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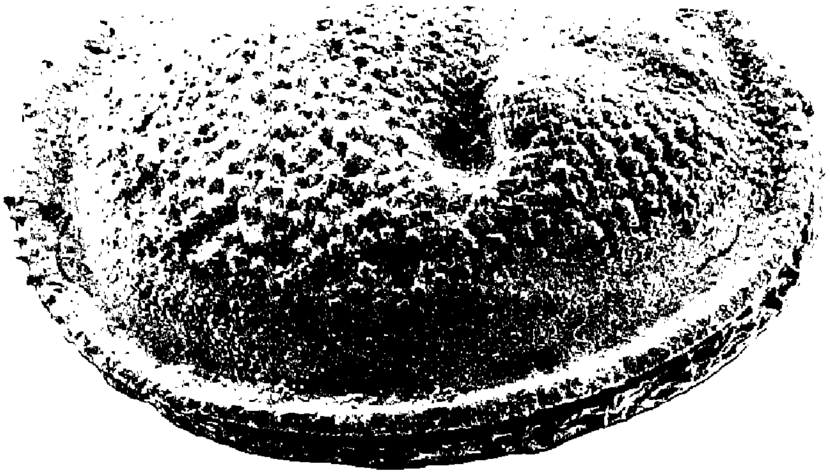

On the cover—

Fossil Ostracode of the Arbuckle Mountains

Scanning electron photomicrographs (× 36) of the male and female carapace of the fossil Ostracode *Bromidella papillata* (Harris, 1957). This species is a characteristic component of the middle Ordovician Bromide Formation, cropping out extensively in the Arbuckle Mountains of southern Oklahoma.

Mark Williams and Rod Branson
University of Leicester, United Kingdom

Notes Questionnaire Enclosed in This Issue

To improve our service to you, the Oklahoma Geological Survey seeks input from readers of the *Oklahoma Geology Notes.* Soon we will be soliciting new materials for upcoming issues of the *Notes.* By your checking a few boxes on the enclosed questionnaire and returning it to us, we can provide you with the information that would be most useful to you. *No postage is required* to return the questionnaire—just refold with the address on the outside and staple or tape shut. Please return the questionnaire by November 30.

We also welcome oral comments or discussion from you with any of the *Notes* review committee members: Brian Cardott, Christie Cooper, LeRoy Hemish, Ken Johnson, Ken Luza, Jo Lynn Pierce, Connie Smith, and Jane Weber. Our phone number is (405) 325-3031.

Thank you for your assistance!

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STANDARD OUTCROP SECTION OF THE BLAINE FORMATION AND ASSOCIATED STRATA IN SOUTHWESTERN OKLAHOMA

Kenneth S. Johnson[1]

Abstract

The Permian Blaine Formation and associated strata comprise ~700 ft of interbedded red beds and evaporites in southwestern Oklahoma. These strata crop out or are in the shallow subsurface in the Hollis and Anadarko basins, and across the western part of the Wichita uplift. The stratigraphy of the Hennessey, Duncan (San Angelo), Flowerpot, Blaine, and Dog Creek formations are presented, and new nomenclature, type localities, and type sections are given for some of the members and beds.

Introduction

The purpose of this report is to describe the lithostratigraphy of the Blaine Formation and associated strata in southwestern Oklahoma, to establish the formal and informal nomenclature of these units, and to propose a standard stratigraphic column for these outcropping strata in the region. Stratigraphic units include (in ascending order) the Hennessey Shale, Duncan (San Angelo) Sandstone, Flowerpot Shale, Blaine Formation, and Dog Creek Shale, all of Permian age. The study area includes outcrops and the shallow subsurface of the Hollis basin, the western end of the Wichita uplift, and the south flank of the Anadarko basin (Fig. 1).

Most of the stratigraphic units were first described by Cragin (1896), Gould (1902,1905,1924), Sawyer (1924), and Suffel (1930). In 1953, a study of these rocks in southwestern Oklahoma was started by the Oklahoma Geological Survey under the direction of W. E. Ham. The initial report of that investigation (Scott and Ham, 1957) set forth the first detailed understanding of the Blaine Formation and associated strata in the region. Subsequent Survey-sponsored master's theses (Murphey, 1958; Edwards, 1958; Hansen, 1958; Richter, 1960; Copley, 1961; Johnson, 1962) and a doctoral dissertation (Johnson, 1967) have amplified the work of Scott and Ham by detailed mapping and stratigraphic work. New nomenclature for some of the beds and members was proposed in several of the theses, but these had not been proposed formally. Pendery (1963) attempted to formalize the thesis-proposed nomenclature, but he did not include type sections. Also, two published geologic maps of the region (Carr and Bergman, 1976; Havens, 1977) incorporate unpublished map data based upon the thesis-proposed nomenclature. In this report, I am proposing a standard outcrop section and nomenclature for these strata in southwestern Oklahoma, including type localities and type sections where they have not been previously designated. The data are mainly from the work by Johnson (1967), which integrates the work done by previous investigators.

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[1] Oklahoma Geological Survey.

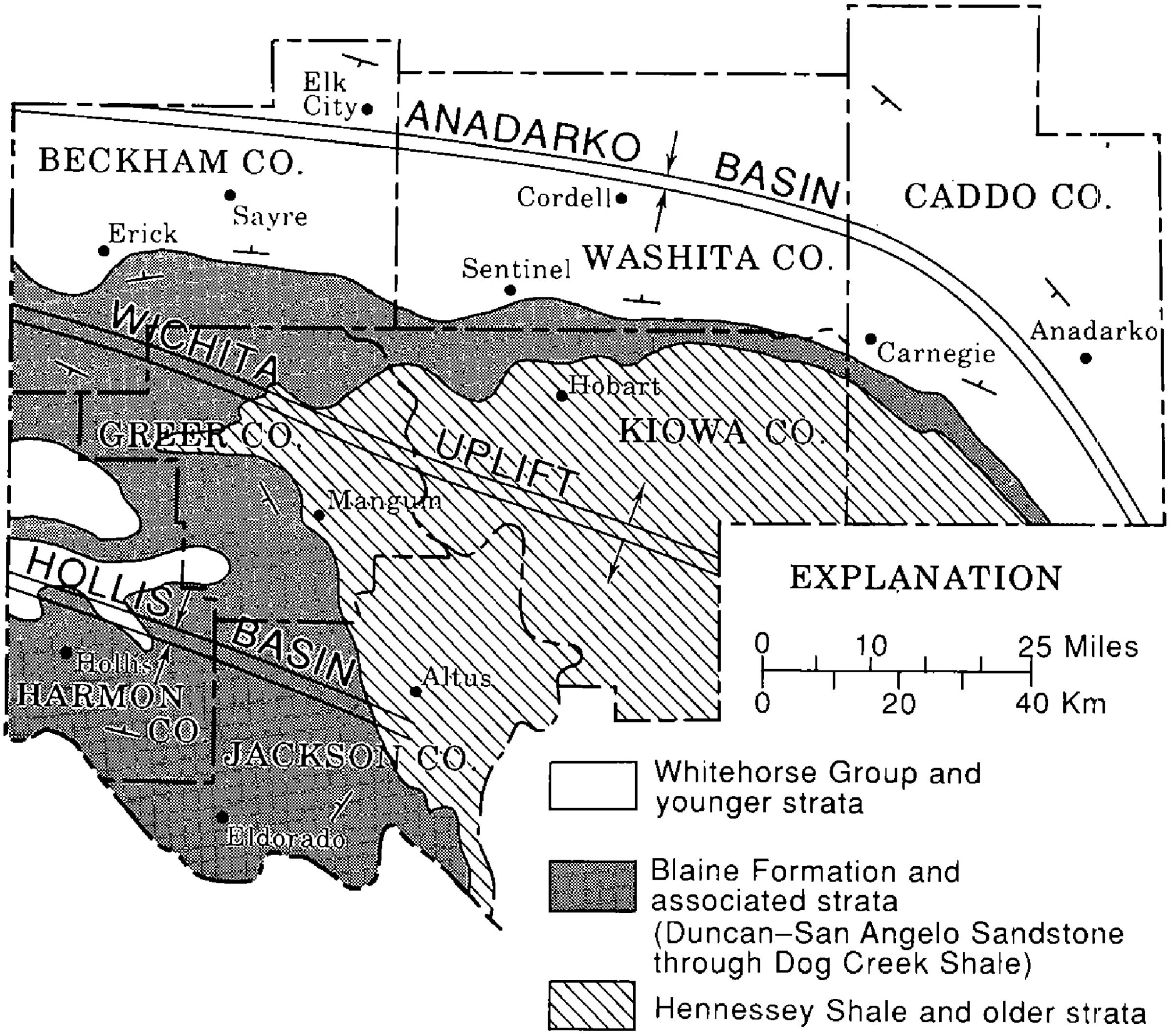

Figure 1. Location map showing principal structural features and outcrop area of Blaine Formation and associated strata in southwestern Oklahoma.

Although this stratigraphic framework is proposed for southwestern Oklahoma, I know (based on reconnaissance field work) that the various formations, members, and beds are recognizable and correlative to the south and west for nearly 100 mi into Texas, and to the north to outcrops in the north flank of the Anadarko basin. The proposed stratigraphy integrates nomenclature from Oklahoma, Texas, and Kansas, and I hope it will eliminate some of the duplication of nomenclature that has risen in the past.

Regional Geologic Setting

The Blaine Formation and associated strata of southwestern Oklahoma were deposited on the eastern side of a broad, epicontinental sea that covered much of the southwestern United States during Permian time (Fig. 2). The sea was ~400 mi wide and 700 mi long, and was connected with the open ocean to the south via the Delaware and Midland basins of west Texas and New Mexico. Surrounding

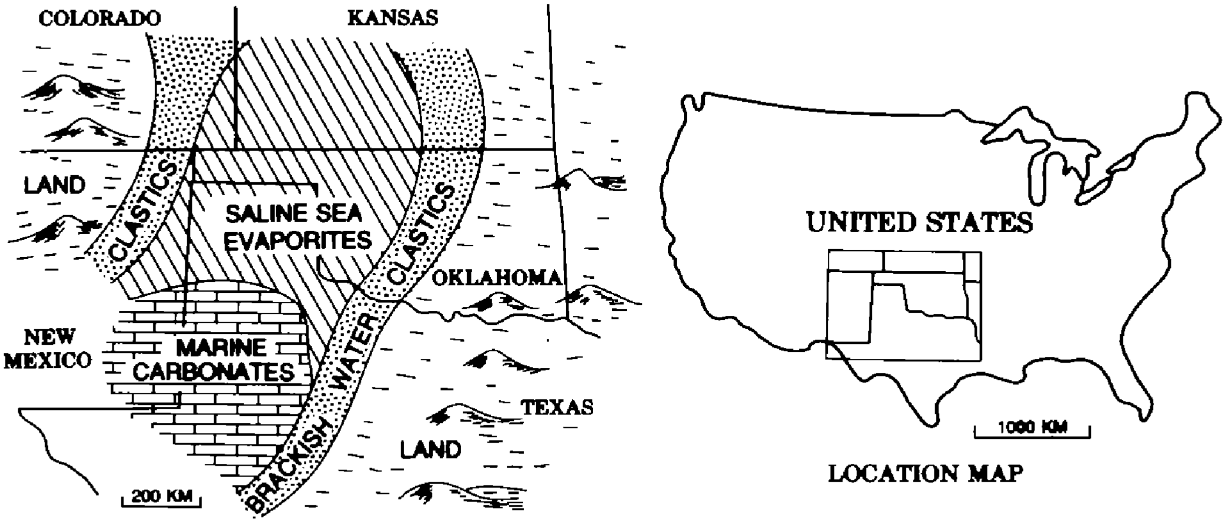

Figure 2. Paleogeography and principal facies during deposition of Permian Blaine Formation evaporites in southwestern U.S.A.

the sea were semiarid or arid lands of low relief from which clay, silt, and sand were eroded. Epeirogenic movements caused slow but continual sinking of the crust beneath the inland sea and permitted accumulation of thick sequences of red-brown shales and interbedded evaporites.

Major structural provinces of southwestern Oklahoma are the Wichita uplift, which separates the Anadarko basin on the north from the Hollis basin on the south. The Wichita uplift, part of which is now exposed as the Wichita Mountains, extended westward beneath the sea; it sank more slowly than the adjacent basins and thus acted as a semi-positive crustal block. The Blaine Formation and associated strata are thicker in the Anadarko and Hollis basins, and are thinner over the Wichita uplift.

Stratigraphy

Stratigraphic units of special interest in this report are, in ascending order, the Hennessey Shale, Duncan (San Angelo) Sandstone, Flowerpot Shale, Blaine Formation, and Dog Creek Shale (Fig. 3). The Duncan through Dog Creek strata comprise the El Reno Group in the eastern part of the Anadarko basin, and they are of early Guadalupian age (Hills and Kottlowski, 1983). The Dog Creek Shale is overlain by the Whitehorse Group.

Hennessey Shale

The Hennessey Shale consists of red-brown shale with thin interbeds of siltstone in southwestern Oklahoma. The unit has been called the Hennessey Shale consistently (Aurin and others, 1926; Miser, 1954; Scott and Ham, 1957; Fay, 1965), although it has informally been referred to as the Hennessey Group (Carr and Bergman, 1976; Havens, 1977). The type region for the Hennessey Shale is just west of Hennessey, in north-central Kingfisher County (Fay, 1965). In southwestern

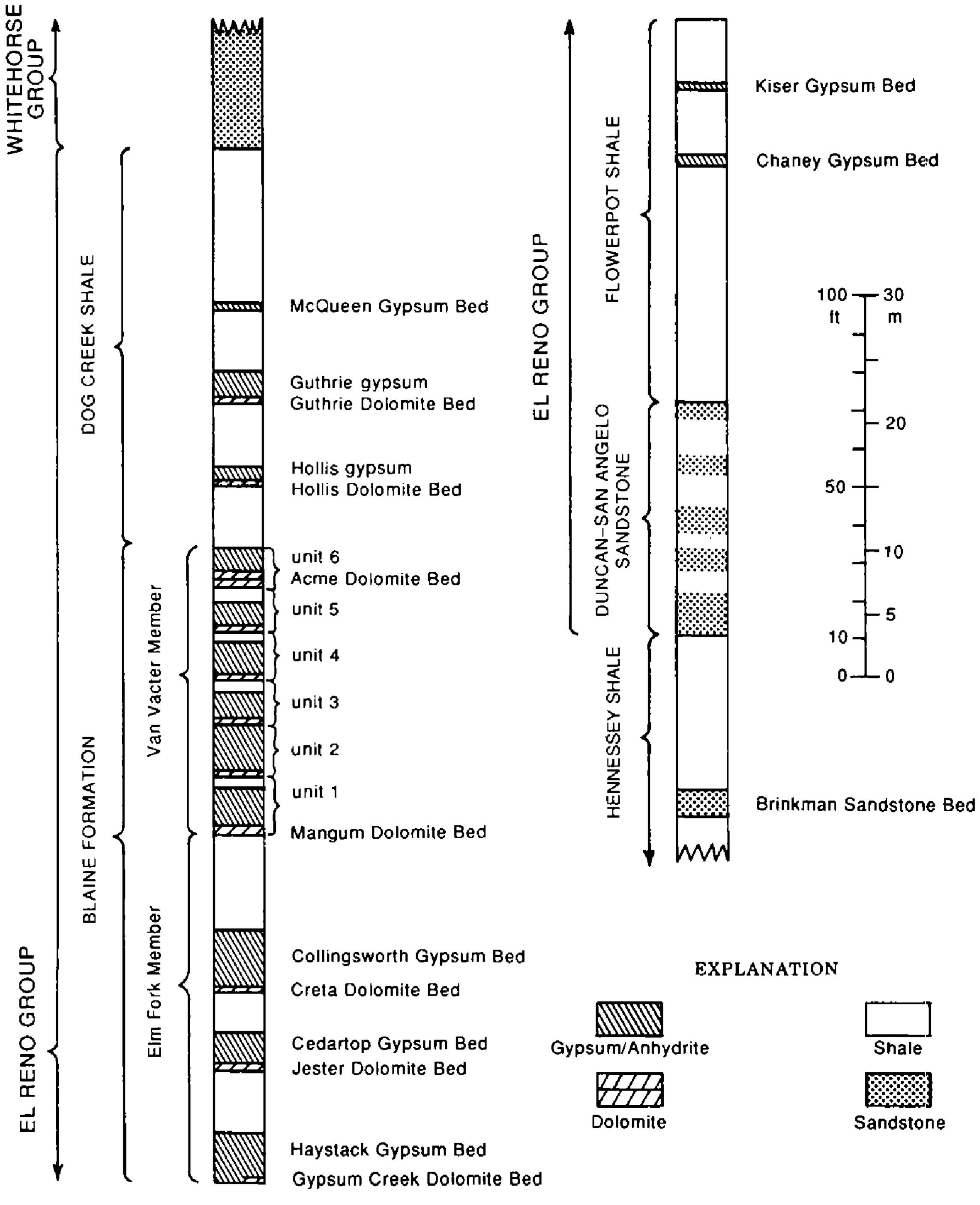

Figure 3. Standard outcrop section of Blaine Formation and associated strata in southwestern Oklahoma (modified from Johnson, 1967).

Oklahoma, as much as 50–150 ft of Hennessey strata crop out directly beneath the Duncan Sandstone on the south flank of the Anadarko basin and beneath the San Angelo Sandstone in the Hollis basin; over the Wichita uplift, the Hennessey Shale is overlain by the Flowerpot Shale.

Brinkman Sandstone Bed.—In Greer County, a 5- to 10-ft-thick, light-gray sandstone in the upper part of the Hennessey Shale crops out extensively. This bed was named the Brinkman Sandstone Bed by Johnson (1967) for exposures southwest of Brinkman, a small community 9 mi north of Mangum. The type locality and type section are in and near NW¼SW¼ sec. 20, T. 6 N., R. 22 W. At its type locality, the Brinkman is 6 ft of light-gray, very fine-grained, massive sandstone (Appendix, measured section A). Here, and elsewhere in the county, the basal several inches contains scattered subrounded to rounded quartz and feldspar grains 0.5–2.0 mm in diameter. In the Haystack core, drilled at the base of Haystack Butte ~7 mi northwest of the type locality, the Brinkman Bed is 15.5 ft of red-brown and light-gray sandstone and siltstone; at Haystack Butte the top of the Brinkman Bed underlies 303 ft of Flowerpot Shale.

In most parts of Greer County the Duncan and San Angelo Sandstones were not deposited, and thus the Hennessey shales are overlain by similar Flowerpot shales. In Greer County, the top of the Brinkman Sandstone Bed is arbitrarily defined as the top of the Hennessey (Johnson, 1967; Carr and Bergman, 1976; Havens, 1977). Elsewhere in southwestern Oklahoma the top of the Hennessey is at the base of the Duncan or San Angelo Sandstone, ~50 ft above the top of the Brinkman Bed.

Duncan and San Angelo Sandstones

The Duncan and San Angelo Sandstones consist mainly of 50–200 ft of light-gray and red-brown sandstone, siltstone, and mudstone conglomerate interbedded with green-gray and red-brown shale. The two sandstone units are stratigraphically equivalent, but each is restricted to a different part of southwestern Oklahoma. The term Duncan Sandstone was first used by Wegeman (1915) for these strata north of the Wichita Mountains, in the Anadarko basin, and this usage has persisted (Gould, 1924; Scott and Ham, 1957; Carr and Bergman, 1976); the term San Angelo Sandstone, proposed by Lerch (1891), is used south of the Wichita Mountains, in the Hollis basin and farther south in Texas, and this usage is well accepted (Beede and Christner, 1926; Havens, 1977; Barnes, 1987).

Flowerpot Shale

The Flowerpot Shale was named by Cragin (1896) for exposures in Kansas, and the type section was designated by Fay (1965) in northwestern Oklahoma. The Flowerpot has been traced to southwestern Oklahoma (Miser, 1954; Scott and Ham, 1957; Carr and Bergman, 1976; Havens, 1977) where it typically consists of 70–300 ft of red-brown shale with thin interbeds of green-gray shale, siltstone, gypsum, and dolomite.

Chaney and Kiser Gypsum Beds.—Two conspicuous and persistent gypsum beds, the Chaney and Kiser Gypsum Beds, are present in the gypsiferous upper part of the Flowerpot Shale. Gould (1902) named the Chaney and Kiser Gypsums after exposures at the Chaney and Kiser salt plains, respectively, in T. 6 N., R. 26 W., Harmon County: Chaney salt plain is in secs. 3 and 4, whereas Kiser salt plain is in sec. 11. Gould (1902) considered the Chaney and Kiser Beds to be part of the Blaine Formation, but Scott and Ham (1957) placed them in the Flowerpot Shale. The type section and type locality for both beds were designated by Hansen (1958) as the SW¼ sec. 11, T. 6 N., R. 26 W. (Appendix, measured section B). At this locality, the Chaney Gypsum Bed is 2.9 ft of white, finely crystalline gypsum 31 ft below the top of the formation; the Kiser Gypsum Bed is 2.1 ft of shaly gypsum 14 ft above the Chaney Bed and 15 ft below the top of the formation. In most parts of southwestern Oklahoma, the Chaney Bed is 2–4 ft of white to light-gray gypsum 25–53 ft beneath the top of the Flowerpot, and the Kiser Bed is 2–3 ft of gray, shaly gypsum and gypsiferous shale 13–36 ft below the top of the formation.

Prewitt and Meadows Copper Shales.—Two medium- to dark-gray copper shales, between the Chaney and Kiser Gypsum Beds in the Hollis basin, were informally named by Johnson (1976). The Prewitt copper shale is 3–12 in. thick, contains ~2.3% copper, and is 35–40 ft below the top of the Flowerpot in the Creta copper district of Jackson County. The Meadows copper shale is 4–18 in. thick, averages ~1.0% copper, and is 30–35 ft below the top of the Flowerpot in the Mangum copper district of southern Greer County.

Marty Dolomite Bed.—A thin, persistent, dolomite marker bed just above the copper shales and the Kiser Gypsum Bed was named the Marty dolomite bed by Johnson (1976), and that name is herein considered to be informal. The Marty dolomite typically is 0.1–0.5 ft of light-gray, platy dolomite 25–30 ft below the top of the Flowerpot Shale.

Blaine Formation

The Blaine Formation consists of interbedded gypsum, shale, and dolomite in outcrops of southwestern Oklahoma, where it ranges from 135 to 255 ft thick and averages 200 ft thick. Individual beds of gypsum and dolomite are laterally persistent throughout the region and can be traced into northwestern Oklahoma, Kansas, and north-central Texas. The Blaine Formation is a series of cyclic rock units, wherein each cycle consists of (in ascending order) dolomite, gypsum, red-brown shale, and green-gray shale. In southwestern Oklahoma, the Blaine typically has nine major cycles: light-gray dolomite beds commonly are 0.5–5.0 ft thick; white to light-gray gypsum beds are 5–30 ft thick; red-brown shales are 1–50 ft thick; and green-gray shales at the top of each cycle typically are 0.5–2.0 ft thick. Some of the dolomite beds locally consist largely of magnesite. Also, where deeply buried, the Blaine Formation normally contains beds of anhydrite instead of gypsum, and in some places anhydrite lenses exist within gypsum at shallow depths and in outcrops.

Gould (1902) named the Blaine Formation for exposures in Blaine County, northwestern Oklahoma, and at the same time applied the name Greer Formation, western division, to equivalent strata (that he then thought were younger) in southwestern Oklahoma. Sawyer (1924) and Gould (1924) later showed that these strata were equivalent, and proposed that the name Blaine Formation be used in both areas. Scott and Ham (1957) established the broad stratigraphic framework for the Blaine Formation that is used in southwestern Oklahoma today, whereas the current report formally divides the Blaine into two members and also proposes several additional formal and informal subdivisions within these members. Scott and Ham (1957) established the Blaine as consisting of (in ascending order) the Haystack Gypsum, Cedartop Gypsum, Collingsworth Gypsum, Mangum Dolomite, and Van Vacter Gypsum. They recognized these five units as members, but, inasmuch as the four lower units are moderately uniform, single beds of gypsum or dolomite, they later (Johnson, 1967) were considered to be beds within members of the Blaine Formation.

The Blaine Formation is subdivided into two members, the Elm Fork Member below and the Van Vacter Member above (Johnson, 1967). Although both members consist of interbedded gypsum, dolomite, and shale, there are distinct differences between them. The Elm Fork Member comprises three thick gypsum beds, each overlain by a thick shale; these gypsum and underlying dolomite beds are readily identifiable in outcrops, where they form a conspicuous series of erosional benches. The Van Vacter Member, on the other hand, comprises six thick gypsum beds separated by thin shales; the member typically crops out as low, rounded hills and is not readily subdivided, except in cores, boreholes, mines, and major bluff exposures. The two members are of nearly equal thickness, ~100 ft each, and are separated by the Mangum Dolomite Bed, an easily recognized, scarp-forming bed in most parts of the region.

Elm Fork Member

The Elm Fork Member embraces the three lowest cyclic units in the Blaine Formation of southwestern Oklahoma, from the base of the Gypsum Creek Dolomite Bed to the base of the Mangum Dolomite Bed (Figs. 3, 4). Thus the Elm Fork Member consists of (in ascending order) the Gypsum Creek Dolomite, Haystack Gypsum, Jester Dolomite, Cedartop Gypsum, Creta Dolomite, and Collingsworth Gypsum Beds, along with the unnamed shales that overlie each of the three gypsums. The Elm Fork Member ranges from 70 to 140 ft thick in southwestern Oklahoma, but commonly it is 90–110 ft thick. Individual gypsum beds thicken to the northwest, toward the large inland sea, whereas shale interbeds are correspondingly thinner in that direction.

The Elm Fork Member was named by Johnson (1967) for its excellent exposures along Elm Fork Red River, mainly on the south side of Elm Fork in T. 6 N., Rs. 25 and 26 W., where many bluffs 100–200 ft high are capped by the overlying Mangum Dolomite. One such exposure, just east of Kiser salt plain in sec. 11, T. 6 N., R. 26 W., is designated the type locality and type section (Appendix, measured section B). At this site, the Elm Fork Member is 82 ft thick and includes all units, except the basal Gypsum Creek Dolomite which was not deposited in the area. At the type locality the Elm Fork is overlain by ~30 ft of the Van Vacter Member (with 0.8 ft of Mangum Dolomite at the base) and is underlain by 63 ft of uppermost Flowerpot Shale strata.

Five out of the six named beds in the Elm Fork Member were first described at

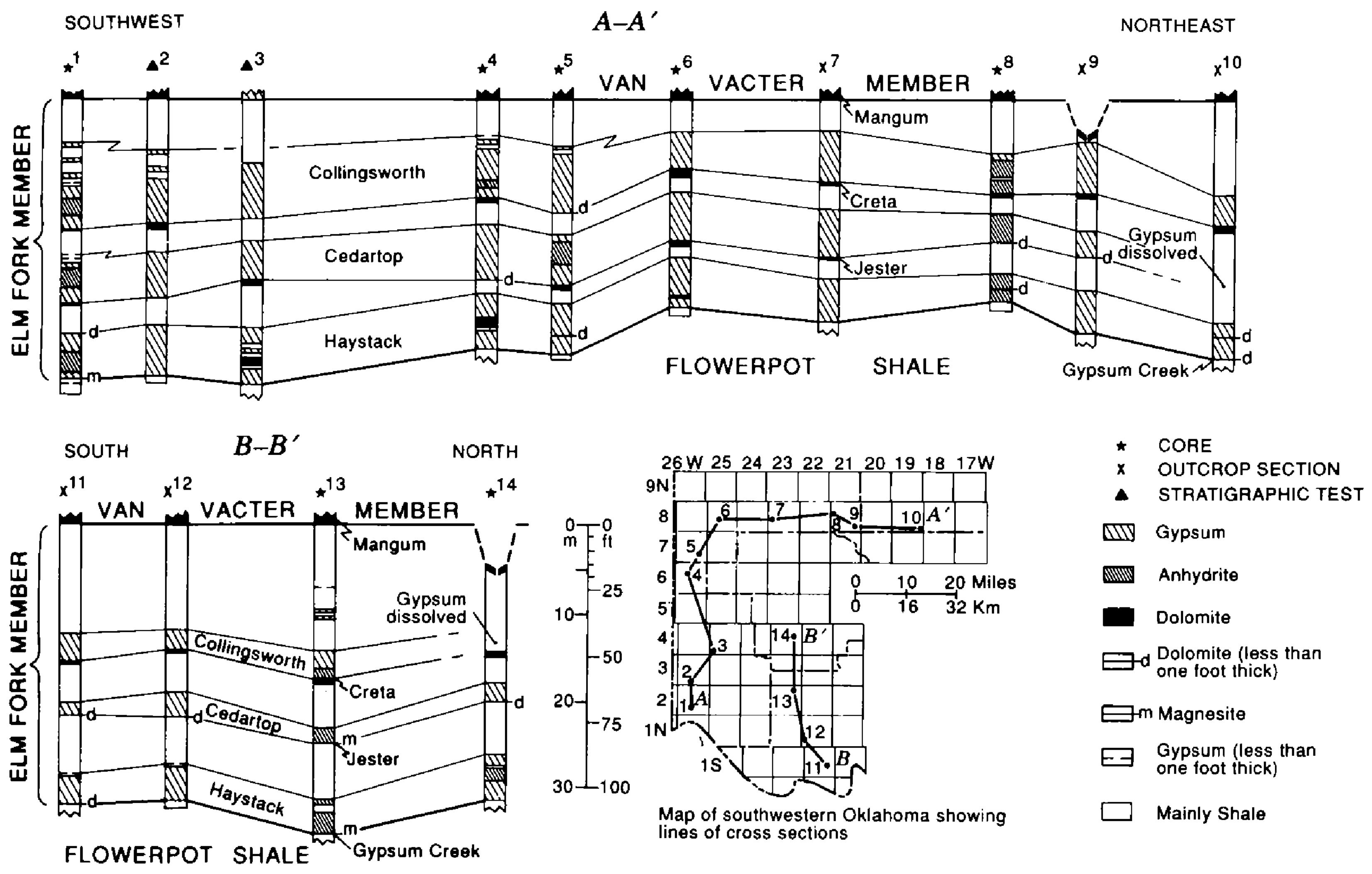

Figure 4. Stratigraphic cross sections of Elm Fork Member of Blaine Formation in southwestern Oklahoma (modified from Johnson, 1967).

least 60 years ago, and one of them (the Gypsum Creek Dolomite Bed) was first described 23 years ago.

Gypsum Creek Dolomite Bed.—Beneath the Haystack Gypsum Bed in several areas of southwestern Oklahoma is a thin dolomite that represents the base of the Blaine Formation. Johnson (1967) named it the Gypsum Creek Dolomite Bed after Gypsum Creek, whose tributaries cut across the bed in western Jackson County. The type locality and type section are just east of NW corner sec. 26, T. 1 S., R. 22 W. (Appendix, measured section C), where the bed is 0.3 ft of light-gray, microgranular, laminated, platy dolomite containing scattered particles of malachite. At this locality, the dolomite is overlain by 12 ft of Haystack Gypsum and is underlain by 25 ft of exposed Flowerpot strata. The thickness of the Gypsum Creek Dolomite ranges from 0.1 to 0.8 ft in southwestern Oklahoma.

The Gypsum Creek Dolomite Bed is limited to two separate areas of southwestern Oklahoma: the south flank of the Anadarko basin along the Kiowa–Washita County line, and the southeast half of the Hollis basin in Jackson County and the southern parts of Greer and Harmon Counties. In areas where the Gypsum Creek Dolomite Bed was not deposited, the Haystack Gypsum Bed is considered the base of the Elm Fork Member.

Haystack Gypsum Bed.—Gould (1902) named the Haystack Gypsum Bed for exposures along Haystack Creek and at Haystack Butte in northwestern Greer County. The type locality and type section were designated by Scott and Ham (1957, measured section II) as Haystack Butte, NW¼NE¼ sec. 23, T. 7 N., R. 23 W. At this site, the Haystack Bed is 17 ft of white, alabaster gypsum underlain by 173 ft of exposed Flowerpot shale strata; the top of the Haystack Bed is eroded here, and the Gypsum Creek Dolomite is absent due to nondeposition. The Haystack Bed is commonly 5–25 ft thick in southwestern Oklahoma, with the thickness increasing to the northwest.

Jester Dolomite Bed.—Suffel (1930) first described the Jester Dolomite and named it for the small community of Jester in western Greer County. He specifically referred to the Jester as being the dolomite between the Haystack and Cedartop Beds. Suffel did not specify a type locality, but he did make his first reference to exposures 2.5 mi north of the town. Hence, this location, SE¼ sec. 26, T. 7 N., R. 24 W., was designated the type location and type section by Murphey (1958) (Appendix, measured section D). At the type locality, the Jester Bed is 0.8 ft of gray, fine-crystalline to oolitic dolomite. It is overlain by 8.3 ft of gray to white Cedartop Gypsum and is underlain successively by 7.6 ft of unnamed shale and 15.6 ft of gray to white Haystack Gypsum. In general, the Jester Dolomite Bed is 0.5–1.0 ft thick in southwestern Oklahoma, but it ranges from 0.1 to 2.0 ft thick.

Cedartop Gypsum Bed.—The Cedartop Gypsum was named by Gould (1902) after Cedartop Butte, a prominent landmark in northwestern Kiowa County. Scott and Ham (1957) pointed out that Cedartop Butte was capped by the Haystack Gypsum and not the Cedartop Gypsum, as may have been thought by Gould, and they changed the type locality to a site 250 yards north of the butte. The type locality and type section (Appendix, measured section E) are in SE¼SE¼ sec. 35, T. 8 N.,

R. 21 W., southeastern Beckham County, where the Cedartop Bed is 10.5 ft of white gypsum underlain by 0.2 ft of Jester Dolomite and overlain by 10.5 ft of unnamed shale and 1.0 ft of Creta Dolomite. The Cedartop Gypsum typically thickens from 3–5 ft in the east to 20–25 ft in the northwestern part of the region.

Creta Dolomite Bed.—The Creta Dolomite was named by Suffel (1930) after Creta station in sec. 31, T. 1 N., R. 22 W., southwestern Jackson County. Inasmuch as Suffel did not specify a type locality for the bed, Richter (1960) designated the SW¼SE¼ sec. 30, T. 1 N., R. 22 W., as the type locality and type section (Appendix, measured section F). At this site, the Creta Bed is 1.1 ft of pale yellow-gray, pelletoidal dolomite overlain by 7.8 ft of Collingsworth Gypsum and underlain by 14.5 ft of shale and 9.0 ft of Cedartop Gypsum. The Creta is typically 1–2 ft thick in the region, but it ranges from 0.5 to 8.0 ft thick.

Collingsworth Gypsum Bed.—Cragin (1897) first used the name Collingsworth Gypsum for the entire sequence of gypsum beds exposed in Collingsworth County, Texas, just west of southwestern Beckham County. Gould (1902) later used the term to refer to a single gypsum bed (as is currently done), but he designated no type locality; a type locality and type section are herein designated as SW¼ sec. 11, T. 6 N., R. 26 W., northern Harmon County (Appendix, measured section B). At the type section, the Collingsworth Bed is 16.2 ft of white, fine-crystalline gypsum; it is underlain by 1.1 ft of Creta Dolomite and is overlain by 13.4 ft of unnamed shale and 0.8 ft of Mangum Dolomite. The thickness of the Collingsworth Bed in the region ranges from 3–5 ft in the east to 20–25 ft in most areas of the northwest; the bed is 25–38 ft thick in much of the western Hollis basin (Harmon County) where the upper 5–15 ft consists of interbedded shale and gypsum.

Van Vacter Member

The Van Vacter Member embraces the six uppermost major cyclic units in the Blaine Formation of southwestern Oklahoma (Figs. 3, 5). Scott and Ham (1957) proposed the term Van Vacter for the thick sequence of gypsum beds above the Mangum Dolomite in southwestern Oklahoma; they designated the type area as outcrops in secs. 10 and 11, T. 8 N., R. 22 W., ~2 mi northwest of the Van Vacter ranch house. Johnson (1967) proposed that the Van Vacter Member be expanded downward to include the Mangum Dolomite Bed at its base, and that its top remain (as before) the base of the overlying Dog Creek Shale.

In the type area, only the lower half of the Van Vacter is exposed. Johnson (1967), therefore, proposed a reference section where a complete sequence of the Van Vacter is present. The reference section comprises fine exposures along Cave Creek, from SW¼ sec. 28 to NE¼ 32, T. 5 N., R. 24 W., northeastern Harmon County (Appendix, measured section G). In this area, and in the Reed core drilled by the OGS near the NW corner sec. 30, T. 5 N., R. 24 W., the Van Vacter Member is 91 ft thick and is typical for most of southwestern Oklahoma.

The six principal cyclic units within the Van Vacter Member are herein numbered consecutively, upward, as units 1 through 6 (Figs. 3 and 5). They are given an informal status inasmuch as the gypsum beds and most of the dolomite beds cannot be easily identified, except in boreholes, mines, or the few places of excep-

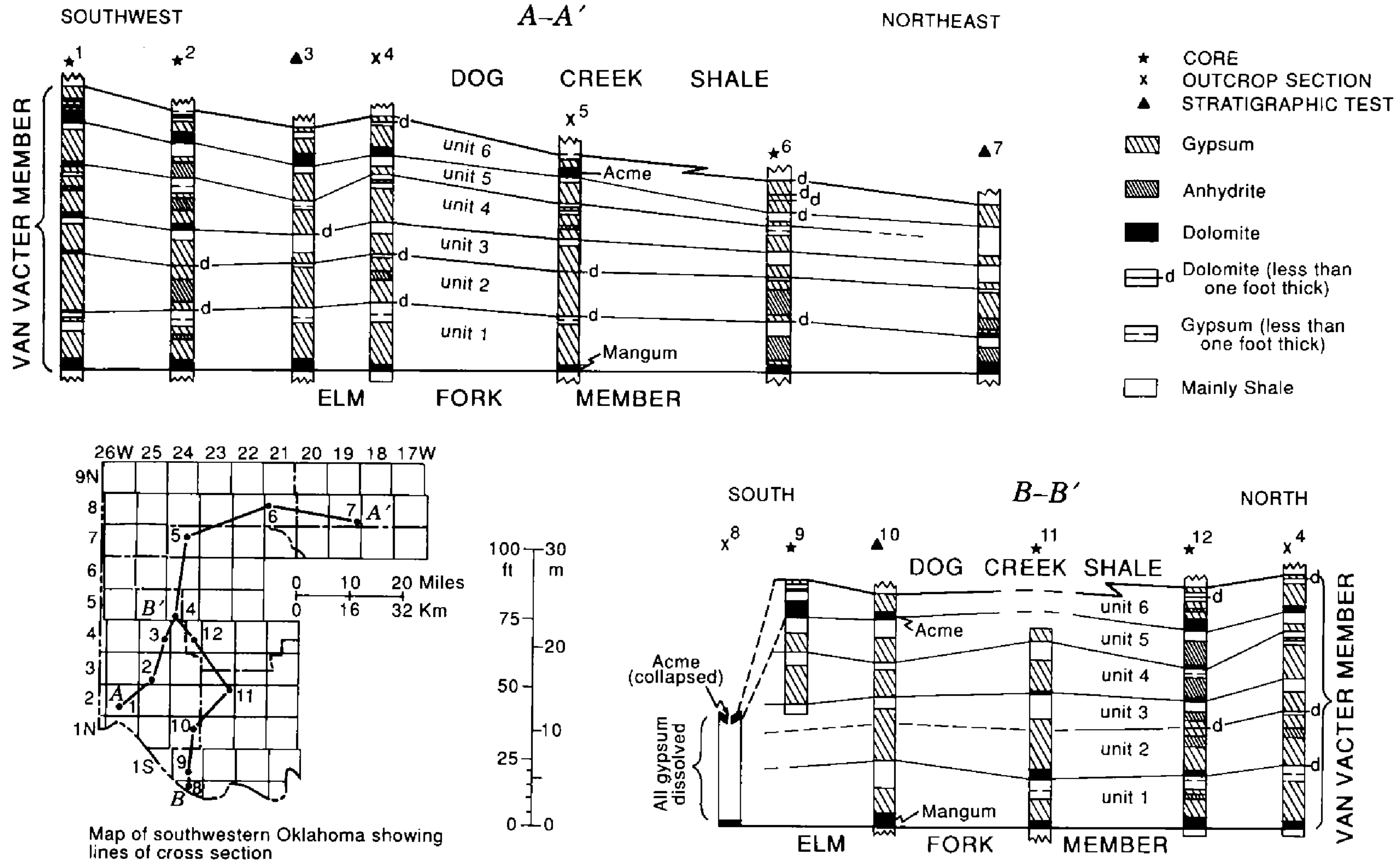

Figure 5. Stratigraphic cross sections of Van Vacter Member of Blaine Formation in southwestern Oklahoma (modified from Johnson, 1967).

tional bluff exposures. Each unit typically consists of, in ascending order, dolomite, gypsum, red-brown shale, and green-gray shale.

Thin gypsum beds are present within the shales in the upper part of several units (mainly in shale units 1, 4, and 6). These gypsum beds typically are only 0.5–2.5 ft thick and are not considered thick enough to be recognized as separate units. Farther south and west, in Texas, these thin gypsums (and a thin dolomite that underlies the thin gypsum at the top of unit 6) may increase markedly in thickness and may warrant designation as separate units in the Van Vacter Member.

The Mangum and Acme Dolomite Beds in the Van Vacter Member were previously named, and their formal status is herein retained.

Mangum Dolomite Bed.—The Mangum Dolomite Bed is probably the most significant bed in the Blaine Formation of southwestern Oklahoma. It is widespread, is typically 2–4 ft thick, caps major buttes and cuestas, and is a key bed that separates the Blaine into two members. Gould (1902) first described the bed and called it the Delphi (Delhi) Dolomite, but as this name was preoccupied he later (1905) changed the name to Mangum Dolomite after the town of Mangum in central Greer County. Gould specified no type locality for the Mangum Bed, but Hansen (1958) proposed the type locality and type section in the SE¼SE¼ sec. 16, T. 4 N., R. 22 W., southern Greer County (Appendix, measured section H). At this site, the Mangum is 3.5 ft of tan, fine-crystalline dolomite, with an eroded upper surface. It is underlain by 22 ft of unnamed shale and 5.5 ft of Collingsworth Gypsum. The Mangum ranges from 1 to 7.5 ft thick in southwestern Oklahoma. It is the basal bed of Van Vacter unit 1 and is everywhere overlain by 5–17 ft of gypsum unit 1 (Figs. 3 and 5), except where the gypsum is removed by erosion or subsurface dissolution.

Acme Dolomite Bed.—Lloyd and Thompson (1929) first referred to the Acme Dolomite Bed and its type exposure in Hardeman County, Texas, "where thick beds of gypsum, below the dolomite, are mined." The Acme Bed has been mapped extensively as a light-gray, platy dolomite 2–10 ft thick throughout north-central Texas in Childress, Cottle, Foard, and King Counties, and the southwestern part of Hardeman County (Lloyd and Thompson, 1929; Barnes, 1968,1987). The dolomite thus mapped is at the base of unit 6 gypsum in the Van Vacter. Upon examination of outcrops in South Groesbeck Creek at Acme (adjacent to the railroad bridge), and in the gypsum quarry just to the north, I find that the uppermost exposed dolomite (above the mined gypsums) is the unit 4 dolomite (Appendix, measured section I), and it is thus ~30 ft below the dolomite commonly recognized and mapped as the Acme Bed. The Acme Dolomite has been eroded from the immediate area of Acme and has not been mapped within 4–5 mi of Acme (Lloyd and Thompson, 1929; Barnes, 1987), and it undoubtedly is the exposures ~5 mi west and/or south of Acme that Lloyd and Thompson (1929) referred to as the type exposure.

The name Acme Dolomite Bed is well-ingrained in the literature, and its stratigraphic position and distribution are well-documented in north Texas and southwestern Oklahoma (except at Acme itself). Therefore, I propose that the name continue to refer to the commonly mapped Acme Bed, but that a reference section be designated as the good exposures ~18 mi to the north in Harmon County, Oklahoma. The reference locality and reference section are in NE¼ sec. 11 and SE¼ sec. 1, T. 1 N., R. 26 W. (Appendix, measured section J). At this site, the Acme is 8.3 ft thick, and consists mainly of pale yellowish-gray, laminated dolomite; it is platy in the middle and contains gypsum in the upper part. It is overlain by 9 ft of gypsum unit 6, and is underlain successively by 4 ft of shale and 15 ft of unit 5 gypsum.

In southwestern Oklahoma, the Acme Dolomite Bed is present throughout the Hollis basin, the Wichita uplift, and the western end of the Anadarko basin. The Acme Bed is typically a light-gray, laminated, platy dolomite; commonly it is 2–5 ft thick, although it is up to 9 ft thick in the far southwest. The Acme Dolomite is the basal bed of Van Vacter unit 6 and it is overlain by 4–9 ft of gypsum unit 6, except where the gypsum has been eroded. At an earlier time, Johnson (1967) proposed the name Salt Fork Bed for this dolomite, before equivalence with the Acme Bed had been established; the term Salt Fork Bed is now dropped.

Dog Creek Shale

The Dog Creek Shale was named by Cragin (1896) for Dog Creek in Barber County, Kansas, and the type locality and type section in that area were described by Fay (1964). The Dog Creek Shale has been correlated with outcrops in southwestern Oklahoma (Miser, 1954; Scott and Ham, 1957; Carr and Bergman, 1976; Havens, 1977) where typically it is 80–200 ft of red-brown shale with thin interbeds of green-gray shale, siltstone, gypsum, and dolomite.

Several widespread gypsum and dolomite beds are present in the lower, gypsiferous part of the formation. These include three formally named beds, the Hollis Dolomite Bed, Guthrie Dolomite Bed, and McQueen Gypsum Bed, and two informally named beds, the Hollis and Guthrie gypsums.

Hollis Dolomite Bed.—The Hollis Dolomite Bed was named by Johnson (1967) for exposures south of the town of Hollis in Harmon County, and he designated the type locality and type section to be SW¼SE¼ sec. 1, T. 1 N., R. 26 W. (Appendix, measured section J). At the type locality, the Hollis Dolomite is 2 ft of pale yellow-gray, fossiliferous, pelletoidal dolomite overlain by 8 ft of the Hollis gypsum and underlain by 11 ft of shale down to the base of the Dog Creek Shale. In southwestern Oklahoma, the Hollis Dolomite typically is 1–2 ft thick and is restricted to the western part of the Hollis basin, which includes Harmon County and southwestern Jackson County. The dolomite commonly is 10–15 ft above the base of the Dog Creek Shale.

Overlying the Hollis Dolomite Bed at most localities is a white gypsum, referred to informally as the Hollis gypsum (Johnson, 1967). The Hollis gypsum commonly is ~5 ft thick, but it ranges from 2 to 10 ft thick. It is 8 ft thick at the type locality of the Hollis Dolomite Bed (Appendix, measured section J). The gypsum is present in the western half of the Hollis basin; as well as to the north over the Wichita uplift, and extends farther north and east than does the Hollis Dolomite.

Guthrie Dolomite Bed.—Cheney (1929) named the Guthrie Dolomite and designated its type locality as exposures in the South Fork Wichita River at Guthrie, in King County, Texas. Cheney did not give a type section, but the one presented later by Roth (1945) at the type locality is herein proposed as the type section for the

Guthrie Dolomite Bed. The Guthrie Dolomite was originally regarded as a formation by Cheney (1929) and then as a member by Lloyd and Thompson (1929); it was later regarded as a bed by Johnson (1967), consistent with the proposed designation of beds in Flowerpot, Blaine, and Dog Creek strata in southwestern Oklahoma. At the type locality, the Guthrie Dolomite Bed is 13.1 ft of limestone and dolomite (Roth, 1945); it is overlain by 8.3 ft of Guthrie gypsum (and anhydrite) and is underlain by 25.3 ft of shale.

A reference section for the Guthrie Dolomite Bed in Oklahoma is herein proposed in SE¼ sec. 1, T. 1 N., R. 26 W. (Appendix, measured section J). In most of the Hollis basin of southwestern Oklahoma, the Guthrie Dolomite commonly is 2 ft thick and locally is up to 4 ft thick. It thins to 0.1–0.3 ft thick in the northeast part of the Hollis basin and over the Wichita uplift, and is 0.2–0.5 ft thick along the south flank of the Anadarko basin. The Guthrie Dolomite is commonly 30–45 ft above the base of the Dog Creek Shale. Johnson (1967) proposed the name Duke Bed for this dolomite before it was known to be correlative with the Guthrie Bed, and the term Duke Bed is now dropped.

Above the Guthrie Dolomite Bed in most parts of Hollis basin is a white gypsum, herein referred to informally as the Guthrie gypsum. The Guthrie gypsum typically is 4–10 ft thick, with the greater thickness toward the southwest. The gypsum is 8.3 ft thick at Guthrie, in King County, Texas, and is 8 ft thick at the Oklahoma reference section for the Guthrie Dolomite (Appendix, measured section J).

McQueen Gypsum Bed.—The McQueen Gypsum Bed was named by Johnson (1967) for exposures in SE¼ sec. 3, T. 2 N., R. 24 W., at the town of McQueen in eastern Harmon County. The type locality and type section for the McQueen Bed are at that site (Appendix, measured section K), where the McQueen Bed is impure gypsum 4.5 ft thick. The bed consists of interlaminated white, red-brown, and gray gypsum in the lower part, light-gray impure gypsum in the upper part, and a medial 1-ft-thick bed of red-brown gypsiferous shale. In southwestern Oklahoma, the McQueen Bed typically is shaly, impure gypsum that is 15–30 ft above the Guthrie Dolomite and 60–80 ft above the base of the Dog Creek Shale. The McQueen Gypsum Bed is 2–4 ft thick and is limited to the Hollis basin and areas to the south and west in Texas; in Texas the bed appears to thicken to 10–15 ft of white gypsum in Childress and Cottle Counties.

Whitehorse Group, Undifferentiated

Disconformably above the Dog Creek Shale is the Whitehorse Group, comprising the Marlow Formation below and the Rush Springs Sandstone above. In southwestern Oklahoma, it consists mostly of orange-brown and light red-brown, quartzose, very fine- and fine-grained sandstone and siltstone, and contains several beds of gypsum. Strata in the Whitehorse Group were not studied for this report, and the reader is referred to Scott and Ham (1957) and Fay (1962,1965) for more information.

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Appendix—Measured Sections

Measured Section A

Measured from SE¼SE¼ sec. 19, T. 6 N., R. 22 W. (base), to east side of outlier in NW¼SW¼ sec. 20 (top). Type section of Brinkman Sandstone Bed.

	Thickness (ft)
HENNESSEY SHALE (partial thickness, 61.5 ft)	
Brinkman Sandstone Bed	
Sandstone, light-gray, very fine-grained, massive-appearing, friable; basal 2 in. contains scattered rounded quartz and feldspar grains 0.5–2.0 mm in diameter; top eroded	6.0
Unnamed beds	
Shale intermixed with siltstone; green-gray in lower half, red-brown in upper half; scattered very fine-grained quartz; few coarse grains of quartz and feldspar	1.5
Shale, red-brown	9.5
Siltstone, light-gray, thin-bedded	0.5
Shale, green-gray	1.0
Shale, red-brown	2.0
Siltstone, light-gray, thin-bedded	0.5
Shale, green-gray	0.5
Shale, red-brown	2.0
Interbedded siltstone and silty shale; siltstone mainly light-gray and thin-bedded; shale mainly red-brown; beds generally 1–2 ft thick	19.0
Shale, red-brown	18.0
Siltstone, light-gray, coarse-grained; ledge former	1.0

Measured Section B

Measured in E½SW¼ sec. 11, T. 6 N., R. 26 W., in escarpment 300 ft east of Kiser salt plain (after Edwards, 1958). Type section of Elm Fork Member and Collingsworth, Kiser, and Chaney Gypsum Beds.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 112.7 ft)	
Van Vacter Member (partial thickness, 30.8 ft)	
Units 1 and 2	
Gypsum, white, massive; top eroded	30.0
Mangum Dolomite Bed	
Dolomite, light brownish-gray, very fine-crystalline and oolitic	0.8
Elm Fork Member (total thickness, 81.9 ft)	
Unnamed beds	
Shale, green-gray	1.5
Shale, red-brown	11.9
Collingsworth Gypsum Bed	
Gypsum, white, finely crystalline, massive; gray laminae; locally contains lenses of gray anhydrite	16.2
Creta Dolomite Bed	
Dolomite, tan, fine-crystalline to pelletoidal, vuggy	1.1
Unnamed beds	
Shale, red-brown and green-gray; thin beds of gypsum	6.4
Cedartop Gypsum Bed	
Gypsum, white to gray, fine-crystalline, massive	21.6
Jester Dolomite Bed	
Dolomite, light-gray, very fine-crystalline, platy, argillaceous	0.8
Unnamed beds	
Shale, light-green, calcareous	1.2
Shale, gray to red, gypsiferous; forms small ledge	0.6
Shale, green-gray, calcareous	1.2
Shale, red-brown and green-gray	2.8
Haystack Gypsum Bed	
Gypsum, white, fine-crystalline, massive; contains gray laminae; forms ledge	10.1
Dolomite, tan, fine-crystalline	0.3
Gypsum, white, fine-crystalline, massive; contains gray laminae	6.2
FLOWERPOT SHALE (partial thickness, 63.4 ft)	
Unnamed beds	
Shale, red-brown and green-gray	10.8
Dolomite, tan, fine-crystalline, vuggy	1.1
Shale, greenish-gray	3.0
Kiser Gypsum Bed	
Gypsum, greenish-white, shaly, hard	2.1
Unnamed beds	
Shale, red-brown and green-gray	13.7
Chaney Gypsum Bed	
Gypsum, white, fine-crystalline, massive; gray laminae in basal 1 ft	2.9
Unnamed beds	
Shale, green-gray	3.8
Shale, red-brown	1.4
Gypsum, white, fine-crystalline; gray laminae	1.3
Shale, green-gray	0.4

Shale, red-brown	2.0
Shale, green-gray, gypsiferous	1.1
Shale, red-brown and green-gray	4.8
Shale, greenish-gray; some red-brown shale	5.2
Shale, red-brown, gypsiferous	2.0
Shale, green-gray and red-brown, gypsiferous; base not exposed	7.8

Measured Section C

Measured from NW¼SW¼ sec. 23, T. 1 S., R. 22 W. (base), to SW corner of sec. 23 and NW corner of sec. 26 (top). Type section of Gypsum Creek Dolomite Bed.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 12.3 ft)	
Elm Fork Member (partial thickness, 12.3 ft)	
Haystack Gypsum Bed	
Gypsum, white, impure; recrystallized to selenite	0.5
Shale, reddish-brown	1.5
Gypsum, white, massive	10.0
Gypsum Creek Dolomite Bed	
Dolomite, light-gray, microgranular, laminated, platy; contains small masses of malachite	0.3
FLOWERPOT SHALE (partial thickness, 25.3 ft)	
Unnamed beds	
Covered; reddish-brown shale at few exposures	8.5
Dolomite, light-gray, platy	0.1
Shale, greenish-gray	0.5
Shale, red-brown; locally contains two beds of gypsum 6–12 in. thick	3.4
Shale, red-brown and green-gray	8.0
Interbedded green-gray shale and satin-spar; thin layer of dolomite at base	0.5
Shale, reddish-brown	3.8
Marty dolomite bed	
Light-gray, microgranular, platy	0.5

Measured Section D

Measured along east side of SE¼SE¼ sec. 26, T. 7 N., R. 24 W. (after Murphey, 1958). Type section of Jester Dolomite Bed.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 75.0 ft)	
Van Vacter Member (partial thickness, 2.4 ft)	
Mangum Dolomite Bed	
Dolomite, gray to yellow, oolitic, honeycombed	2.4
Elm Fork Member (total thickness, 72.6 ft)	
Unnamed beds	
Shale, green-gray	1.4
Shale, red-brown; gypsiferous in lower part	18.7
Collingsworth Gypsum Bed	
Gypsum, gray to white, coarse-crystalline, partly covered	10.7

Creta Dolomite Bed	
Dolomite, yellowish-gray, fine-crystalline, platy	0.3
Shale, orange-brown	0.3
Dolomite, yellowish-gray, fine-crystalline to oolitic, platy	0.7
Unnamed beds	
Shale, gray-green	1.8
Shale, red-brown	2.1
Shale, gray-green	1.0
Shale, red-brown	3.3
Cedartop Gypsum Bed	
Gypsum, gray to white, medium- to coarse-crystalline	8.3
Jester Dolomite Bed	
Dolomite, gray, fine-crystalline to oolitic	0.8
Unnamed beds	
Shale, gray-green	2.3
Shale, red-brown; partly covered	5.3
Haystack Gypsum Bed	
Gypsum, gray to white, medium- to coarse-crystalline	8.0
Dolomite, yellowish-gray, fine-crystalline, platy	0.3
Gypsum, gray to white, medium- to coarse-crystalline	7.3

Measured Section E

Measured in bluff in SE¼SE¼ sec. 35, T. 8 N., R. 21 W., just northeast of Cedartop Butte. Type section of Cedartop Gypsum Bed.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 49.9 ft)	
Elm Fork Member (partial thickness, 49.9 ft)	
Creta Dolomite Bed	
Dolomite, light-gray, very fine-crystalline; weathers to large slabs	1.0
Unnamed beds	
Shale, greenish-gray	2.0
Shale, red-brown	8.5
Cedartop Gypsum Bed	
Gypsum, white, very fine-crystalline; highly weathered	10.5
Jester Dolomite Bed	
Dolomite, yellowish-brown, medium-crystalline, platy; discontinuous	0.2
Unnamed beds	
Shale, greenish-gray	0.5
Shale, red-brown	7.5
Gypsum, light-gray, shaly	0.7
Shale, red-brown, gypsiferous	3.0
Haystack Gypsum Bed	
Gypsum, white and light-gray, very fine-crystalline; uppermost 2 ft poorly exposed and shaly	16.0

Measured Section F

Measured in escarpment in SW¼SW¼SE¼ sec. 30, T. 1 N., R. 22 W., ~0.2 mi northwest of Creta (after Richter, 1960). Type section of Creta Dolomite Bed.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 111.6 ft)	
Van Vacter Member (partial thickness, 7.5 ft)	
Mangum Dolomite Bed	
Dolomite, gray, oolitic; locally cross bedded; ripple marks; quarried for building stone; caps butte	6.5
Dolomite, yellowish-gray, pelletoidal, thin-bedded	0.8
Dolomite, gray to yellowish, microgranular, laminated	0.2
Elm Fork Member (total thickness, 104.1 ft)	
Unnamed beds	
Shale, gray-green	2.0
Shale, red-brown, few thin layers of gray-green shale	38.0
Collingsworth Gypsum Bed	
Gypsum, white, medium-crystalline, massive; mottled gray in basal 2 ft	7.8
Creta Dolomite Bed	
Dolomite, pale yellowish-gray, pelletoidal; compact layers weather to flagstones	1.1
Unnamed beds	
Shale, gray-green	1.0
Shale, red-brown; 1.0 ft of gray-green shale in middle	12.5
Shale, gray-green	1.0
Cedartop Gypsum Bed	
Gypsum, light-gray, fine-crystalline	2.0
Gypsum, gray and mottled pale green, medium-crystalline; thin seams of shale in top 1.5 ft	7.0
Jester Dolomite Bed	
Dolomite, yellowish-brown, pelletoidal, thin-bedded	0.2
Unnamed beds	
Shale, gray-green	1.0
Shale, red-brown	6.0
Gypsum, gray-green	0.5
Shale, red-brown; two thin beds of gypsum in lower half	9.5
Haystack Gypsum Bed	
Gypsum, gray-green; forms small ledge	0.5
Shale, gray-green, somewhat fissile	1.0
Gypsum, light-gray and mottled green-gray, medium crystalline; forms bench	11.0
Shale, gray-green, somewhat fissile	1.2
Gypsum, gray-green	0.8

Measured Section G

Measured in bluffs on southeast side of Cave Creek from NW¼SW¼ sec. 28, T. 5 N., R. 24 W. (base), through the SE¼SE¼ sec. 29 and NE¼NE¼ sec. 32 (top). Reference section of Van Vacter Member.

	Thickness (ft)
DOG CREEK SHALE (partial thickness, 35.6 ft)	
Guthrie gypsum bed	

White, fine-crystalline; much collapse; estimated maximum thickness	7.0
Guthrie Dolomite Bed	
Dolomite, light-gray, microgranular	0.1
Unnamed beds	
Shale, green-gray, gypsiferous	1.5
Shale, red-brown; poor exposures; much collapse	13.0
Hollis gypsum bed	
Impure gypsum, red-brown and medium-gray, shaly; intermixed with beds of shale; poorly exposed; estimated thickness	3.0
Hollis Dolomite Bed	
Shale and siltstone, green-gray; contains scattered plates of dolomite	1.0
Unnamed beds	
Shale, green-gray; silty in part; gypsiferous in part	4.0
Shale, red-brown	6.0
BLAINE FORMATION (partial thickness, 97.9 ft)	
Van Vacter Member (partial thickness, 91.9 ft)	
Unit 6	
Gypsum, white, fine-crystalline; impure in part	2.0
Dolomite, light-gray, microgranular, platy	0.5
Shale, red-brown, gypsiferous	1.0
Gypsum, white and light-gray, fine-crystalline; shaly in upper part	8.0
Acme Dolomite Bed	
Dolomite, light-gray, microgranular, platy; contains scattered irregular masses of gypsum	2.2
Unit 5	
Shale, green-gray	2.0
Shale, red-brown	2.0
Gypsum, white, fine-crystalline	3.5
Unit 4	
Shale, red-brown; largely covered	2.0
Gypsum, white and light-gray, fine-crystalline, banded	1.0
Shale, red-brown, gypsiferous	1.0
Gypsum, white, fine-crystalline	12.0
Unit 3	
Shale, green-gray	1.0
Shale, red-brown; gypsiferous in lower part	3.0
Gypsum, white, fine-crystalline	7.0
Dolomite, brownish-gray, pelletoidal	0.5
Unit 2	
Shale, dark green-gray and brown	1.0
Shaly gypsum, red-brown and green-gray; shale is 30% of rock	0.5
Gypsum, white, fine-crystalline; 9–12 ft above base is lens of light-gray medium-crystalline anhydrite 3 ft thick	17.0
Dolomite, pale brownish-gray, pelletoidal	0.2
Unit 1	
Shale, light-gray; gypsiferous in lower part	1.6
Shale, red-brown	1.6
Gypsum, white, fine-crystalline	0.8
Shale, red-brown	3.0
Gypsum, white, fine-crystalline; irregular masses and veinlets of dolomite in lower 5 ft	15.0
Mangum Dolomite Bed	
Dolomite, brown-gray, pelletoidal	2.5

Elm Fork Member (partial thickness, 6.0 ft)	
Unnamed beds	
Shale, green-gray	2.0
Shale, red-brown; base not exposed	4.0

Measured Section H

Measured along east–west road in SW corner sec. 15 and SE corner sec. 16, T. 4 N., R. 22 W. (after Hansen, 1958). Type section of Mangum Dolomite Bed.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 82.6 ft)	
Van Vacter Member (partial thickness, 3.5 ft)	
Mangum Dolomite Bed	
Dolomite, tan, fine-crystalline; oolitic in part; honeycombed weathered surface	3.5
Elm Fork Member (total thickness, 79.1 ft)	
Unnamed beds	
Shale, red and green, blocky	22.0
Collingsworth Gypsum Bed	
Gypsum, white, fine-crystalline	5.5
Creta Dolomite Bed	
Dolomite, tan to gray, pelletoidal to fine-crystalline, well-bedded	2.3
Unnamed beds	
Shale, green-gray	1.9
Shale, red-brown	3.0
Shale, green-gray	2.0
Shale, tan	3.0
Shale, red-brown	1.5
Shale, gray-green	0.5
Cedartop Gypsum Bed	
Gypsum, gray to white, fine-crystalline, well-banded; ledge-former	7.5
Jester Dolomite Bed	
Dolomite, gray to tan, fine-crystalline	0.5
Unnamed beds	
Shale, green-gray	1.5
Shale, red-brown	11.9
Gypsum, pale green to white, shaly	0.9
Shale, red-brown and green-gray	4.4
Haystack Gypsum Bed	
Gypsum, grayish-white, fine-crystalline	10.4
Gypsum Creek Dolomite Bed	
Dolomite, tan, fine-crystalline	0.3

Measured Section I

Measured along South Groesbeck Creek in Hardeman County, Texas. Unit 1 and most of unit 2 exposed at Talbert Crossing, 4 mi NNW of Quanah; top 4 ft of unit 2 and units 3 and 4 exposed in creek at Acme (between old Highway 287 and north bridge of railroad), ~4.5 mi WNW of Quanah.

	Thickness (ft)
BLAINE FORMATION (partial thickness, 59.3 ft)	
Van Vacter Member (partial thickness, 59.3 ft)	
Unit 4	
Gypsum, white, nodular near base, top eroded; in nearby quarry, residual blocks up to 10 ft thick	3.0
Dolomite, pale yellow-brown, fine-crystalline, platy in part; in quarry, well-exposed above "top rock" gypsum; was called Acme Bed, but is not equivalent to commonly accepted and mapped Acme farther west	4.0
Unit 3	
Shale, pale green-gray; approximate thickness	2.0
Shale, red-brown; approximate thickness	3.0
Impure gypsum, medium-gray, some red-brown and white; interbedded with gypsiferous shale	3.0
Gypsum, white; contains red-brown shale	4.0
Dolomite, light-gray; shaly in lower half	1.0
Unit 2	
Gypsum; only top 4 ft of banded medium-gray, red-brown, and white gypsum is exposed in creek at Acme; lower 20 ft of white gypsum is mined in quarry and is exposed at Talbert Crossing	24.0
Dolomite, gray-brown	0.2
Unit 1	
Shale, green-gray; gypsiferous at top	1.8
Shale, red-brown	3.3
Interbedded gypsum and shale	1.0
Shale, red-brown; many satin spar veins	3.0
Gypsum, white; upper 4 ft massive; lower 2 ft nodular; base not exposed	6.0

Measured Section J

Measured in bluff in SE¼SW¼NE¼ sec. 11, T. 1 N., R. 26 W. (base), in southwest-flowing creek in SW¼ and SE¼ sec. 1, to the NE¼NE¼SE¼ sec. 1 (top). Type section of Hollis Dolomite Bed and reference section of Acme and Guthrie Dolomite Beds.

	Thickness (ft)
DOG CREEK SHALE (partial thickness, 83.3 ft)	
McQueen Gypsum Bed	
Gypsum, white; bands and irregular blotches of light-gray and red-brown rock	1.3
Unnamed beds	
Shale, red-brown	15.0
Dolomite, light-gray, microgranular, platy	0.3
Shale, green-gray	0.5
Shale, red-brown	2.0
Impure gypsum, white and light-gray; nodular in part	0.5
Shale, green-gray	0.5
Gypsiferous shale, red-brown and green-gray; much intermixed selenite	5.0
Dolomite, light-gray, microgranular, platy	0.2
Shale, olive-gray	1.0

Shale, maroon; some olive-gray shale	2.0
Guthrie gypsum bed	
Gypsum, white, very fine-crystalline	8.0
Guthrie Dolomite Bed	
Dolomite, pale yellowish-gray and light-gray, microgranular, platy; highly weathered and honeycombed at most places	2.0
Unnamed beds	
Shale, greenish-gray	1.0
Shale, red-brown	21.0
Shale, green-gray and red-brown; plates of light-gray dolomite locally present	2.0
Hollis gypsum bed	
Gypsum, white, fine-crystalline; much recrystallization; estimated maximum thickness	8.0
Hollis Dolomite Bed	
Dolomite, pale yellowish-gray; pelletoidal and massive in lowerhalf, very fine-crystalline and platy in upper half	2.0
Unnamed beds	
Shale, green-gray and olive-gray	6.0
Shale, red-brown	5.0
BLAINE FORMATION (partial thickness, 36.8 ft)	
Van Vacter Member (partial thickness, 36.8 ft)	
Unit 6	
Impure gypsum; white, brown, and gray; much shale; poorly exposed	4.0
Gypsum, white and light-gray, fine-crystalline	5.0
Acme Dolomite Bed	
Dolomite, pale yellowish-gray, microgranular, laminated; few layers of gypsum	2.0
Gypsum; white alabaster; thin plates of dolomite	1.0
Dolomite, pale yellowish-gray; few scattered gypsum nodules and layers; laminated and platy in upper 3.3 ft; thick-bedded and compact in lower 2.0 ft	5.3
Unit 5	
Shale, olive-gray; gypsiferous in part	2.5
Shale, red-brown	1.5
Gypsum; white, with irregular blotches of light-gray and some red-brown toward base; fine-crystalline; massive	15.0
Dolomite, light-gray, microgranular	0.5

Measured Section K

Measured from NW¼SW¼SE¼ sec. 3, T. 2 N., R. 24 W. (base), in a southeast direction to SE¼SW¼SE¼ sec. 3 (top). Type section of McQueen Gypsum Bed.

	Thickness (ft)
DOG CREEK SHALE (partial thickness, 43.9 ft)	
McQueen Gypsum Bed	
Gypsum, light-gray, very fine-crystalline, partly impure; much coarse selenite	1.5
Shale, red-brown; much coarse selenite	1.0
Gypsum, multicolored (white, red-brown, and gray), banded; mostly coarse-crystalline selenite; some interlaminated shale	2.0

Unnamed beds	
Shale, mostly red-brown; some olive-gray shale	7.0
Impure gypsum; selenite crystals in a matrix of red-brown shale	0.3
Shale, olive-gray	1.2
Shale, red-brown	0.8
Gypsum, gray and red-brown, impure; thin plates of pale yellowish-gray microgranular dolomite locally present at base	0.5
Shale, olive-gray	0.9
Covered; probably red-brown shale	4.0
Shale, green-gray	1.0
Shale, red-brown	1.7
Dolomite, light-gray, microgranular, platy; highly fractured	0.2
Shale, olive-gray	1.3
Gypsum, white, impure; mostly coarse selenite nodules	0.2
Shale, red-brown and green-gray	2.6
Guthrie gypsum bed	
White and light-gray, very finely crystalline, faintly banded	5.0
Guthrie Dolomite Bed	
Dolomite, pale yellowish-brown, microgranular; interbedded with impure (mostly satin spar) gypsum	1.5
Dolomite, pale yellowish-brown, microgranular; platy in part, blocky in part; pelecypod molds	1.2
Unnamed beds	
Shale, greenish-gray	1.0
Shale, red-brown; base not exposed	9.0

NEW OGS PUBLICATION

GEOLOGIC MAP GM-32. ***Radon-Potential Map of Oklahoma,*** by James R. Flood, Tom B. Thomas, Neil H. Suneson, and Kenneth V. Luza. 1 sheet, scale 1:750,000, with accompanying 28-page text. Price: $5.

Excerpts from authors' text:

The Oklahoma Geological Survey in cooperation with the Oklahoma State Department of Health evaluated and rated the near-surface geological conditions in Oklahoma for radon potential. The study, which included a report and map showing radon potential in Oklahoma, was intended to assist the Oklahoma State Department of Health in planning site-specific indoor-radon surveys.

Four fundamental factors determine how much radon in the ground enters a building: (1) the amount of radium (uranium) in the soil and/or bedrock, (2) the amount of pore space in the rock or soil, (3) the number of openings (pores, cracks) below ground level in a building, and (4) the pressure differential across the ground/structure interface. This study only addresses the distribution and concentration of uranium in Oklahoma's soils and/or bedrock; this represents only one of the four factors that determine whether an indoor-radon hazard may exist.

This report uses uranium as a mappable indicator for radon. Uranium has been studied in great detail because of its economic and strategic importance. In Oklahoma, uranium is associated with many different rock types and geologic environments. The principal Oklahoma uranium occurrences are associated with (1) granite and sediments derived from the erosion of granitic rocks; (2) dark, organic-rich shale; (3) phosphatic black shale; and (4) coal beds.

Analytical data, airborne radiometric surveys, and uranium occurrence were the principal factors used to evaluate the bedrock formations for radon potential. Five radon-potential categories were developed: *generally very low, generally low, locally low to moderate, locally moderate, and locally moderate to high*. The modifiers *generally* and *locally* are used because the rating for a given area may not be uniformly distributed. A summary of the principal rating factors used to identify and classify geologic formations and/or units for radon potential is given.

Twenty-six areas in the State were outlined, numbered, and assigned a radon-potential category. The boundary lines are approximate; the map scale is too small to accurately portray individual beds within a formation. For organization and discussion, each area was assigned to one of four regions. Approximately 80% of the State is included in two categories, generally very low or generally low. About 7% of the State's land area has a locally moderate to locally moderate to high radon-potential rating. The rest of the State, 13%, is included in the locally low to moderate radon-potential category.

This study is a reconnaissance-level investigation based on existing geologic literature. The map scale, limited analytical data, time constraints, and lateral lithologic variations in rock units precluded a site-by-site analysis. This map does not predict indoor-radon levels. Climate, rock/soil permeability, ground-water saturation and movement, and building construction and usage strongly affect indoor-radon levels. The low–moderate–high radon-potential rating scheme only compares the distribution of uranium-bearing rocks from one outlined area to another.

GM-32 can be obtained over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

John H. Webb
(1918–1990)

In Memoriam

JOHN H. WEBB
Oklahoma Geological Survey Geologist

John H. Webb, 71, a 50-year veteran of the oil industry in Oklahoma, died Sunday, June 10, at Norman Regional Hospital, Norman, Oklahoma, after an extended illness.

Mr. Webb was born in Nashville, Tennessee, on December 26, 1918, to Hanor and Willard Holmes Webb. His career in geology began at Vanderbilt University, where he graduated Phi Beta Kappa with a bachelor's degree in geology in May of 1939. He continued his education at the University of Oklahoma, where he received a master's in geology in 1942. From 1940 to 1946, he worked as a well-site geologist for Carter Oil Co., which now is merged into Exxon.

In 1946, he returned to the University of Oklahoma, where he taught geology until joining Phillips Petroleum Co. in Bartlesville in 1948 as a staff geologist. Mr. Webb moved to Phillips' offices in Oklahoma City in 1965 and worked there until his retirement in 1985. After his retirement from Phillips, the Oklahoma Geological Survey benefited from his knowledge of geology and years of experience in Oklahoma when he joined the staff on a part-time basis.

"John brought to the Survey a wealth of professional experience in petroleum geology," Dr. Charles J. Mankin, director of the Survey, said. "His knowledge of petroleum development in the State was a valuable asset. At the time of his death, John was working on a regional subsurface correlation study of the middle Pennsylvanian in the eastern part of the Anadarko basin. His concise notes and careful documentation of his data will permit other staff to complete this important study.

"John was an enthusiastic and dedicated geologist," Mankin said. "In spite of his obvious health problems, John projected a positive outlook on life and was a source of inspiration to all who knew and worked with him. The profession has lost a dedicated geologist and we have lost a good friend."

Survivors include his wife, Carolyn, of the home; one daughter, Betty Ann Beasley, of Conway, Arkansas; one stepdaughter, Janice McGuire, of Collinsville; one stepson, Eric L. Edwards, of McPherson, Kansas; three sisters, Martha Webb, of Miami, Florida, and Ruth Siegerson and Mary Jensen, both of Albuquerque, New Mexico; and three grandchildren. Mr. Webb married Carolyn Ketcham in 1974, following the death of his first wife, Elizabeth Crain, whom he married in 1940.

He was a member of AAPG, AIPG, Oklahoma City Geological Society, and McFarlin Methodist Church in Norman. The family has designated McFarlin Memorial United Methodist Church, 419 S. University Blvd., Norman, Oklahoma 73069, or a charity of the donor's choice for memorial contributions.

Connie Smith

UPCOMING MEETINGS

Gas Technology Meeting, January 23–25, 1991, Houston, Texas. Information: Sally Goldesberry, Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 669-3377.

American Association of Petroleum Geologists, Southwest Section, Annual Meeting, February 9–12, 1991, Abilene, Texas. Information: J. Bill Hailey, Delray Oil, Inc., 205 Wagstaff Bldg., Abilene, TX 79601; (915) 672-9411.

Society for Mining, Metallurgy and Exploration, Annual Meeting and Exhibit, February 25–28, 1991, Denver, Colorado. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550.

Geotechnical Earthquake Engineering, International Meeting, March 11–15, 1991, St. Louis, Missouri. Information: Shamsher Prakash, Dept. of Civil Engineering, University of Missouri, Rolla, MO 65401; (314) 341-4489.

Lunar and Planetary Science, Annual Meeting, March 18–22, 1991, Houston, Texas. Information: Pam Jones, Program Services Dept., Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058; (713) 486-2150.

Petroleum-Reservoir Geology Meeting, March 26–27, 1991, Norman, Oklahoma. Information: Kenneth Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031.

NOTES ON NEW PUBLICATIONS

This Dynamic Planet

A five-foot-wide, computer-generated, color map of the world that can serve as a primer on plate tectonics and on volcanoes and earthquakes has been published by the USGS and the Smithsonian Institution. Authors Tom Simkin, Henry Spall, William Jones, Robert I. Tilling, and James N. Taggart have plotted nearly 1,450 volcanoes active during the past 10,000 years, along with more than 140,000 earthquakes from as far back as 1897. Text on the map sheet explains, in layman's language, what causes volcanoes and earthquakes and why they occur mostly in certain parts of the world. The map, intended as a classroom teaching aid and for general research, shows Earth's topographic and bathymetric features, overlain by its volcanoes, earthquake epicenters, and boundaries and movements of the large tectonic plates.

Order from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $4. (A $1 postage and handling charge is applicable on orders of less than $10.)

Abstracts of the U.S. Geological Survey, Central Region, 1989 Poster Review

Compiled by C. E. Barker and A. B. Coury, this 23-page open-file report contains collected abstracts of selected poster papers presented at scientific meetings.

Order OF 89-0644 from: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225. The price is $4 for microfiche and $4 for a paper copy; add 25% to the price for shipment outside North America.

Precambrian Basement Map of the Northern Midcontinent, U.S.A.

This USGS miscellaneous investigations series map is part of a cooperative federal-state project. P. K. Sims compiled the map from 1:500,000-scale maps, submitted by participating state geological surveys, which show basement drill holes, lithotype or simplified geologic map units, or basement topography, contoured at 200-ft intervals. Latitude 36° to 46°, longitude 88° to 100°. Scale: 1:1,000,000 (1 in. = ~16 mi). The color sheet measures 45 × 56½ in. The map shows the extent of individual tectonostratigraphic terranes in the buried basement, which ranges in age from Archean to early Proterozoic. The accompanying 10-page text discusses the eight terranes, the origin and age of dextral faults, and the tectonic evolution of the north-central United States.

Order I-1853-A from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $3.10. (A $1 postage and handling charge is applicable on orders of less than $10.)

Water Resources Data—Oklahoma, Water Year 1988

Records on surface water in Oklahoma are contained in this 326-page report by L. D. Hauth, D. M. Walters, T. E. Coffey, and D. K. White. Specifically, it includes (1) discharge records for 126 streamflow-gaging stations and 23 partial-record or miscellaneous streamflow stations, (2) stage and content records for 30 lakes and reservoirs, and (3) water-quality records for 39 streamflow-gaging stations and two lakes.

Order USGS Water-Data Report OK-88-1 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.

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

A brief description of each unit is accompanied by a generalized stratigraphic column. This description identifies the geologic units that comprise the geohydrologic units in selected areas of the Ozark Plateaus. The areal distribution of each geohydrologic unit at land surface is presented as a geohydrologic map. A geohydrologic section from northeastern Oklahoma through the St. Francois Mountains to Illinois depicts the vertical distribution and relative thickness of the geohydrologic units. J. L. Imes prepared this USGS hydrologic investigations atlas at a scale of 1:750,000 (1 in. = ~12 mi). Latitude 36° to 40°, longitude 89° to 96°. The color sheet measures 40 × 42 in.

Order HA 0711-A from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $3.60. (A $1 postage and handling charge is applicable on orders of less than $10.)

Major Geohydrologic Units in and Adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma; St. Francois Aquifer

The St. Francois Aquifer is defined and the geologic units that compose the aquifer are identified by J. L. Imes in this USGS hydrologic investigations atlas. Maps showing the altitude of the top of the aquifer and thickness of the aquifer are presented. A map of the predevelopment potentiometric surface of the aquifer in the vicinity of the St. Francois Mountains shows water levels area controlled by topography. The dissolved-solids concentration of the water in the aquifer does not exceed 500 mg/L near the outcrop area. Scale 1:750,000 (1 in. = ~12 mi). Latitude about 34°30′ to about 39°30′, longitude about 89°15′ to 96°. Two color sheets measure 35 × 41 in. each.

Order HA 0711-C from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $4.80. (A $1 postage and handling charge is applicable on orders of less than $10.)

OKLAHOMA ABSTRACTS

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

Arbuckle Group Depositional Cycles, Southern Oklahoma

ROBERT F. LINDSAY, Chevron U.S.A. Inc., P.O. Box 670,
Hobbs, NM 88240; and KAHTY M. KOSKELIN, Chevron,
U.S.A., P.O. Box 599, Denver, CO 80201

Outcrop and/or subsurface core studies of Butterly Dolomite, Cool Creek, Kindblade, and West Spring Creek formations reveal most of the Arbuckle Group to have been deposited as a series of storm-dominated, shallowing-upward sequences. They were deposited upon an extremely broad, nearly flat carbonate ramp that formed the southern margin of the North American craton (Knox, Arbuckle, Ellenburger, and El Paso groups) in the Upper Cambrian and Lower Ordovician.

Shallowing-upward sequences were deposited in a cyclic manner, with individual fifth-order cycles only a few feet to tens of feet thick. These cycles record abrupt transgressions, caused by quick sea level rise, followed by progradation of a paleoshoreline as sea level gradually fell. Each cycle is divided into subtidal and tidal-flat components. Subtidal and tidal-flat components can be of equal thickness or can be skewed with one component becoming dominant and the other subordinate.

Only half of all cycles are complete shallowing-upward sequences. Once understood, the vertical stacking of facies in a cycle is predictable so that complete vs. incomplete cycles can be easily recognized. These distinctions are very important to recognize because well-developed subtidal portions of a cycle can form reservoir intervals when dolomitized.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin,* v. 74, p. 705, May 1990.

Geology of the Cottonwood Creek Field, Carter County, Oklahoma

MICHAEL T. ROBERTS and DAVID READ, CNG Producing Co., 1580 Lincoln, Suite 1200, Denver, CO 80203

In late 1987, the Cottonwood Creek field, Carter County, Oklahoma, was heralded by flows of nearly 4000 BOPD and 3 MMCFGD from the upper Arbuckle Group. The field structure is part of the buried Criner uplift along the southwest

flank of the Ardmore basin. The uplift formed during a Late Mississippian/Early Pennsylvanian episode of bidirectional thrusting (northeast and southwest) probably related to convergent strike-slip faulting. The basic field structure formed as a northeast-directed thrust plate, cored with Arbuckle Group carbonates and cut by a backthrust. The Cottonwood Creek anticline was near the crest of the uplift. It was erosionally denuded of its Simpson through Caney cover and karsted to depths of at least 1600 ft. Subthrust strata include the Woodford source rocks.

In the Middle to Late Pennsylvanian the uplift was buried by clastics (about 8000 ft thick over Cottonwood Creek). Culminating in the late Pennsylvanian, a second episode of wrench faulting sliced through the Criner uplift. About 3 mi of left-lateral slip occurred on this Criner–Healdton fault, which also dropped the anticline about 3000 ft relative to the block to the south, completing the trap at Cottonwood Creek field.

Fourteen wells have found oil in the anticline over an approximately 2.5 by 0.5-mi area. The oil column is at least 900 ft thick. Eight of the wells tested for 1200–3700 BOPD plus associated gas from a complex of fractures, Brown Zone dolomite, and karst-enhanced porosity in the West Spring Creek and Kindblade formations.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 74, p. 749–750, May 1990.

Evidence for Existence of Sabkhalike Conditions in Upper Arbuckle Group, Slick Hills, Southwestern Oklahoma

D. A. RAGLAND, School of Geology, Oklahoma State University, Stillwater, OK 74078; and R. N. DONOVAN, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

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In the Slick Hills of southwestern Oklahoma, the Ordovician upper Arbuckle Group carries a cryptic record of evaporite precipitation. This record is particularly well developed in the Cool Creek and, to a lesser extent, the West Spring Creek formations. Principal lines of evidence supporting this conclusion are (1) salt pseudomorphs [after gypsum(?)] preserved in chert and, less commonly, in limestone (principal pseudomorphing minerals are calcite and dolomite), (2) molds of salts in cherts, (3) traces of anhydrite and celestite within chert nodules, (4) collapse breccias we interpret as resulting from the solution of sulfate deposits, (5) dolomite beds that have appropriate isotope values, and (6) length-slow and other varieties of chert indicative of waters of high ionic strength, some of which are the distinctive "cauliflower" variety. In addition, a number of features suggest that waters of unusual composition (i.e., "modified" seawater) were present on the Arbuckle platform from time to time. These features include rare bedded [primary(?)] cherts, subaqueous shrinkage cracks, and ooids of unusual and variable textures.

Our conclusion is that during upper Arbuckle Group deposition, particularly Cool Creek deposition, the vast Arbuckle platform was periodically exposed and a sabkhalike environment developed in which dolomitization and gypsum/anhydrite precipitation took place. Subsequent reestablishment of fully marine conditions resulted in the early removal of the sulfates, leaving only a cryptic evaporite signature.

Our interpretation can be supported in a general sense by the fact that (1) the fauna of the Cool Creek Formation is impoverished by comparison with adjacent formations, (2) the area was in a suitable climatic zone, and (3) the widespread occurrence of detrital quartz in the Cool Creek is compatible with exposure of the platform and consequent movement of clastics into the area. However, we do not wish to push the uniformitarian analogy with the modern sabkha environment too far. The enormous Arbuckle carbonate platform was an order of magnitude greater than anything existing at present, and it is unlikely that the regular shoreline paralleling and vectored facies belts seen, for example, in the Persian Gulf, could have developed on the Arbuckle platform during low-amplitude sea level fluctuations. Rather, we envisage the development of an archipelago of sabkha islands, where high points on the platform, marking sediment buildup nodes, emerged many miles from the landward margin of the craton. We have found several such islands and have been able to document their geometry in a fair degree of detail.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin,* v. 74, p. 220–221.

Southern Oklahoma Aulacogen: An Integrated Basin Model

D. A. WAVREK, Dept. of Geosciences, University of
Tulsa, Tulsa, OK 74104

A basin model has been developed for the southern Oklahoma aulacogen that includes geochemical data, structural analysis, and regional mapping. This integrated approach has been used to reconstruct the basin's complex history.

Geochemical characterization of over 400 oil samples indicates the presence of four major oil types together with mixtures of these end members. Type A oils have abundant isoprenoids and relatively abundant C_{15+} n-alkanes that show a linear decrease with increasing carbon number. Type B oils have a moderate amount of isoprenoids and an n-alkane profile that decreases exponentially with increasing carbon number. Type C oils have a moderate odd-carbon preference in the nC_{11}-nC_{19} range, moderate isoprenoids, and anomalous concentrations of alkyl-benzenes and alkyl-cyclohexanes. Type D oils have a strong odd-carbon preference in the nC_{11}-nC_{19} range, minor isoprenoids, and limited n-alkanes longer than nC_{19}. These four oil types appear to correlate with Middle Pennsylvanian shales, the Devonian–Mississippian rock units, the Viola Group (tentative), and an unidentified Ordovician unit, respectively.

Because the sedimentation history of a region reflects the tectonic development, burial reconstructions are combined with a thermal model to establish the timing of hydrocarbon generation. The three-dimensional extension of this procedure demonstrates that the major pulse of oil migration from the Ardmore basin was concurrent with the fold development during Early Pennsylvanian deformation, whereas migration from the Marietta basin was affected by fault displacements that were more extensive during Late Pennsylvanian deformation. The distribution of various oil types helps constrain the basin model and demonstrates the application of geochemistry in a mature exploration province.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 74, p. 788, May 1990.

Seismic Exploration of Ouachita Frontal Fairway, Southeastern Oklahoma

ALLEN J. BERTAGNE and TIM C. LEISING, CGG American Services, Inc., 2500 Wilcrest Dr., Houston, TX 77042

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The Ouachita frontal fairway has been the site of considerable recent exploration and significant discoveries. Targets include Spiro and Wapanucka reservoirs on thrusted structures, and deeper Arbuckle carbonates on fault-bounded blocks. Because of the tectonic complexity of the area, favorable trends and prospects are defined using modern seismic data. High quality seismic data requires careful acquisition and processing. Acquisition should aim to minimize skips, to maintain a close group interval, and to record data on far offsets. In processing, migration velocities must be selected carefully because they affect apparent size of a structure. Interpretation should be based on simultaneous examination of migrated and unmigrated sections. Sections exhibiting sideswipe should be interpreted with caution.

Recently acquired seismic data illustrates the structural style and exploration challenges of the Ouachita frontal fairway.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 74, p. 610, May 1990.

Woodford Shale (Upper Devonian–Lower Mississippian) and Associated Phosphate Nodules

SUZAN SIY, Bridge Oil (USA) Inc., 12377 Merit Dr.,
Suite 1600, Dallas, TX 75251

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A deep-water marine environment is inferred for the Woodford Shale formation (Upper Devonian–Lower Mississippian) in the Arbuckle and Ouachita mountains of southern Oklahoma. Black shales and associated phosphate nodules were deposited peripherally to the carbonate shelf adjacent to the North American craton. Analysis indicates that shales and interbedded cherts lack siliciclastic detritus and shallow-water fauna, and that they have an abundance of siliceous organisms. Depletion of Ce in the Woodford Shale relative to average shale compositions suggests the influence of deep oceanic water. Carbon isotope compositions of shales, cherts, and phosphates for $\delta^{13}C$ range from –27.5 to –30.2‰. These values are compar-

able to Devonian–Mississippian values reported for distal marine sediments that get successively lighter farther from shore.

In-situ phosphate nodules occurring in the top of the formation are early diagenetic features that formed in the upper few centimeters of organic-rich sediment in a poorly oxygenated subaqueous environment. A hierarchy of apatite morphologies in nodules indicates stages of diagenesis. Structureless collophane probably is representative of primary marine apatite. Higher order apatite phases successively include globular collophane, botryoidal apatite, and apatite crystallites. The latter commonly is associated with silicified nodules. Silicification of phosphate nodules represents the most advanced stage of diagenesis prior to sediment lithification, and it implies that silica diagenesis within the Woodford occurred after nodules formed. Preserved radiolarians and sponge spicules observed in nodules also indicated that apatite precipitated before biogenic silica dissolved.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 74, p. 222, February 1990.

Exceptional Marine Sand Bodies in the Paleozoic of Oklahoma

RICHARD D. FRITZ, M. D. KUYKENDALL, ELLEN O. HOOKER, and JOHN W. SHELTON, MASERA Corp., 1743 E. 71, Tulsa, OK 74136

Of the wide variety of sandstone reservoirs in Oklahoma, the most unusual types of sand bodies are present in the Atokan Spiro Sandstone, Devonian Misener Sandstone, and Morrowan lower Morrow Sandstone. The common factors are that upon correlation and mapping these units are channel-like (fluvial-deltaic) in geometry, but from petrographic evidence are quartz-rich shallow-marine units, with the exclusion of intraclastic and diagenetic constituents.

Stratigraphic mapping of the Spiro Sandstone of the Arkoma basin indicates two types of sand bodies: channel and sheet. The marine channel-like deposits, 10–150 ft. thick, probably were deposited on a paleosurface produced by a pre-Atokan unconformity. Examination of cores and outcrop indicate that both the channel and sheet Spiro sands contain shallow-marine fossils, limestones, peloidal chamosite, burrows, and bioturbation, all indicative of a shallow-marine setting.

The Misener Sandstone of north-central Oklahoma ranges from 10 to 100 ft. thick with sharp boundaries. It was deposited in pre-Frisco/Woodford eroded paleochannels. Core evidence for shallow-marine deposition is glauconite, phosphatic fossils and clasts, burrows, and bioturbation. These were probably deposited in an embayed, estuary-like environment.

The lower Morrow Sandstone of the Anadarko basin is similar in geometry, except that the sand bodies are multistoried and multilateral and do not appear to be associated with a regional unconformity. The lower Morrow sandstones, usually 30–60 ft. thick, commonly are elongated and deposited parallel to the shoreline. Deposition is inferred to be shallow-marine from marine fossils and glauconite.

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The Thermal History of the Arkoma Basin and the Eastern Ouachita Mountains from AFTA (Apatite Fission Track Analysis)

D. C. ARNE, I. R. DUDDY, and P. F. GREEN, Geotrack International Pty. Ltd., Victoria, Australia

Results of an Apatite Fission Track Analysis (AFTA) study indicate that regional cooling commencing around the middle Cretaceous (~100 Ma) has affected both the relatively undeformed Arkoma basin sediments and the folded rocks of the eastern Ouachita Mountains (Benton uplift). Outcropping Pennsylvanian rocks of the Arkoma basin sequence in a section along the Arkansas River between Little Rock and Ozark, Arkansas, as well as Mississippian and older rocks in a section across the Ouachitas between Russellville and Hot Springs, Arkansas, experienced paleotemperatures between about 90 and 110°C immediately prior to middle Cretaceous cooling. Cretaceous intrusive rocks have apatite fission track ages indistinguishable from K–Ar and Rb–Sr ages at about 95 Ma, with mean track lengths greater than 14 μm indicating rapid cooling from temperatures greater than approximately 110–50°C or less at this time.

AFTA data from Missouri also show evidence of cooling from elevated paleotemperatures during the middle Cretaceous and suggest the possibility of raised thermal gradients (~50°C/km). These data emphasize the regional extent of the observed cooling episode, which appears to have involved uplift and erosion of at least 1–2 km of section from across the region since the middle Cretaceous.

Comparison of these results with published vitrinite reflectance data suggests that the Arkoma basin sequence achieved maximum paleotemperatures during late Paleozoic burial, and that paleotemperatures reached in the Mesozoic, during rifting in the Mississippi Embayment, were of lower magnitude. These observations have important implications for hydrocarbon generation and exploration in the Arkoma basin.

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Red Oak and Fanshawe Sands: Two Submarine-Fan Channel Tight-Gas Reservoirs in a Complex Thrust Belt, Arkoma Basin, Oklahoma

LAURA L. WRAY, AMOCO Production Co., 1670 Broadway, Denver, CO 80202

Pennsylvanian–Atokan-age sedimentation and subsequent structural development of a foreland thrust belt have created traps for large hydrocarbon accumulations in the Arkoma basin in eastern Oklahoma and western Arkansas. Red Oak field, located in Latimer and Le Flore counties in Oklahoma, is the largest dry gas reservoir in the basin. The middle Atokan Fanshawe and Red Oak sands are the two dominant clastic reservoirs and have produced 800 bcf of gas to date.

The submarine-fan-channel depositional origin proposed for these two sands is supported by sedimentary structures visible in cores, petrologic evidence, and the three-dimensional distribution of sands. Variations in these criteria exist between the Red Oak and Fanshawe sands, representing the evolutionary development of the Arkoma basin that affected sediment discharge, transport mechanisms, and sea level fluctuations.

Convergent tectonism along the Ouachita orogenic belt resulted in the development of Atokan thrust imbricates in Red Oak field. Thrust repetition of Fanshawe and Red Oak sands increases reservoir thicknesses in a given well bore but necessitates the palinspastic restoration of these imbricates in order to reconstruct the original depositional trends of these sinuous, anastomosing fan channels.

Field-wide correlation of these stacked channels is impossible. Petrologic studies have failed to provide depositional or diagenetic criteria for distinguishing sedimentary episodes during fan development. Isopach maps of the total clean sand intervals have been utilized successfully to maximize reservoir thicknesses in 45 infill well locations.

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Early Diagenetic, Aerobic Degradation of Organic Matter and Sulfides in Some Middle and Upper Pennsylvanian Marine Shales, Mid-Continent Region, United States

J. R. HATCH, J. S. LEVENTHAL, and G. A. DESBOROUGH, U.S. Geological Survey, Box 25046, Denver CO 80225

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Organic and elemental analyses of 127 core samples of Middle and Upper Pennsylvanian organic-matter-rich marine shales (offshore shale lithofacies) from the Mid-Continent region of the United States show that organic matter and sulfides in some shales have been extensively altered. Altered and unaltered shales are similar in that they are laminated, phosphatic, organic-matter rich, and metalliferous with V contents 500–2500 ppm; cr, 200–800 ppm; Ni and Mo, 100–500 ppm; and U, 30–100 ppm. Other compositional parameters, however, are significantly different. For example, the Desmoinesian Excello Shale Member of the Mouse Creek Formation in southern Iowa and northern Missouri is altered and has (1) relatively low organic carbon contents (3.8–9.2% compared to 8.2–30% for unaltered shales from the same area); (2) very low hydrogen indices (3–58 mg/g compared to 230–410 mg/g; (3) isotopically heavy organic matter ($\delta^{13}C = -22.0$ to –24.3‰ compared to –25.2 to –27.2‰); and (4) low contents of sulphur (<0.1 to 1.0% compared to 1.2 to 2.6%). These differences suggest that hydrogen-rich, isotopically light organic matter and most sulfides have been lost from the Excello Shale.

Alteration apparently took place during subaerial exposure following marine regression. Oxygenated rainwater circulated down to the level of the Excello mud and allowed metabolism of organic matter and sulfides by aerobic microorganisms. This hypothesis is supported by previous researchers, who have identified freshwater carbonate cements within, and soil horizons at the top of the limestone overlying the Excello Shale (Blackjack Creek Limestone Member of the Fort Scott Limestone). The period of alteration is constrained in that organic matter and sulfides appear unaltered in the Little Osage Shale Member of the Fort Scott Limestone, which immediately overlies the Blackjack Creek Limestone, 20–25 ft (6.1–7.6 m) above the Excello Shale. Alteration similar to that in the Excello Shale has also occurred in the Missourian Husllpuckney Shale Member of the Swope Limestone in north-central Kansas.

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Comparison of Depositional Elements of an Ancient and a "Modern" Submarine Fan Complex: Early Pennsylvanian Jackfork and Late Pleistocene Mississippi Fans

JAMES L. COLEMAN, JR., AMOCO Production Co.,
P.O. BOX 3092, Houston, TX 77253

Normark urged that all future, meaningful deep-sea fan comparisons be confined to key depositional elements common to most turbidite systems. These elements should include basin size, tectonic and eustatic setting, and depositional process indicators. A test case for elemental comparisons between two widely studied fan complexes is presented and evaluated.

The lower Pennsylvanian (Morrowan) Jackfork submarine fan complex extends from central Arkansas to northeast Texas. Sequence analysis suggests that the Jackfork is composed of four to seven depositional episodes and occupies the floor of a deep basin bordered to the north and east by a passive carbonate-siliciclastic shelf margin and to the south and east by a northward-advancing orogenic belt. The Jackfork apparently unrestricted to the west and southwest.

The Mississippi submarine fan complex extends from the submerged continental shelf of southern Louisiana to the abyssal depths between Yucatan and Florida. The fan complex is primarily Pleistocene in age, with the present morphologic fan being late Wisconsinian. The Mississippi Fan is composed of 17 depositional episodes. It occupies the floor of a deep basin bordered on the north and west by quiescent(?) halokinetic-siliciclastic shelf margins and to the east and south by passive carbonate margins.

Elemental comparisons between the Mississippi fan and a palynspastically restored Jackfork fan complex suggest that both are quite similar, even though the Mississippi fan is up to three times larger in some categories. Comparative study of key depositional elements facilitates a more complete understanding of both modern and ancient submarine fans.

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Recent Developments at Wilburton Field, Latimer County, Oklahoma

RICHARD C. HOOK, Anadarko Petroleum Corp., 211 N.
Robinson, Oklahoma City, OK 73102

Recent deeper drilling in Wilburton field has resulted in new production from the Spiro, Cromwell, and Arbuckle formations. The new field reservoirs occur on a large horst block that underlies the old field pay in the overthrust Spiro. ARCO Oil and Gas first discovered this production in Sec. 36, T5N, R17E from the in-situ Spiro, beneath a low-angle thrust fault. Nine wells now produce from this Spiro reservoir.

Structural data generated by drilling the in-situ Spiro reservoir revealed a southwest-dipping, upthrown fault block with nearly 2000 ft. of vertical relief. ARCO Oil and Gas tested this feature to basement with their 2 Yourman well in Sec. 15, T5N, R18E, discovering prolific gas production from the Arbuckle. The Arbuckle porosity consists largely of vugs, solution channels, and open fractures in a clean dolostone. The trap is created by the fault juxtaposition of the Arbuckle reservoir against impermeable Mississippian and Pennsylvanian shales along the updip (north) edge of the field. Conventional neutron-density logs show low porosity, but cores and Formation Microscanner images reveal the vugs, some of which are several inches across. Permeability is created by the solution channels, and a pervasive system of open fractures and microfaults. All current production is from the uppermost 700 ft. of the Arbuckle, with a gas column of at least 1100 ft. To date, ten Arbuckle wells have been completed, one is in completion, and one is drilling. Exploration is currently focused along the southern edge of the Arkoma basin, in a similar structural setting to Wilburton field.

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Geologic Controls on the Production Characteristics of Cyclical, Mixed Carbonate-Clastic Gas Reservoirs, Lower Permian Chase Group, Guymon-Hugoton Field, Oklahoma

TERRY W. SIEMERS, Phillips Petroleum Co., Bartlesville, OK 74004; and WAYNE M. AHR, Geology Dept., Texas A&M University, College Station, TX 77843

The Lower Permian Chase Group, Guymon-Hugoton field, Oklahoma, is composed of interlayered carbonates, siliciclastics, and evaporites deposited in cyclical, shallowing-upward sequences on a gently dipping, low-relief shelf. Each cycle forms a reservoir layer comprised of laterally continuous, successively shallower water marine carbonates and siliciclastics capped and separated by shaly red beds and paleosols. Reservoir studies indicate that individual reservoir layers have contrasting permeabilities and volumes, are not in pressure communication, and

exhibit different depletion characteristics. No virgin pressures have been revealed by recent drilling, indicating that no new gas has been discovered and that the current well-spacing pattern has been efficiently draining the field.

Siltstones and sandstones consist of framework quartz, feldspar, mica, and rock fragments and interstitial clay, carbonate, and anhydrite; porosity is primarily intergranular. Within cycles, limy or dolomitic skeletal, pelletal, and oolitic subtidal grainstones to wackestones grade upward into intertidal to supratidal wackestones and mudstones. Intergranular and crystal- or grain-moldic pore types and a well-developed, laterally continuous, intercrystalline pore system, produced by dolomitization and independent of depositional texture and other pore types, provide fair to excellent porosity and permeability within individual reservoir layers. Lateral continuity of the intercrystalline pore network and individual reservoir layers promotes good field drainage.

Shaly layers are composed of shaly mudstones and argillaceous carbonates that exhibit low permeabilities and high threshold entry pressures. Primary components include illitic, chloritic, and smectitic clays, authigenic carbonate and anhydrite, and detrial quartz, feldspar, and micaceous silt. Lateral continuity, low permeability, and high threshold entry pressures make shaly layers effective regional barriers to vertical fluid flow and prevent pressure communication between reservoir layers.

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Iron Sulfide Minerals at Cement Oil Field, Oklahoma: Implications for Magnetic Detection of Oil Fields

RICHARD L. REYNOLDS, NEIL S. FISHMAN, RICHARD B. WANTY, and MARTIN B. GOLDHABER, U.S. Geological Survey, Federal Center, Denver, CO 80225

Aeromagnetic anomalies at Cement oil field (Anadarko basin, Oklahoma) have been attributed to authigenic magnetite. The following characteristics of the magnetite, however, indicate that it is contamination introduced by drilling: (1) occurrence as sharp angular blades and as spheres, commonly with metallographic textures typical of industrial alloys and with associated steel and wustite (FeO); (2) presence only in well cuttings and absence from core and quarry samples; and (3) lack of association with detrital framework grains or with authigenic carbonate and sulfide minerals.

Ferrimagnetic pyrrhotite occurs in well cuttings, cores, and quarry samples at Cement and is a possible natural source of the magnetic anomalies. Pyrrhotite, which is intergrown with more abundant FeS_2 minerals, formed as a result of hydrocarbon seepage. Pyrrhotite is confined to beds above oil and gas reservoirs. These beds, which lack detrital organic matter, contain higher mineral sulfide and lower mineral sulfate sulfur (1.7 and 0.1 wt %, respectively) than do correlative beds off the field (0.2 and 1.1 wt %, respectively). In the field, isotopic values of sulfide S show a systematic decrease upward through the Permian section from positive values (maximum, +12 per mil at ~610–760 m depth) to negative values (–1 to –11 per mil between 32 and 230 m; –26 to –30 per mil at the surface). Geochemical results, together with time-tempertaure data derived from burial curves, limit the major sources of the sulfide in the Fe–S minerals to two possibilities. Isotopically heavy sulfide was generated either inorganically at temperatures >~90°C in beds beneath Permian beds, or by bacterial sulfate reduction at temperatures <~60°C in Permian strata. If the latter, microbial sulfate reduction occurred under sulfate-limited conditions. The isotopically light sulfide occurring in minerals near the present surface is attributed to bacterial reduction of sulfate. Sulfate-reducing bacteria derived metabolic energy from leaking hydrocarbons and associated organic compounds.

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Remagnetization of the Rush Springs Formation, Cement, Oklahoma: Implications for Dating Hydrocarbon Migration and Aeromagnetic Exploration

R. DOUGLAS ELMORE and MARK C. LEACH, School
of Geology and Geophysics, University of Oklahoma,
Norman, OK 73019

The Permian Rush Springs Formation above the Cement anticline in Oklahoma contains a Late Permian–Early Triassic chemical remanent magnetization (CRM) that is interpreted to reside in authigenic magnetite. The CRM is found in bleached, carbonate-cemented sandstones that were altered by hydrocarbons and contain authigenic magnetite. The magnetite presumably precipitated in the Late Permian–Early Triassic as a result of chemical conditions created by hydrocarbons or associated fluids that migrated from underlying reservoir units. Red sandstones around Cement that were not altered by hydrocarbons contain a Permian CRM that resides in hematite. The red and bleached sandstones have similar magnetization intensities and susceptibilities; this raises questions about the use of aeromagnetic surveys in hydrocarbon exploration.

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Magnetic Forward Models of Cement Oil Field, Oklahoma, Based on Rock Magnetic, Geochemical, and Petrologic Constraints

R. L. REYNOLDS, M. WEBRING, V. J. S. GRAUCH, and
M. TUTTLE, U.S. Geological Survey, Federal Center,
Denver, CO 80225

Magnetic forward models of the Cement oil field, Oklahoma, were generated to assess the possibility that ferrimagnetic pyrrhotite related to hydrocarbon seep-

age in the upper 1 km of Permian strata contributes to aeromagnetic anomalies at Cement. Six bodies having different magnetizations were constructed for the magnetic models, based on geology and on petrologic and geochemical results, supplemented by rock magnetic measurements of shallow-core and outcrop samples. The column of rock through which hydrocarbons have passed is divided into three sulfide zones on the basis of pyrrhotite content, and the column is capped by a 30-m-thick zone that contains ferric oxide minerals formed mainly from oxidized pyrite. Red beds unaffected by sulfidization, as well as a zone of rock depleted in hematite but lacking sulfide, surround sulfidic zones.

The synthetic magnetic profiles are controlled mainly by pyrrhotite-bearing strata at depths of 200–500 m. The magnetizations of these bodies are calculated from: (1) petrographic estimates of pyrrhotite content relative to pyrite; (2) content of sulfide sulfur determined from chemical analysis; and (3) values for the magnetic susceptibility of monoclinic pyrrhotite. Total magnetizations of the bodies of highest pyrrhotite content range from about 3×10^{-3} to 56×10^{-3} A/m in the present field direction and yield magnetic anomalies (at 120 m altitude) having amplitudes of less than 1 nT to ~6 to 7 nT, respectively. Such amplitudes are much lower than those (as high as 60 nT) reported from the original total-field survey over the Cement field.

Numerous assumptions were made in the generation of the models, and thus the results neither prove nor disprove the existence of aeromagnetic anomalies related to hydrocarbon seepage at Cement. Nevertheless, the results suggest that pyrrhotite, formed via hydrocarbon reactions and within a range of concentrations estimated at Cement, is capable of causing magnetic anomalies.

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Morphology of the Frontal Fault Zone, Southwest Oklahoma: Implications for Deformation and Deposition in the Wichita Uplift and Anadarko Basin

DAVID A. McCONNELL, MICHAEL J. GOYDAS,
GRAHAM N. SMITH, and JOHN P. CHITWOOD, Dept.
of Geology, Kansas State University, Manhattan, KS
66506

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Structural fabrics along the northern margin of the Wichita uplift, southwestern Oklahoma, are compared with depositional patterns in the adjacent Anadarko basin. The Frontal fault zone, the structural transition between the uplift and basin, is divisible into three segments that reflect the partitioning of deformation along the northern margin of the uplift. Variations in Pennsylvanian isopach patterns within the Anadarko basin suggest changing conditions of tectonic loading along the basin's southern margin. Anomalously thin sections of syntectonic rocks in the deep basin are interpreted to have been deposited on the crests of growing anticlines.

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Cyclic Sedimentation in the Desmoinesian Cabaniss ("Upper Cherokee") Group, Anadarko Basin

JAMES O. PUCKETTE, School of Geology, Oklahoma
State University, Stillwater, OK 74078

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Pennsylvanian transgressive-regressive sedimentary cycles related to eustatic sea-level changes are well documented in rock sequences of the Midcontinent outcrop belt. Facies equivalent to the repetitive limestone-and-shale units composing these cycles are mappable in the Anadarko basin. Basinal sedimentary cycles are not well documented, due to a scarceness of data from cores and the difficulty in recognizing the components of cycles on wire-line logs. Mud-rich deep-water limestones have less-responsive resistivity and "hotter" gamma-ray log signatures than their shallow-water equivalents. Diagnostic features of emergent terrane—such as paleosoils and caliche—are not detectable on logs. Gamma-ray curves are useful in identifying "hot" shales, which correlate to core shales of the shelf. "Hot" shales are the record of maximal transgressions, whereas soil zones and calcrete nodules preserved in a few cores indicate subaerial exposure and extensive regression.

Sedimentary structures and lithofacies changes are important in identifying the disconformable boundary between the Cabaniss (Upper Cherokee) the Krebs (Lower Cherokee) Groups. A cored caliche zone defines the boundary between the Skinner progradational (regressive) sequence and the overlying Verdigris transgressive interval. The upper boundary of the Cabaniss Group in the Anadarko basin is the "Cherokee hot shale." This shale is equivalent to the Excello Shale on the shelf and represents a maximal transgression prior to deposition of the Marmaton Group.

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Geologic History of the Anadarko Basin, Western Oklahoma, North Texas Panhandle, and Southwestern Kansas

J. K. PITMAN, R. C. BURRUSS, T. S. DYMAN, R. M.
FLORES, J. R. HATCH, M. HENRY, C. W. KEIGHIN,
W. J. PERRY, JR., R. M. POLLASTRO, J. E. REPETSKI,
R. L. REYNOLDS, D. D. RICE, R. L. ROBBINS, and
J. W. SCHMOKER, U.S. Geological Survey, Box 25046,
Denver, CO 80225

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The deep Anadarko basin in western Oklahoma, the north Texas panhandle, and southwestern Kansas is a major hydrocarbon-bearing province in the Mid-Continent that has had a complex depositional and structural history. From the Late Cambrian through Early Mississippian, thick sequences of shallow-marine carbon-

ate rocks, organic-rich shale, and sandstone were deposited in a broad epicontinental sea that extended across the southern Mid-Continent. This sea formed an embayment that opened to the southeast into the proto-Tethys ocean. During the Pennsylvanian, the Anadarko basin formed, in its approximate present configuration, along the northern shelf of the older southern Oklahoma trough. Uplift of the Amarillo–Wichita Mountains and related structural blocks caused basin downwarping by thrust or transpressional loading. Deposition of coarse clastic sediment along mountain fronts accompanied Pennsylvanian and Permian deformation. This course sediment graded basinward into well-dated marine sandstone, shale, and limestone, allowing the timing of deformation to be precisely determined. In the basin interior, fault-bounded beheaded folds formed islands that were surrounded by coarse clastic wedges that became traps for hydrocarbons. Typically these fault-bounded folds produced as much as 2 km of structural relief; however, only a few hundred meters of topographic relief probably existed at any one time. Likewise, although the cumulative vertical component of fault separation along the Wichita fault system may have exceeded 12 km, topographic relief at any one time was probably less than 1000 m.

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Character, Origin and Occurrence of Natural Gases in the Anadarko Basin, Southwestern Kansas, Western Oklahoma and Texas Panhandle, U.S.A.

DUDLEY D. RICE, CHARLES N. THRELKELD, and APRIL K. VULETICH, U.S. Geological Survey, Federal Center, Denver, CO 80225

Natural gas production in the Anadarko basin comes from three geographically separated areas that can be differentiated by age of reservoir and by inferred nature of organic, thermal origin of the gases. In the central basin, non-associated gases are produced mainly from Upper Mississippian and Pennsylvanian sandstones. Gas samples are from reservoirs as much as 6588 m deep. Gases become isotopically heavier ($\delta^{13}C_1$-values range from –49.8 to –33.2‰) and chemically drier (C_{2+}-values range from 1–33%) with increasing level of thermal maturity. Gases were generated mainly from interbedded shales with type-III kerogen during the mature and post-mature stages of hydrocarbon generation. Deviations from the trend are due to vertical migration and mixing of gases generated at different levels of thermal maturity over the past 250 Myr.

In the giant Panhandle–Hugoton field, non-associated gases are generally produced from Permian carbonates at depths of <900 m. Gases display little compositional variation (mean $\delta^{13}C_1$ value is –43.2‰, mean C_{2+}-value is 14%). Because organic-rich, mature source rocks are not present in the area, gases probably were generated in the central basin from Pennsylvanian or older source rocks during the mature stage of hydrocarbon generation. This interpretation implies migration over distances as much as several hundred kilometers.

In the Sooner Trend, associated gases are produced from Silurian, Devonian and Mississippian carbonates at depths as great as 2950 m and were generated from type-II kerogen during the mature stage of hydrocarbon generation. Associated oil usually correlates with extracts of the Upper Devonian and Lower Mississippian Woodford Shale. Gases are isotopically lighter (mean $\delta^{13}C_1$-value is −43.9‰) and chemically wetter (mean C_{2+} value is 14%) than those derived from type-III kerogen at an equivalent level of thermal maturity.

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Oils and Source Rocks from Pauls Valley, Anadarko Basin, Oklahoma, U.S.A.

P. J. JONES, Union Pacific Resources Co., 801 Cherry St., Fort Worth, TX 76102; and R. P. PHILP, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

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Thirty oils from the Pauls Valley area of the Anadarko Basin, Oklahoma, have been analyzed for *n*-alkane, terpane and sterane distributions in an effort to classify genetically related oils. Ten rock samples from the area were also analyzed in an attempt to relate oil types to their possible source rocks. The Pauls Valley area, located near the southeast corner of the Anadarko Basin, has producing formations ranging in age from Middle Ordovician to Late Pennsylvanian. Trapping mechanisms responsible for the accumulation of hydrocarbons vary from purely structural traps, to fractured reservoirs, to up-dip truncations of reservoirs and up-dip pinchouts of sandstones.

Results show that 85% of oils in the area probably have a common source, the Woodford Shale. A group of oils reservoired in the Viola Group exhibit distinct geochemical characteristics and are thought to have a different source. The differences between the oils from these two sources include: enhanced C_{24} tetracyclic terpane concentrations relative to C_{26} tricyclic terpanes; diminished C_{28-30} tricyclic terpanes relative to T_s and T_m; diminished C_{30}-steranes relative to their C_{29} counterparts; predominance of C_{35} over C_{34} extended hopanes and an even/odd predominance of the normal alkane distribution. Extracts from the Viola Group generally exhibit the same qualities as the associated oils and the limestone is proposed as their probable source rock. The predominance of C_{29}-steranes for oil samples which appear to have a marine source (inferred by their *n*-alkane distribution, the presence of C_{30}-steranes and high levels of tricyclic terpanes) suggests that caution be used in the interpretation of terrigenous sources based on the high abundance of C_{29}-steranes.

The Deese Group, the Springer Formation, the Sylvan Shale, and the Arbuckle Group are not likely sources for the oils analyzed from the Pauls Valley area. Differences in API gravity and color, previously used to classify oils in this region, are not source-related but are related to maturation and migration effects.

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Channel Trenching and Climatic Change in the Southern U.S. Great Plains

STEPHEN A. HALL, Dept. of Geography, University of
Texas, Austin, TX 78712

Fifteen alluvial sequences in Texas and Oklahoma exhibit the same late Holocene record of channel trenching at 1 ka. The erosion was preceded by slow alluvial sedimentation in most stream valleys, resulting in the formation of a cumulic, organic-rich flood-plain soil previously named the Copan Soil. The soil formed during a period of regionally moister climate, as indicated by pollen spectra, molluscan faunas, vertebrate faunas, sedimentary structures, and high alluvial water tables. At 1 ka, the regional climate changed from moist to dry, coinciding with an episode of channel incision of valley floors throughout the southern Great Plains. Channel trenching occurred simultaneously in both small and large streams in drainage basins of the Arkansas, Red, Trinity, Brazos, and Colorado rivers; the sequences are the first documented example of widespread Holocene incision accompanied by firm evidence for a synchronous change in regional climate.

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Shallow Seismic Reflection Survey across the Meers Fault, Oklahoma

RICHARD D. MILLER, DON W. STEEPLES, Kansas
Geological Survey, University of Kansas, Lawrence, KS
66046; and PAUL B. MYERS, AMOCO Production Co.,
P.O. Box 3092, Houston, TX 77253

A high-resolution seismic-reflection survey over part of the Meers fault scarp in Comanche County, Oklahoma, provides an improved understanding of the shallow structure associated with the fault zone. The objective of this survey was to detect and identify shallow faulting near the Meers fault and to appraise the resolving power of the shallow seismic reflection technique in a structurally complex area. Three reflection profiles were acquired using a downhole .50-caliber rifle energy source and two 100-Hz geophones per channel connected in series. Field parameters were designed to optimize the recording of seismic reflections from geologic units in the 40- to 200-m-depth range. Severe analog low-cut filters helped to increase the dominant recorded reflection frequencies into the 100- to 250-Hz range, providing minimum bed resolution of about 6 m. Lines 1 and 2 straddle and cross the scarp orthogonally, and line 3 was acquired approximately parallel to the scarp. Seismic data along line 2 show reverse faulting that extends from 250 m southwest to 200 m northeast of the scarp. The CDP stacked seismic data are sufficiently good to interpret an up-to-the-north, vertical to high-angle reverse displacement on the Meers fault. The amount of vertical displacement on the fault

associated with the scarp cannot be determined with these seismic data. Maximum vertical displacement is less than 10 m on other secondary faults interpreted on seismic lines 1 and 2. Normal faulting is common on line 3. The major structural feature on line 3 is a graben with net displacement of between 5 and 30 m. The deformation on line 3 may be evidence of strike-slip motion along the main fault. The Meers fault was in a transpressive tectonic setting during Quaternary time as shown by strike-slip motion in conjunction with high-angle, up-to-the-north, reverse faulting. Evidence for angular unconformities within the Permian section exists on individual unprocessed field seismograms, suggesting that some complex bedforms (channel sands?) are present.

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Methodology for Regional Evaluation of Confining Bed Integrity

GARY F. STEWART, JAMES O. PUCKETTE, LYLE G. BRUCE, KEVIN D. FLANAGAN, LONNIE G. KENNEDY, and MICHAEL R. THORNHILL, School of Geology, Oklahoma State University, Stillwater, OK 74078

For safe underground injection of liquid waste, confining formations must be thick, extensive, and have low permeability. Recognition of faults that extend from the potential injection zone to underground sources of drinking water is critical for evaluation of confining-bed integrity.

In the Southwest Enid Area and West Edmond Field, Oklahoma, rocks at the surface reveal little evidence of subsurface faulting. Oil reservoirs are "tight," fractured limestones. Cumulative-production mapping (Southwest Enid), initial-production mapping (West Edmond), structural contour mapping, and analysis of lineaments from stream patterns (Southwest Enid) and Landsat imagery (West Edmond) were combined. Production at Southwest Enid Area seems to be correlated with intersections of lineaments. At West Edmond Field, lineaments suggested penetrative fractures; an injection-sensitivity map was based on inferences from lineaments and subsurface mapping.

The sandstone reservoir at Burbank Field, Oklahoma, almost certainly is jointed systematically. Structural contour maps and initial-production maps do not show the fracture system. Faults are few or are of little displacement; geometry of the channel-fill reservoir influences production more so than natural fractures. Fitts Pool, Oklahoma, is in a complexly faulted graben. Areas near bounding faults were interpreted as injection-sensitive. Faults in thick shales that seal Fitts Pool are suggested by the many lineaments shown on satellite imagery; the faults are believed to be closed. Confining beds probably would be effective if fluid injected did not exceed volumes withdrawn, and injection pressures were below original formation pressure.

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Records of Climatic Change Preserved in Holocene Stratigraphic Deposits: Black Bear Creek, Oklahoma

KAY C. McQUEEN, 214 E. 28th Street, Tulsa, OK 74114

Black Bear Creek, an east-west trending stream, with a 1,500 sq. km. drainage area in north-central Oklahoma is located in a nonglaciated region that has experienced climatic shifts from semi-arid to humid climate over the Quaternary.

Paleosol recognition and the determination of the length of development provides evidence for paleoenvironmental conditions. Paleoconditions are not well documented in Oklahoma but initial analyses indicate that slackwater deposits have buried paleosols, and have been well preserved in the Black Bear Creek watershed. Along Camp Creek, near its junction with Black Bear Creek, the presence of a paleosol 91 cm below the surface shows moderate soil development, i.e., some translocation of clay, an abundance of humified organic matter, and strong soil structure within the soil solum. This buried soil surface was stable for several thousand years, and was buried by deep alluvial sediments approximately 750 years BP (soil organic date). A flood event on the Big Thompson River occurred 750 years BP, and the "Little Ice Age" began approximately at this time. A variety of evidence indicated shifting and unstable climatic conditions world-wide, and also in the Great Plains.

Well-preserved slackwater deposits, approximately 100 cm in thickness, overlie the paleosol at the site described above. The associated discharge with this magnitude of deposition is approximately 1,680 cms which represents a 1,000 year flood. The largest known historical flood in 1959 had a discharge of 850 cms, and is commonly accepted as the 100 year flood event. Widespread human destruction occurred in the drainage basin. No discernable slackwater deposits are preserved from this flood at Camp Creek but they exist elsewhere in the basin.

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Quaternary Stratigraphy and Paleoenvironments of the Texas Rolling Plains

S. CHRISTOPHER CARAN, Dept. of Geological Sciences, University of Texas, Austin, TX 78712; and ROBERT W. BAUMGARDNER, JR., Bureau of Economic Geology, Austin, TX 78713

The Lingos Formation (new) comprises a thick sequence of Quaternary alluvial-fan, lacustrine, fluvial, and eolian deposits. These strata cover 9,250 km^2 of the western Rolling Plains of Texas. The Lingos Formation is part of the newly designated Paducah Group, which includes three previously recognized middle to upper Pleistocene formations in addition to the Lingos Formation and several unnamed or uncorrelated stratigraphic units. The origin of these formations is closely associated with westward retreat of the Caprock Escarpment and with subsidence resulting from regional intrastratal dissolution of Permian evaporites. Dissolution produced subsidence basins, which gradually filled with sediment derived from the retreating escarpment. Lakes occupied at least some of the subsidence basins and were sustained by emergent ground water rather than by surficial inflow. Stratigraphic relations and paleofaunas document significant Quaternary environmental change linked to subsidence, stream incision, and climatic variation. Chronologic control is afforded by diagnostic vertebrate faunas (Rancholabrean and Holocene), Paleoindian through historic archaeological remains, and more than 50 radiocarbon ages. On the basis of these data, deposition of the Lingos Formation spanned the period from less than 300 ka ago to the present. The depositional history of the Lingos Formation provides a model for the origin of the Paducah Group as a whole, and for Quaternary landscape evolution throughout the Rollings Plains.

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