the Simpson Group (Middle Ordovician), Anadarko Basin, Oklahoma

RICHARD M. POLLASTRO, U.S. Geological Survey,
Denver, CO 80225

.....

The mineral composition and petrography of sandstones, shales, and carbonates were determined from 120 core samples of the Middle Ordovician Simpson Group recovered from present depths of 15,900 to 17,200 ft. Although the bulk-rock mineral composition of these rocks is quite diverse, clay minerals are restricted to illite and chlorite due to deep burial conditions.

The main clay mineral in the Simpson Group at these depths is illite, though iron-rich chlorite is sometimes concentrated locally in sandstones. Illite, defined as both a discrete 10-angstrom phase and an apparent "mixed-layer" illite/smectite (R3) from X-ray powder diffraction (XRD) profiles, is of both detrital and diagenetic origin; it typically makes up >90 relative weight percent (wt%) of the clay minerals in sandstone and >95 wt% of those in shale and carbonate. SEM shows that much of the diagenetic illite occurs as tabular fibers in pores or as pseudomorphic intergrowths after smectite. Thin section microscopy also shows that much of the illite appears as sericite. Textural relationships also suggest that the conversion of smectite to illite at depth contributed, in part, to the formation of dolomite and ankerite cements. Much of the dolomite is found replacing detrital clay.

Iron-rich chlorite typically makes up <10 wt% of the clay minerals; however, chlorite sometimes composes >80 wt% of the clay minerals in sandstones. Most chlorite is authigenic and occurs as a pore-lining cement and as a pseudomorphic replacement after kaolinite. Such an assemblage is consistent with burial conditions wherein temperatures exceeded 150°C.

Shales are clay rich and quartz poor, averaging about 85 wt% clay minerals, 7 wt% quartz, and 3 wt% feldspar, as determined by XRD; carbonate minerals and pyrite are present in variable amounts. Such high clay/quartz ratios are not characteristic of shales and suggest that significant quantities of silica have been expelled by diagenetic processes during deep burial.

Reprinted as published in the Clay Minerals Society 25th Annual Meeting Program and Abstracts, p. 54.

Index¹

Volume 49, 1989

abstracts	
American Association of Petroleum Geologists	100,143,234
Carbonates and Evaporites	141
Clay Minerals Society	237
Geological Society of America	62,100,142,236
Oklahoma State University	191
Society of Economic Paleontologists and Mineralogists	58
U.S. Geological Survey	99
University of Oklahoma	20,191
<i>Zeitschrift für Geomorphologie</i>	234
Ahern, Judson L., see Cardott, Brian J.; Metcalf, William J., III; and Ahern, Judson L.	
Alberta, Patricia L., see Al-Shaieb, Zuhair; Alberta, Patricia L.; and Gaskins, Mike	
Aledo gas field	125
Alfalfa County	
ground water, Great Salt Plains	200
Al-Shaieb, Zuhair; and Lynch, Mark—Chamosite: Critical Ingredient in Diagenetic Differentiation of Sandstone Reservoirs [abstract]	144
Al-Shaieb, Zuhair; Alberta Patricia L.; and Gaskins, Mike—Role of Diagenesis in Development of Upper Morrow Fan-Delta Reservoirs in Anadarko Basin [abstract]	143
American Association of Petroleum Geologists	
abstracts	100,234
annual convention	11
Friedman elected to EMD executive committee	185
Mid-Continent Section meeting	92
Amoco Foundation, makes donation to OU	15,139
Amthor, Joachim E.; Kopaska-Merkel, David C.; and Friedman, Gerald M.—Reservoir Characterization, Porosity, and Recovery Efficiency of Deeply Buried Paleozoic Carbonates: Examples from Oklahoma, Texas, and New Mexico [abstract]	141
Anadarko basin	125
ARCO Foundation, makes donation to OU	139
Association of American State Geologists	
annual meeting	14
Atoka Formation	150
Austin, Michael N.—Seismic Stratigraphy of the Upper Pennsylvanian Swope Limestone, Comanche County, Kansas, and Woods County, Oklahoma [abstract]	25
Babaei, Abdolali—Anti-Verging Folds in the Western Plunge of the Benton Uplift, Arkansas [abstract]	105

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

Bertagne, Allen J.; Vuillermoz, Claude; and Maxwell, Richard A.— Megaregional Seismic Approach to New Play Concept Development [abstract]	143
Bierschenk, Arnold F.—Sedimentary Character and Provenance of the Crystal Mountain Sandstone, Broken Bow Uplift, McCurtain County, Oklahoma [abstract]	106
Bingham, Roy H., see Marcher, Melvin V.; and Bingham, Roy H. Bluejacket Sandstone Member	70,72
Boardman, Darwin R., II; and Heckel, Philip H.—Glacial-Eustatic Sea- Level Curve for Early Late Pennsylvanian Sequence in North- Central Texas and Biostratigraphic Correlation with Curve for Midcontinent North America [abstract]	236 70,72
Boggy Formation	
Braile, L. W., see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen- Fong; and Jardine, W. G.	
brines	200
Brown, Darren L.—The Stratigraphy and Petrography of the Wapanucka Formation Along the Northeastern Flank of the Arbuckle Mountains in Southern Oklahoma [abstract]	22
Bruce, Lyle G.—Radial-Drainage Anomaly over Aledo Gas Field in the Anadarko Basin: Example of a Poor Man's Remote-Sensing Technique	125
Burchfield, Margaret R., compiler of OGS Map GM-28	230
Cambrian–Ordovician symposium	131
Campbell, Jock A., see Suneson, Neil H.; and Campbell, Jock A.	
Campbell, Jock A.; Mankin, Charles J.; Schwartzkopf, A. B.; and Raymer, John H.—Habitat of Petroleum in Permian Rocks of the Mid- continent Region [abstract]	58
Cardott, Brian J.—A Petrographic Survey of High-Volatile Bituminous Oklahoma Coal Beds	112
Cardott, Brian J.; Metcalf, William J., III; and Ahern, Judson L.—Thermal Maturation by Vitrinite Reflectance of Woodford Shale, Arbuckle Mountains, Oklahoma [abstract]	235
Cardott, Brian J.; Suneson, Neil H.; and Ferguson, Charles A.—The Page Impsonite Mine, Le Flore County, Oklahoma	32
carpoid	2
Caspar, Barry C.—Deposition of a Late Permian Mud-Rich Sabkha in Northern Caddo County, Oklahoma [abstract]	21
Chafetz, Henry S., see Utech, Nancy M.; and Chafetz, Henry S.	
Chang, Wen-Fong, see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.	
Chaplin, James R.—Lithostratigraphy of Lower Permian Rocks in Kay County, North-Central Oklahoma, and Their Stratigraphic Relationships to Lithic Correlatives in Kansas and Nebraska [abstract]	59
Chronostratigraphic Boundaries in the Midcontinent—Problems, Practices, and Proposals [abstract]	106
Chitwood, J. P., see Goydas, M. J.; Smith, G. N.; Chitwood, J. P.; and McConnell, D. A.	
Cimarron County Black Mesa region	4

Cleaves, A. W.—Controls on Cyclic Sedimentation in the Strawn–Canyon Interval of North-Central Texas: Confessions of a Reformed Eustatiphobe [abstract]	100
coal	
new underground mine in Okmulgee County	224
petrographic survey of high-volatile bituminous beds	112
Cocke, J. M.—Rugose Coral Occurrence in Pennsylvanian Transgressive and Regressive Missourian Limestones of Kansas with Remarks on Deep and Shallow Water Corals of Texas and Oklahoma [abstract]	104
Cody, R. D., see Slaughter, C. B.; and Cody, R. D.	
COGEOMAP program	152
Cole, Tony—A Surface-to-Subsurface Study of the Sycamore Limestone (Mississippian) Along the North Flank of the Arbuckle Anticline [abstract]	27
Conoco/Du Pont, makes donation to OU	15,139
Cox, Eldon R.; and Summers, Michelle J., compilers of OGS Special Publication 88-4	14
Craig County	
Bluejacket Sandstone	70,72
Crawford, Lisa D.—Paleomagnetic Dating of Calcite Speleothems in Arbuckle Group Limestones, Southern Oklahoma: A Possible Relationship Between Hydrocarbons and Authigenic Magnetite [abstract]	20
Crone, A. J.—The Meers Fault, SW Oklahoma: Evidence of Multiple Episodes of Quaternary Surface Faulting [abstract]	64
see Jones-Cecil, Meridee; Robbins, S. L.; and Crone, A. J.	
Decade of North American Geology (DNAG)	
chapter reprinted as OGS SP89-2	229
review of Centennial Field Guide, South-Central volume	186
De Medina, Diana M. D.—Geochemistry of the Sandy Creek Gabbro, Wichita Mountains, Oklahoma [abstract]	26
Dennen, Mark M.—Brachiopod Biostratigraphy and Paleoecology of the Upper Dornick Hills Group, Middle Pennsylvanian, Ardmore Basin, Southern Oklahoma [abstract]	21
Donovan, R. Nowell—Review: Knapping the Chucky Stanes with DNAG	186
The Everlasting Hills of Oklahoma [cover-photo description]	110
see Hanson, R. E.; Donovan, R. N.; and Wilson, T. J.	
earthquakes	
Oklahoma, 1988	40
Fay, Robert O., author of OGS Guidebook 26	133
Ferebee, Clive D.—Cottonwood Creek–Hewitt Trend Arbuckle Play (Southern Oklahoma): Example of Complexly Faulted and Fractured Karst Trap [abstract]	148
Ferguson, Charles A.—Climbing Translatent Stratification in a Pennsylvanian Sandstone from the Ouachita Mountains [cover-photo description]	150
see Cardott, Brian J.; Suneson, Neil H.; and Ferguson, Charles A.	
see also Suneson, Neil H.; and Ferguson, Charles A.	
Fies, Michael W.—Depositional Environments and Diagenesis of the Tonkawa Format (Virgilian) in Woods and Part of Woodward Counties, Oklahoma [abstract]	194
Francis, Bill M., see Prezbindowski, Dennis; Fritz, Richard D.; and Francis, Bill M.	

Friedman, Gerald M., see Amthor, Joachim E.; Kopaska-Merkel, David C.; and Friedman, Gerald M.	
Friedman, Samuel A., elected to AAPG EMD executive committee	185
Fritz, Richard D., see Prezbindowski, Dennis; Fritz, Richard D.; and Francis, Bill M.	
see also Shelton, John W.; Fritz, Richard D.; and Johnson, Chris	
Fryklund, Robert E.—Oil and Gas Developments in Oklahoma and Panhandle of Texas in 1987 [abstract]	100
Gaskins, Mike, see Al-Shaieb, Zuhair; Alberta, Patricia L.; and Gaskins, Mike	
Gay, S. Parker, Jr.—Gravitational Compaction, A Neglected Mechanism in Structural and Stratigraphic Studies: New Evidence from Mid-Continent, USA [abstract]	147
Geological Society of America	
abstracts	62,100,236
annual meeting	135
review of DNAG volume	186
South-Central Section meeting	228
geomorphology	
Wichita Mountains	30,198
Grasmick, Mary K., see Suneson, Neil H.; and Grasmick, Mary K.	
Goydas, M. J.; Smith, G. N.; Chitwood, J. P.; and McConnell, D. A.—Spatial and Temporal Correlation of Pennsylvanian Uplift and Subsidence: Wichita Uplift and Anadarko Basin, Southwest Oklahoma [abstract]	104
Great Salt Plains	200
ground water, Great Salt Plains	200
gypsum	200
halite	200
Halliburton Foundation, makes donation to OU	15
Hanson, R. E.; Donovan, R. N.; and Wilson, T. J.—The Late Proterozoic Zambezi Belt in Southern Africa: A Model for the Deeper Levels of the Southern Oklahoma Aulacogen [abstract]	102
Harder, Steven H., see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.	
Harrell, James A.—Granite Platforms of the Western Wichita Mountains, Oklahoma [cover-photo description]	30
Grooved Granites of the Western Wichita Mountains, Oklahoma [cover-photo description]	198
Harrell, James A.; and Twidale, Charles R.—Horizontal Grooves in Granite, Western Wichita Mountains, Oklahoma [abstract]	63
Horizontal Grooves in Granite, Western Wichita Mountains, Oklahoma, U.S.A. [abstract]	234
hazardous-waste-disposal symposium	184
Heckel, Philip H., see Boardman, Darwin R., II; and Heckel, Philip H.	
Hemish, LeRoy A.—author of OGS Geologic Map GM-30	56
Bluejacket (Bartlesville) Sandstone Member of the Boggy Formation (Pennsylvanian) in Its Type Area	72
Core from the Bluejacket Sandstone in Its Type Area [cover-photo description]	70
New Underground Coal Mine Opens in Okmulgee County	224

Hester, Timothy C.; Schmoker, James W.; and Sahl, Howard L.—Regional Depositional Trends and Organic-Carbon Content of the Woodford Shale, Anadarko Basin, Oklahoma, Based on Gamma-Ray, Density and Resistivity Logs [abstract]	103
Hofman, Jack—Late Pleistocene and Early Holocene Deposits in Western Oklahoma: Archaeological Implications [abstract]	101
Hooker, Ellen M. Ostroff—The Distribution and Depositional Environment of the Basal Atokan Spiro Sandstone, Arkoma Basin, Haskell, Latimer, and Pittsburg Counties, Oklahoma [abstract]	195
Horak, William F.; and Johnson, Kenneth S.—Principal Aquifers in Permian Strata of Central and Western Oklahoma [abstract]	60
hydrogeology	
ground water, Great Salt Plains	200
impsonite	32
International Geological Congress, 28th Session	49
Jardine, W. G., see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.	
Johnson, Chris, see Shelton, John W.; Fritz, Richard D.; and Johnson, Chris	
Johnson, Kenneth S., co-author of OGS SP89-2	229
editor of OGS Circular 90	132
Nonpetroleum Mineral Resources of Permian Rocks in Oklahoma and the Texas Panhandle [abstract]	59
see Horak, William F.; and Johnson, Kenneth S.	
Jones-Cecil, Meridee; Robbins, S. L.; and Crone, A. J.—Aeromagnetic and Gravity Signature of the Wichita Frontal Fault System [abstract]	64
Keck, W. M., Foundation, makes donation to OU	139
Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.—Paleozoic Continent–Ocean Transition in the Ouachita Mountains Imaged from PASSCAL Wide-Angle Seismic Reflection–Refraction Data [abstract]	142
King, W. E.—Permian Fusulinids from the Conoco Inc. 33-1 Core, Kay County, Oklahoma [abstract]	61
Kolata, Dennis R.—Newly Discovered Carpod from Pennsylvanian Rocks of Oklahoma [cover-picture description]	2
Kopaska-Merkel, David C., see Amthor, Joachim E.; Kopaska-Merkel, David C.; and Friedman, Gerald M.	
Lambert, Lance L.—A Proposed Basis for Establishing a Formal Atokan/Desmoinesian Boundary [abstract]	101
Lawson, James E., Jr.; and Luza, Kenneth V.—Oklahoma Earthquakes, 1988	40
Leach, Mark C.—A Paleomagnetic Study of Altered Permian Rush Springs Sandstones, Cement Oil Field, Oklahoma: A Relationship with Hydrocarbon Migration and Seepage [abstract]	192
Le Flore County	
Page impsonite mine	32
Lin, Li-Hua—Effect of Biodegradation on Tar-Sand Bitumen of South Woodford Area, Carter County, Oklahoma [abstract]	23
Luza, Kenneth V., see Lawson, James E., Jr.; and Luza, Kenneth V.	
Luza, Kenneth V.; and others, authors of OGS Special Publication 89-1	90
Luza, Kenneth V.; and Suneson, Neil H.—Site Selection Process for Oklahoma's Superconducting Super Collider [abstract]	66
Lynch, Mark, see Al-Shaieb, Zuhair; and Lynch, Mark	

Mankin, Charles J., see Campbell, Jock A.; Mankin, Charles J.; Schwartzkopf, A. B.; and Raymer, John H.	
Marcher, Melvin V.; and Bingham, Roy H.—co-authors of OGS Hydrologic Atlas 2	56
Maxwell, Richard A., see Bertagne, Allen J.; Vuillermoz, Claude; and Maxwell, Richard A.	
McConnell, David A.—Determination of Offset across the Northern Margin of the Wichita Uplift, Southwest Oklahoma [abstract]	236
McConnell, D. A., see Goydas, M. J.; Smith, G. N.; Chitwood, J. P.; and McConnell, D. A.	
McMechan, G. A., see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.	
Metcalf, William J., III, see Cardott, Brian J.; Metcalf, William J., III; and Ahern, Judson L.	
Michael, Gerald E.—Effect of Biodegradation Upon Porphyrin Biomarkers in Upper Mississippian Tar Sands and Related Oils, Southern Oklahoma [abstract]	24
mineral industry of Oklahoma, 1988	96
Mobil Foundation, makes donation to OU	15
Mulvany, Judith O., see Mulvany, Patrick S.; and Mulvany, Judith O.	
Mulvany, Patrick S.; and Mulvany, Judith O.—Geologic Map Revision of the Black Mesa Region, Cimarron County, Oklahoma	4
Natural Resources Information System	152
Oklahoma Academy of Sciences	
co-sponsors hazardous-waste-disposal symposium	184
Oklahoma Geological Survey	
co-sponsors hazardous-waste-disposal symposium	184
publications	14,56,90,132,229
sponsors Cambrian–Ordovician symposium	131
sponsors Southern Midcontinent Hydrocarbons workshop	230
Oklahoma Geophysical Observatory	40
Oklahoma State University	
theses abstracts	191
Okmulgee County	
new coal mine	224
Ouachita Mountains	150,152
Page impsonite mine	32
paleontology	
carpoid	2
vertebrate fossils	4
petroleum	
wells in the Ouachita Mountains	152
Phillips Petroleum Foundation, makes donation to OU	15,139
Pollastro, Richard M.—Clay Mineralogy and Diagenetic Evolution of Deeply Buried Rocks of the Simpson Group (Middle Ordovician), Anadarko Basin, Oklahoma [abstract]	237
Pollastro, Richard M.; and Schmoker, James W.—Relationship to Clay-Mineral Diagenesis to Temperature, Age, and Hydrocarbon Generation—An Example from the Anadarko Basin, Oklahoma [abstract]	99

Prezbindowski, Dennis; Fritz, Richard D.; and Francis, Bill M.—Diagenetic Controls on Primary and Secondary Porosity in Valley-Fill Marine Sandstones—Misener Formation, North-Central Oklahoma [abstract]	146
Ragusa, Donald P.—Interpretation of “Old” Electric Logs, Red Fork Sandstone, Payne County, Oklahoma [abstract]	195
Rascoe, Bailey, Jr.—Permian System in Western Midcontinent [abstract]	61
Raymer, John H., see Campbell, Jock A.; Mankin, Charles J.; Schwartzkopf, A. B.; and Raymer, John H.	
remote sensing	125
Robbins, S. L., see Jones-Cecil, Meridee; Robbins, S. L.; and Crone, A. J.	
Sahl, Howard L., see Hester, Timothy C.; Schmoker, James W.; and Sahl, Howard L.	
Schmoker, James W., see Hester, Timothy C.; Schmoker, James W.; and Sahl, Howard L.	
see also Pollastro, Richard M.; and Schmoker, James W.	
Schwartzkopf, A. B., see Campbell, Jock A.; Mankin, Charles J.; Schwartzkopf, A. B.; and Raymer, John H.	
Scott, Thomas D., Jr.—A Geochemical and Isotopic Study of the Garber–Wellington Aquifer, Cleveland County, Oklahoma [abstract]	25
seismology	40
Shelton, John W.; Fritz, Richard D.; and Johnson, Chris—Red Fork Sandstone of Oklahoma: Depositional History and Reservoir Distribution [abstract]	234
Shinol, John H.—Seismic Analysis of a Complex Structure in Stephens County, Oklahoma [abstract]	26
Slaughter, C. B.; and Cody, R. D.—Geochemistry of Near-Surface Ground Water, Great Salt Plains, Alfalfa County, Oklahoma	200
Slick Hills	110
Smith, G. N., see Goydas, M. J.; Smith, G. N.; Chitwood, J. P.; and McConnell, D. A.	
Society of Economic Paleontologists and Mineralogists	
abstracts	58
Midcontinent Section meeting	134
new officers	98
Steuer, Richard C.—Depositional and Diagenetic Framework of the Lower Permian Chase Group, Southern Hugoton Embayment [abstract]	22
Summers, Michelle J., see Cox, Eldon R.; and Summers, Michelle J.	
Suneson, Neil H., see Cardott, Brian J.; Suneson, Neil H.; and Ferguson, Charles A.	
see also Luza, Kenneth V.; and Suneson, Neil H.	
Suneson, Neil H.; and Campbell, Jock A.—Petroleum Production and Exploration in Ouachita Region of Oklahoma [abstract]	145
Suneson, Neil H.; and Ferguson, Charles A., co-authors of OGS COGEOMAP geologic quadrangle maps	90
Suneson, Neil H.; and Grasmick, Mary K.—Oil and Gas Wells, Ouachita Mountains, Oklahoma	152
Sun Exploration and Production Co., makes donation to OU	15,139
Sutherland, Patrick K.—Late Mississippian and Pennsylvanian Depositional History in the Arkoma Basin Area, Oklahoma and Arkansas [abstract]	62

Thomas, William A., see Keller, G. R.; Braile, L. W.; McMechan, G. A.; Thomas, William A.; Harder, Steven H.; Chang, Wen-Fong; and Jardine, W. G.	
Twidale, Charles R., see Harrell, James A.; and Twidale, Charles R.	
Union Pacific Foundation, makes donation to OU	15
U.S. Geological Survey	
abstract	99
University of Oklahoma	
receives grants from industry	15,139
T. H. Lee Williams appointed College of Geosciences associate dean	91
theses abstracts	20,191
Utech, Nancy M.; and Chafetz, Henry S.—Geochemical and Petrographic Analyses of Travertine-Precipitating Waters and Travertine Deposits, Arbuckle Mountains, Oklahoma [abstract]	145
Viele, George W.—Geologic History of the Ouachita Orogenic Belt [abstract]	65
Vuillermoz, Claude, see Bertagne, Allen J.; Vuillermoz, Claude; and Maxwell, Richard A.	
Wichita Granite Group	30,198
Wichita Mountains	30,110,198
Williams, T. H. Lee, appointed OU College of Geosciences associate dean	91
Willis, Larry A.—Seismic Stratigraphy of the Chester "J" Limestone in the S.W. Trivoli Field, Dewey and Major Counties, Oklahoma: A Case Study in Seismic Reservoir Characterization [abstract]	193
Wilson, T. J., see Hanson, R. E.; Donovan, R. N.; and Wilson, T. J.	
Woodhouse, John C., II—Fracturing in a "Novaculite" Reservoir: A Surface Example from Black Knob Ridge, Atoka County, Oklahoma [abstract]	191

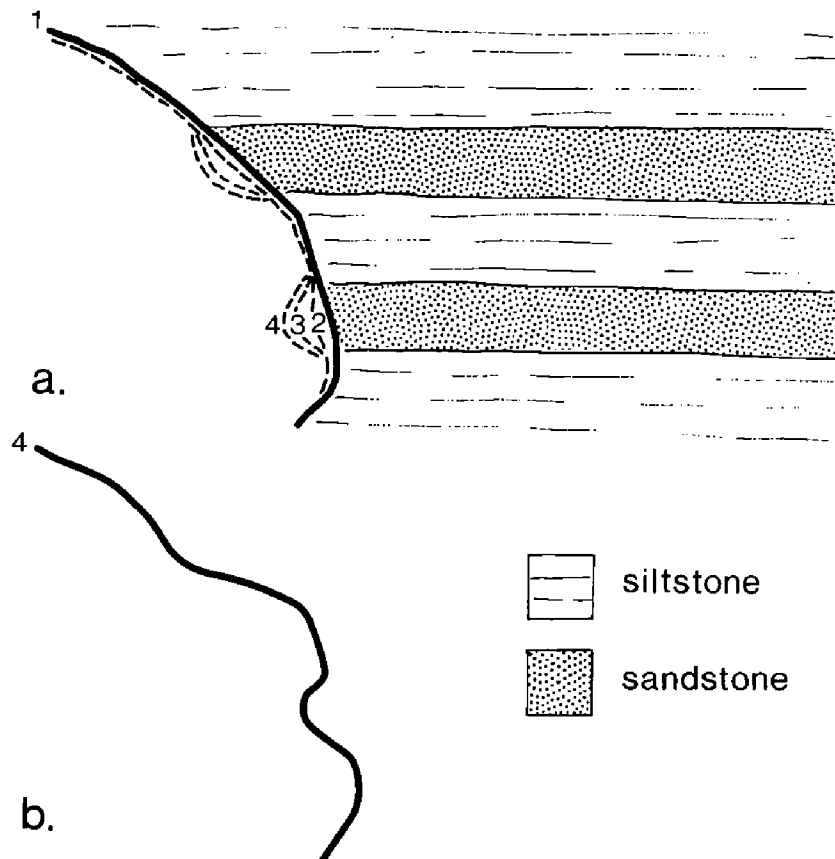
Grooved Granites—continued from p. 198

The generally accepted explanation for the origin of the grooves was popularized by Evans (1929), who suggested that they were “wave-cut notches” of Permian age that are now in the process of exhumation from beneath the Hennessey Formation. This interpretation has recently been challenged by Harrell and Twidale (in press), who demonstrate that the grooves are a subsurface weathering phenomenon of Quaternary age. They formed in the vadose zone where chemically active waters caused accelerated disintegration of granite opposite high-permeability layers in the well-stratified, flat-lying Hennessey sediments. The original slope of the granite surfaces determined whether the grooves developed as narrow benches or concavities.

References

- Evans, O. F., 1929, Old beach markings in the western Wichita Mountains: *Journal of Geology*, v. 37, p. 76–82.
Harrell, J. A.; and Twidale, C. R. [in press], Horizontal grooves in granite, western Wichita Mountains, Oklahoma, U.S.A.: *Zeitschrift für Geomorphologie*.
Merritt, C. A., 1958, Igneous geology of the Lake Altus area: *Oklahoma Geological Survey Bulletin* 76, 70 p.

James A. Harrell
University of Toledo



Development of grooves and benches on a sloping granite surface opposite high-permeability strata.