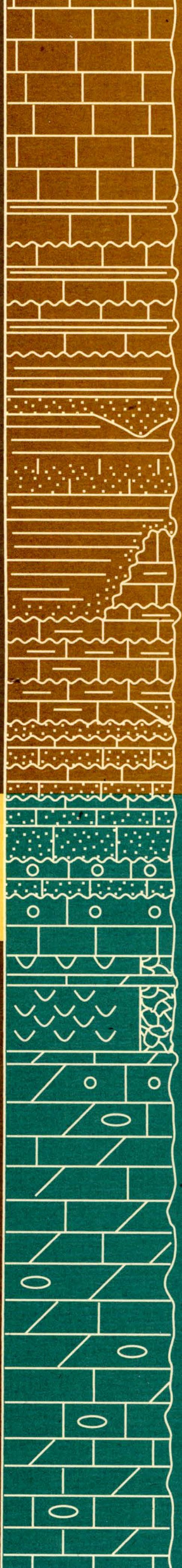

Revision of Stratigraphic Nomenclature in Kansas

compiled by D. L. Baars

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Review of Precambrian Rift Stratigraphy

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Rice Formation

A thick sequence of feldspathic sandstone, arkose, and red and green, sandy, micaceous shale that underlies sedimentary rocks of Late Cambrian age in northern Kansas was named the Rice Formation by Scott (1966). The feldspathic sandstones are fine grained and predominantly grayish red to grayish orange-pink, or (in a very few samples) dark reddish brown in color. Some interbedded strata contain medium to coarse grains. The grains are generally rounded to subangular and frosted. The feldspathic sandstone generally is well-sorted and closely packed, but in some strata it is poorly sorted; conglomeratic accessory constituents are dark-gray schist, quartzite, felsite, and granitic granules to pebbles, black ilmenite? grains, reddish-brown argillitic grains, and pyrite. Dolomite cement is common. Illitic clay matrix is 5-10% of the rock.

Interbedded with the feldspathic sandstone is gray and dark-reddish-brown shale. Red shale in core chips locally grades into green or mottled green shale that grades into siltstone. Observable accessory minerals are quartz, feldspar, and mica.

Distribution

The Rice Formation is recognized in two linear north-northeast-trending basins. From the basin west of the Sixth Principal Meridian, 36 wells, core chips from one well, plus thin sections from five holes have been studied. Twenty other drill holes reportedly penetrate pre-Reagan sedimentary rocks, but samples are not available. This western basin in which the Rice was deposited is called the Rice basin. It extends from Reno County north-northeast to Washington County. In the basin east of the Sixth Principal Meridian, 13 holes penetrate pre-Reagan sedimentary rocks that informally have been called the Rice sedimentary group by Muehlberger et al. (1964), who correlate the thick sedimentary sequences in the eastern and western basins on the bases of lithology and stratigraphic position. No time relations are implied. Not a single well penetrates the entire formation. Therefore four typical drill holes, rather than a type well, are designated to represent the typical stratigraphic succession of rocks in the formation. In each of these holes, the Late Cambrian Reagan Sandstone overlies the Rice Formation and underlies the Arbuckle Group. The four wells are listed below:

Operator, Farm, Date Drilled	Location	Surface	Top of Elev.	T.D. Rice	Lithology
Continental No. 3 "A" HodgsonC SE 9-29-53	32-16S-8W Ellsworth Co.	1684	3873	3905	Feldspathic sandstone
Empire No. 13 Rolfs 9-25-35	14-17S-9W SE NW NE Ellsworth Co.	1795	3741	4050	Feldspathic sandstone, green and red shale
Continental No. 9 Ainsworth 7-23-51	24-18S-8W SE NE SE	1694	3658	3691	Feldspathic sandstone, green and red shale
Bishop No. 5 Reese 12-5-51	22-19S-9W NE NE NW Rice Co.	1694	3645	3820	Feldspathic sandstone, arkose, green and red shale, dolomite, and limestone

Age Relationships

Sedimentary rocks of pre-Upper Cambrian age that underlie the Paleozoic sedimentary rocks in the general area described above are collectively assigned to the Rice Formation; they range in age from as old as approximately 1,100 m.y. to about 525 m.y. The oldest Precambrian sedimentary rocks overlie the youngest volcanics associated with the main phase of rifting. It is thus tacitly assumed that the main phase of rifting in the southern portion of the rift is coeval with the rifting in the much better understood and dated northern part of the rift. The oldest Paleozoic sedimentary rocks overlying the Rice Formation are the sandstones of the Lamotte Sandstone or the equivalent Reagan Sandstone.

Another rock type that commonly is encountered in drill holes is arkosic detrital material generally called "granite wash," a term used to describe mostly arkosic detrital material resting on older Precambrian rocks (Goebel, 1968). It may range in age from Precambrian to Middle Pennsylvanian. These rocks are not restricted to the same area as those of the Rice Formation, but can occur anywhere in the state. It consists essentially of weathered and not necessarily transported material from the ubiquitous granite intrusives. Locally, the granite wash may reach thicknesses of up to 150 ft. This material may range in age from Precambrian to Middle Pennsylvanian.

Naming of the Rice Formation

The formal name, Rice Formation, was substituted for Rice sedimentary group by Scott (1966) and is applied to sub-Reagan rocks in both basins. A name is necessary because: 1) The Rice Formation is lithologically distinct from other material called "granite wash" and from overlying Reagan Sandstone; 2) many drill holes penetrate the Rice Formation in a 2,300 mi^2 area; and 3) the Rice Formation is evidence of important tectonic and sedimentary activity in pre-Late Cambrian time in Kansas that was previously unknown.

Discussion

Since the report of Scott (1966), a considerable amount of new information has become available, resulting in a better understanding of the nature of the sediments, their stratigraphic position, and the tectonic setting. The deepest penetration of the sediments in 1966 was 1,015 ft in the Wrightsman No. 1 Kunkle in Ellsworth County. Today, many more drill holes have penetrated Precambrian sedimentary rocks in excess of 1,000 ft, with the deepest penetration being 8,450 ft in the Poersch #1 drill hole completed by Texaco in 1985.

Based upon the new information it is necessary to reconsider the present usage of the term *Rice Formation* as defined originally and described above. The reasons for proposing to change the classification of the lithostratigraphic Rice Formation to the chronostratigraphic *Rice Series*, and a revised and updated definition of the rocks present within the "series" are discussed below.

Rice Series

Studies of the rocks in the better exposed northern portion of the rift in Minnesota, Michigan, and Wisconsin show that a package of mostly sedimentary rocks were deposited in a rift-tectonic setting following the main phase of rifting characterized by the voluminous outpouring of basalts and related intrusive and extrusive rocks. These rocks are Precambrian in age and assigned to the Keweenawan Supergroup. Within the section, several formations are recognized and named in the three states; however, definite correlation between the variously named formations is in part controversial. The age of these sedimentary units is quite uncertain (Van Schmus and Hinze, 1985). Younger, mostly clastic sedimentary rocks of possible Precambrian and Cambrian age, such as the thick clastic sequence of the Mt. Simon Sandstone, occur widespread but are not necessarily related to rift tectonism.

In Kansas and adjoining portions of southern Nebraska, sediments deposited within the rift tectonic setting represent a unique and possibly economically significant package of rocks. The boundaries of the rift basin or basins into which these rocks were laid down are not well defined, especially along the western and southern margins of the rift trend. The area largely coincides with that proposed by Scott (1966) but may differ somewhat in the western part of the area where our knowledge of rift tectonism is poor.

Within the past few years, three drill holes have contributed greatly to our understanding of rift stratigraphy. Each of the holes penetrated several thousand feet of pre-Paleozoic rocks. Following is a list of the three holes:

Operator, Farm, Date Drilled	Location	Surface	Top of Elev.	T.D. Rice	Lithology
Texaco Inc. No. 1 Noel Poersch 3-6-85	31-5S-5E SW SW Washington Co.	1383	2846	11,300	Red arkose subarkose and siltstone. Basalt and gabbro.
Producers Eng. Co. No. 1-8 Friedrich 11-9-86	8-7S-5E NW NE NE Riley Co.	1317	2655	4439	Varicolored volcano-clastics and mafics
Producers Eng. Co. No. 1-4 Finn 10-26-86	4-4S-7E S S NE Marshall Co.	1348	2134	3972	Red arkose, gray shale and siltstone, minor volcanics

The Poersch #1 drill hole penetrated the thickest section of pre-Paleozoic rocks (Berendsen et al., 1988). A 300-ft-thick gabbro tops the sequence, followed by a thick unit dominated by basalt down to 7,429 ft. Minor pegmatites and red oxidized siltstone and arkose also occur in this interval. The lower part of the section consists mainly of red arkose and subarkose, together with minor amounts of red oxidized siltstone and shale. Some volcanic and other mafic units are interspersed. In the #1-8 Friedrich drill hole, the section consists of mafic intrusive and extrusive rocks that are partially oxidized, overlaying varicolored rocks that are predominantly volcaniclastics. In the Finn #1-4 drill hole, the top part of the section is marked by several hundred feet of medium- to dark-gray siltstone and shale, which is calcareous in part. Minor gray limestones are also part of the sequence. Downward, red oxidized arkoses and siltstones and minor mafic rocks characterize the section.

In addition to the three deep drill holes that provide excellent stratigraphic information, a significant number of basement drill holes have been completed since 1966 that give important structural information. This information suggests that along the trend of the rift, structurally separated basins occurred in which the stratigraphic succession may differ from neighboring basins.

The rocks that occur within the rift tectonic setting in Kansas and adjoining parts of southern Nebraska differ from the typical succession of rocks in the northern portion of the rift. To the north the extrusive activity seemed to have taken place in a well-defined relatively narrow time interval, followed by sedimentary rocks that filled the rift basin or basins. Thus the Keweenawan clastic rocks form a definite package of sedimentary rocks above the mafic extrusives that can be correlated over large distances.

In Kansas, on the other hand, it seems that mafic intrusive and extrusive rocks commonly overlie or are interbedded with sedimentary rocks. A large variety of sedimentary rocks have been encountered in the drill holes, making it impossible at this time to define the typical stratigraphy of sedimentary rocks within the rift. Because no thick section of exclusively mafic rocks not underlain by sedimentary rocks was encountered in any of the drill holes, and because no age dates are presently available for any of the mafic units, one can only speculate as to the relative age and stratigraphic position of the units in comparison with those found in the northern portion of the rift.

It is also impossible at this time to define meaningful stratigraphic units or to correlate rock units between the drill holes for which we have stratigraphic information. Neither are we able to compare relative ages of the rocks encountered in the drill holes. It is likely that significant thicknesses of rocks have been removed during erosional cycles prior to the deposition of the Upper Cambrian rocks or in certain places even at later times up to the Pennsylvanian.

Thus the typical rocks so far encountered within the rift basins of Kansas and parts of southern Nebraska are clastics, intrusive and extrusive mafic and minor acidic rocks, and some carbonate units. The clastics consist mostly of red, oxidized, fine- to coarse-grained arkoses, subarkoses, siltstones, and conglomerates. Medium- to dark-gray, partially calcareous siltstone and shale, interbedded with limestone, also occur in the sequence. The mafic rocks are gabbros and lavas. Some intermediate or acidic rocks including pegmatites occur. Flow tops are recognized in the lavas. The rocks are altered (albitized and epidotized) to varying degrees.

Recommendation

The term *Rice Series* is hereby proposed for the above-described sequence of rocks. The basis for reclassifying this package of rocks is that they cannot be correlated on lithostratigraphic criteria, but they occupy a clearly defined time-stratigraphic interval between the close of volcanism associated with major rift activity and deposition of the pre-Upper Cambrian or younger sedimentary rocks. The series thus constitutes a major time-stratigraphic unit that can be correlated with other units deposited within the same time span in the rift tectonic setting.

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Proposed Repositioning of the Pennsylvanian–Permian Boundary in Kansas

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Abstract

The Pennsylvanian–Permian boundary in North America has not corresponded with the Carboniferous-Permian boundary in Europe for decades. To facilitate global correlations, an attempt is here made to suggest a possible solution to the dilemma by making the best possible correlation of the Kansas stratigraphic section with the recently proposed boundary location in the Russian type section.

The Virgilian Stage (Upper Pennsylvanian) was defined nearly 60 years ago to include those rocks lying between the Missourian Stage and the base of the Permian System. In the type area in east-central Kansas, the Virgilian Stage comprised the Douglas, Shawnee, and Wabaunsee Groups. In Kansas, the Pennsylvanian–Permian boundary was placed eventually at the top of the Brownville Limestone Member on the basis of what was then believed to be a regional disconformity rather than on paleontological criteria. Recent advances in fusulinid and conodont biostratigraphy provide tentative criteria upon which to suggest a change in the placement of the Virgilian–Permian boundary.

A Russian delegation formally proposed at the International Congress on the Permian System of the World held in Perm, U.S.S.R. (Russia) in August 1991 that the base of the Permian System be established at the base of the Asselian Stage at the approximate stratigraphic position of the first inflated fusulinids (*Sphaeroschwagerina vulgaris-S. fusiformis*). Inflated schwagerinids (*Paraschwagerina kansasensis*) first occur, along with evolutionary changes in conodonts, in the Neva Limestone Member of the Grenola Limestone (Council Grove Group). Thus, if we assume that inflated schwagerinids arose globally at about the same time, the Neva Limestone Member is the oldest definitive Permian in the United States midcontinent, as related to the newly proposed boundary in Russia and Kazakhstan. Consequently, we propose that the Virgilian Stage in Kansas include rocks between the top of the Missourian Stage and the base of the Neva Limestone Member.

Introduction

The location of the Pennsylvanian–Permian boundary in the stratigraphic section in North America has been under dispute for decades. As such, the upper limits of the Pennsylvanian System have not corresponded with the Carboniferous–Permian boundary in Europe, causing unnecessary confusion and debate on a global basis. With the advent of consensus by Russian geologists on a proposed Carboniferous–Permian boundary in the type Permian section in the Southern Ural Mountains (Davydov et al., 1991), the controversy potentially can be resolved.

As originally defined, the Virgilian Stage comprised the youngest rocks of Pennsylvanian age in the midcontinent (Moore, 1932a, 1932b, 1936, 1949). Stage boundaries were defined at regional disconformities, rather than by biostratigraphic zonations. Placement of the upper boundary, or base of the Permian System, has been in dispute for decades. The Virgilian Stage was first mentioned by Moore (1932a), and formally proposed by Moore (1932b). At that time, Moore (1932b, p. 89) indicated that the base of the Neva Limestone was adopted in Oklahoma as the Pennsylvanian–Permian boundary, but considered the base of the Americus Limestone Member (Foraker Limestone, Council Grove Group) to better represent the systemic boundary stating: ". . . if the Cottonwood and Neva are to be reckoned as Permian, then the beds beneath them down to the Americus seem surely to belong to the same division." He later (Moore, 1936, p. 143) designated the type section as being along the Verdigris River in east-central Kansas. After numerous vascillations, Moore (1940) concluded that the base of the Permian System should be placed at the disconformity between the Wabaunsee and Admire Groups (top of the Brownville Limestone). Mudge and Yochelson (1962) coordinated an exhaustive study of stratigraphy and paleontology of the Pennsylvanian–Permian boundary in Kansas. However, they did not examine the paleontology in detail above the Americus Limestone Member; thus, they reached the conclusion that: "... any boundary established in Kansas must be regarded as tentative and subject to change when more is known of the type area in Russia or of the standard sequence for North America" (Mudge and Yochelson, 1962, p. 127). More is now known of the type area in Russia. After reviewing the typical Permian in the southern Ural Mountains, Baars et al. (1991) and Baars et al. (1992) proposed that the base of the Permian System in Kansas is best placed again at the base of the Neva Limestone Member.

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Fusulinids

In writing early drafts of this manuscript, we experienced difficulty in communicating to each other about the taxonomy of inflated schwagerinids and their significance to stratigraphic zonation. Early problems of the taxonomy of inflated schwagerinids have been extensively discussed by Dunbar and Skinner (1936), Dunbar (1958), Rauser-Chernousova (1936, 1956), and Skinner and Wilde (1966b).

The basic problem revolves around the question of the correct concept of the genus *Schwagerina* Möller. Möller (1877, 1878) misidentified specimens that he studied for an earlier species that had been poorly described and illustrated by Ehrenberg (1854) as *Borelis princeps*. Möller (1877), believing the specimens he was studying were the same as Ehrenberg's *B. princeps*, selected Ehrenberg's species (and specimens) as the type of his new genus *Schwagerina*. Much later Dunbar and Skinner (1936) restudied the type specimens of Ehrenberg's *Borelis princeps* and discovered they were significantly different from the highly inflated specimens illustrated under that name by Möller (1878). Dunbar (1958) compared the general morphological feature of *Borelis princeps* Ehrenberg with those in *Schwagerina uralica* Krotow. Both are from the Lower Permian of the Russian Platform.

Based on their restudy of Ehrenberg's specimens of *Borelis princeps*, Dunbar and Skinner (1936) defined two genera of inflated schwagerinids from the midcontinent and southwestern North America. For *Pseudoschwagerina* they selected as type species *Schwagerina uddeni* Beede and Kniker, 1924, and for *Paraschwagerina* they selected *Schwagerina gigantea* White, 1932, both common North America species from the lower part of the Wolfcampian Series.

Beede and Kniker (1924) who had first recognized the worldwide geographical and stratigraphic significance of the "Zone of *Schwagerina*," were at that time using Möller's misidentified illustrations as their concept of *Schwagerina*. Thus, after 1936, the "Zone of *Schwagerina*" became the "Zone of *Pseudoschwagerina*," at least in much of the world.

Rauser-Chernousova (1936) recognizing that the Ehrenberg specimens restudied by Dunbar and Skinner (1936) could not be the same species as the specimens illustrated by Möller (1878) renamed Möller's specimens *Schwagerina mölleri*, then proposed *S. mölleri* as the type species of *Schwagerina* in an attempt to correct the misidentification. The International Commission on Zoological Nomenclature (1954; Opinion 213) upheld Möller's original (1877) designation of *Borelis princeps* Ehrenberg. Rauser-Chernousova (1956) protested on the grounds that Ehrenberg's specimens had only vague locality information and were silicified and sufficiently poorly preserved to be unidentifiable (however, Opinion 213 has not been reversed). Thus, in the former Soviet Union, use of the "Zone of *Schwagerina*" continued unchanged so that the "Zone of *Schwagerina*" and the "Zone of *Pseudoschwagerina*" represent essentially the same zone of inflated schwagerinids. Lower Permian Asselian to Sakmarian (Wolfcampian) genera of inflated schwagerinids that concern us are shown in table 1.

Ozawa et al. (1990) recognized five main lineages in the Asselian inflated schwagerinids in the Akiyoshi Limestone, Southern Honshu, Japan. The *Sphaeroschwagerina* lineage becomes inflated beginning with *Sphaeroschwagerina fusiformis* at the base of the Asselian and evolves through *Sphaeroschwagerina mölleri* (=*Schwagerina mölleri* Rauser-Chernousova) and *Sphaeroschwagerina sphaerica* to become extinct at the end of the Asselian. (These are the "Zone of Schwagerina" species of Rauser-Chernousova and most other "Soviet" studies.) Rauser-Chernousova (1949) suggested that this lineage had its roots in *Schubertella* based on features of the juvenarium, and others (Davydov, 1984) have found additional evidence to support this evolutionary history. (Here we are going to ignore the taxonomic implications that *Sphaeroschwagerina* may not even be a schwagerinid.) This lineage is widespread in the Paleotethys (Japan, South China, Indochina, Central Asia and Carnic Alps, and, with question, from Cache Creek terrane of British Columbia), on the Russian Platform, northeast Greenland, Franklinian region of northern Canada, and as far south on the Euramerican craton as central eastern British Columbia. It has not been recorded from the non-Tethyan accreted terranes of the western Cordillera or from either the western or the southern part of the Paleozoic craton of United States or from South America.

Ozawa et al. (1990) recognized an *Alpinoschwagerina* line that evolved from a species group of *Triticites*, starting with *T. schwageriniformis*, through *T. convexus* and, in the middle Asselian, to the inflated *Alpinoschwagerina turkestanica* (fig. 1). The *Alpinoschwagerina* lineage ranges through the middle and upper Asselian into the lower Sakmarian before becoming extinct. It is apparently widespread, particularly in the Paleotethys, and is even reported from an isolated locality in south-central Texas.

The two southwestern United States lineages of Ozawa et al. (1990), their *Pseudoschwagerina uddeni* and *Pseudoschwagerina texana* lineages (fig. 1), probably both originated from the same *Triticites* ancestor, perhaps *T. subventricosus* or a similar species. *Pseudoschwagerina beedei* and *P. needhami* are among the early species of this group and some specimens are closely similar to *Occidentoschwagerina fusulinoides*, which is one of the zone species to the lowest Asselian. Ozawa et al. (1990) perceived three branches evolving from this earliest species complex of *Pseudoschwagerina*. Their *Pseudoschwagerina muongthensis* lineage leading to *Zellia* and *Robustoschwagerina* in the Sakmarian is predominantly a Paleotethys line, even if one species of *Robustoschwagerina* briefly floated into West Texas in the earliest Leonardian. In the midcontinent and southwestern United States, the *P. uddeni* lineage evolved toward subspherical tests and the *P. texana* lineage evolved toward slightly less inflated tests. If one accepts that the earliest part of these lineages includes *Occidento-schwagerina fusulinoides*-like forms, then during the early Asselian they were cosmopolitan and become geographically separate lineages in the middle and late Asselian. The derived genera, *Zellia* and *Robustoschwagerina*, in the Sakmarian are mainly Paleotethys.

In spite of a complex, and at first glance, a confused taxonomic nomenclature, the inflated schwagerinids are reasonably well studied and may form a very useful group to zone the Asselian and Sakmarian Stages (and the Wolfcampian Series). In the southwestern United States, early Wolfcampian species of *Pseudoschwagerina* are more common and more abundant than those of *Paraschwagerina*; however, they occur in many of the same collections and both are part of the same early Wolfcampian fossil community and stratigraphic zone. The presence of a species of *Paraschwagerina*, such as *Paraschwagerina kansasensis*, in the Neva Limestone Member of Kansas, without accompanying species of *Pseudoschwagerina*, is an example of an incomplete community assemblage. *Pseudoschwagerina* is scarce everywhere in the Kansas lower Permian succession.

Conodonts

Conodont workers note significant faunal changes that coincide with the appearance of *Paraschwagerina kansasensis*, a constituent of the *Pseudoschwagerina uddeni* biozone, in the midcontinent United States (Ritter, 1989; Wardlaw, 1989). These faunal changes occur at the level of the Neva Limestone Member in Kansas, Oklahoma, and Nebraska (Ross, 1963; King, 1988). Conodont faunas from the Late Carboniferous are dominated by *Idiognathodus*, *Streptognathodus*, and *Adetognathus*. The Early Permian is characterized by the inception of *Sweetognathus* and continued evolution of *Streptognathodus*. Conodonts within the Late Pennsylvanian and Early Permian (Wabaunsee, Admire, and Council Grove Groups) reflect the changeover from faunas of Late Carboniferous aspect to typical Permian faunas. *Sweetognathus* first occurs in the basal limestone of the Neva Limestone Member along with the appearance of *Streptognathodus* cf. *S. longissimus* (Ritter, 1991). This horizon also marks a decline in the relative abundance of nodose *Streptognathodus wabaunsensis*. This faunal changeover provides a conceptual and practical basis for correlating the Carboniferous–Permian boundary in the midcontinent at the level of the Neva Limestone Member using conodonts, although correlations are not yet firmly established in the Southern Ural Mountains of Russia and Kazakhstan (Ritter, in preparation). If an ammonoid or some other conodont zonation were to be employed in defining the basal Permian in the type area, the Pennsylvanian–Permian boundary may move eventually somewhat below the Neva Limestone Member. Wherever the boundary is placed officially, the Neva Limestone Member represents the lowest undisputed Permian rocks in the midcontinent.

Discussion

Much of the early confusion resulted from a lack of agreement among Russian geologists as to what constituted the Permian in the type area (Baars, 1990). There also was confusion regarding critical fusulinid nomenclature that clouded the issue (Ross, 1963). Following Likharev (1959), most stratigraphers have placed the Carboniferous–Permian boundary at the base of the Asselian Stage (Ross and Ross, 1979; Waterhouse, 1978; Chuvashov, 1989; Davydov et al., 1991). During the International Congress on the Permian System of the World held in Perm, U.S.S.R. (Russia) in August 1991, a Russian delegation proposed that the historical base of the Asselian, as established by V. E. Ruzhenzev at the first occurrence of *Sphaeroschwagerina vulgaris* and *S. fusiformis*, be accepted by the International Stratigraphic Commission as the base of the Permian System (Davydov et al., 1991). The proposed boundary stratotype was indicated as between Bed 19 and Bed 20 in the Aidaralash section in the southern Ural Mountains of northern Kazakhstan. Bed 20 lies 12 m (36 ft) stratigraphically above the base of the *S. vulgaris–S. fusiformis* fusulinid biozone (Bed 19.6). The *S. vulgaris–S. fusiformis* interval lies immediately stratigraphically below *Pseudoschwagerina* occurrences in the southern Urals and in Japan; however, it is not known to occur in the Glass Mountains of Texas or in Kansas. We therefore interpret the first occurrence of the *Ps. uddeni* biozone to constitute the earliest Permian interval represented in Kansas, and interpret that position as approximately equivalent to the *S. vulgaris–S. fusiformis* biozone as it occurs in the southern Ural Mountains. Fusulinid paleontologists generally agree that the base of the *Pseudoschwagerina* biozone marks the base of the Permian System in the United States (Ross, 1989), because the *S. vulgaris–S. fusiformis* is missing. Our assumption here is that inflated schwagerinids arose penecontemporaneously on a global basis (in low paleolatitudes) irrespective of generic assignment, or that *S. vulgaris-S. fusiformis* are missing due to stratigraphic or paleoenvironmental aberrations. In other words, the base of the Neva Limestone Member is the closest possible correlation between the Kansas section and the type Permian on the basis of the presently known distribution of fusulinids.

If our proposed repositioning of the base of the Permian at the base of the Neva Limestone Member in Kansas is accepted, it would necessitate repositioning the top of the Pennsylvanian upward stratigraphically to that boundary. A section including the Admire Group and the lower formations of the Council Grove Group would be reassigned to the Upper Pennsylvanian Series (Virgilian Stage). This section has traditionally been considered as early Wolfcampian in North America for decades and includes the Bursum and Pueblo intervals in Texas and New Mexico (Ross, 1963) and parts of the Elephant Canyon Formation of eastern Utah (Baars, 1962). Microfaunas in this Admire–Bursum–Pueblo interval include the *Triticites–Schwagerina* biozone that predates the zone of *Pseudoschwagerina uddeni*. The base of the Permian *Ps. uddeni* biozone is closely constrained at the base of the Neva Limestone Member by the presence of *Triticites creekensis*, a component of the *Schwagerina–Triticites* biozone of Bursum–Pueblo–Admire affinities, in the Burr Limestone Member of the Grenola Limestone, the next underlying limestone below the Neva Limestone Member (King, 1988). This biozone is considered to be latest Carboniferous (Orenburgian/Gzhelian) in Europe. This proposed repositioning would make the top of the Pennsylvanian in North America coincident with the top of the Carboniferous in Europe.

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TABLE 1—LOWER PERMIAN ASSELIAN TO SAKMARIAN (WOLFCAMPIAN) GENERA OF INFLATED SCHWAGERINIDS.

Genera	Type Species
Sphaeroschwagerina Miklukho–Maklai	*Schwagerina sphaerica* var. *karnica* Shcherbovich *in* Rauser–Chernousova and Shcherbovich
Alpinoschwagerina Bensh	*Alpinoschwagernia turkestanica* Bensh
Occidentoschwagerina Miklukho–Maklai	*Schwagerina fusulinoides* Schellwien
Pseudoschwagerina Dunbar and Skinner	*Schwagerina uddeni* Beede and Kniker
Parazellia Rauser–Chernousova	*Fusulina muongthensis* Depart
Paraschwagerina Dunbar and Skinner	*Schwagerina gigantea* White
Zellia Kahler and Kahler	*Pseudoschwagerina* (*Zellia*) *Heritschi* Kahler and Kahler
Eozellia Rozovskaya	*Pseudoschwagerina primigena* Rauser–Chernousova, *in* Rauser–Chernousova and Shcherbovich

(Several of these genera, such as *Pseudoschwagerina*, *Parazellia*, and *Alpinoschwagerina* are similar to one another in certain, but not all, of their morphological features and were subjectively synomonized by Loeblich and Tappan, 1988.)

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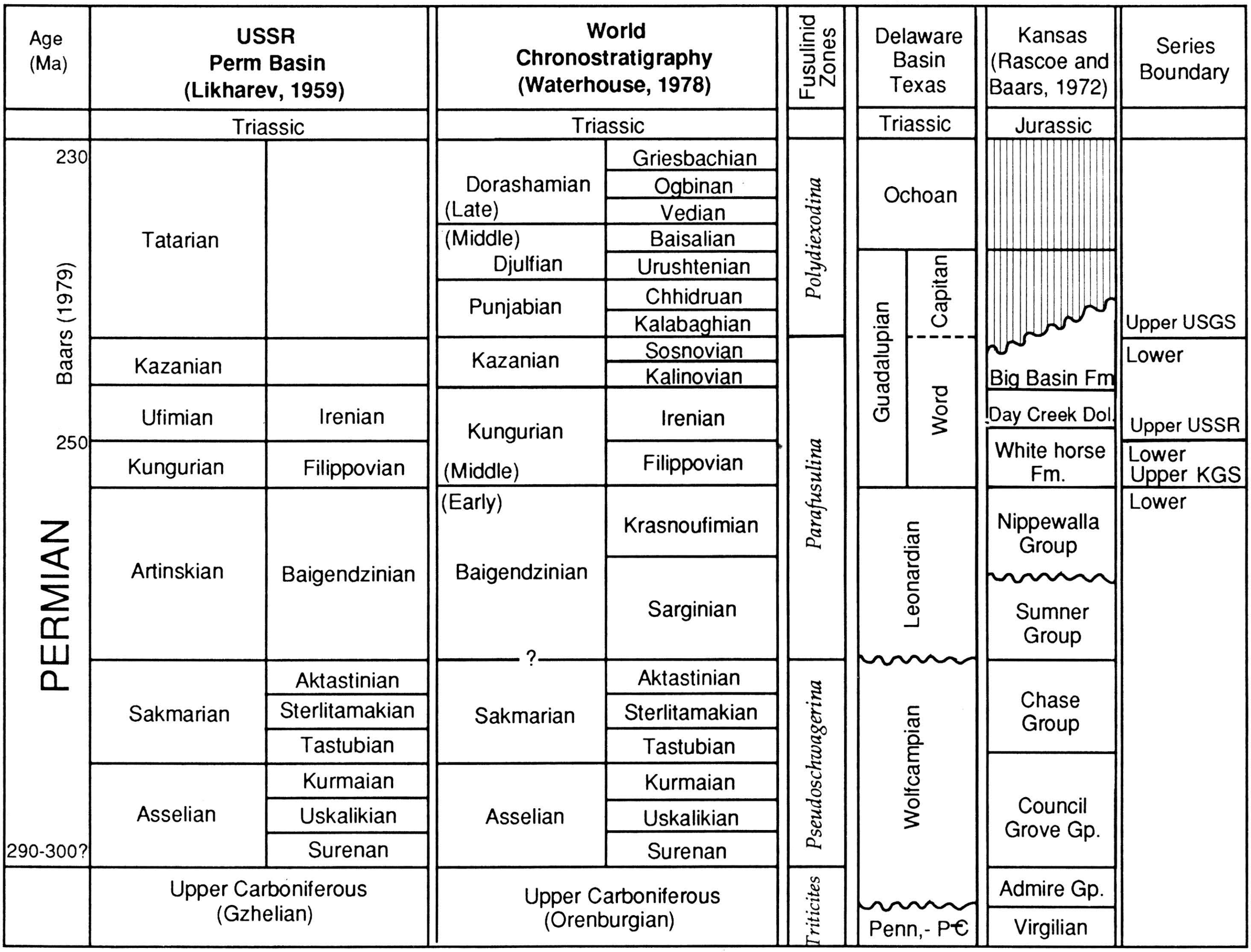

FIGURE 1—Range of characteristic genera and species of inflated schwagerinids and their possible evolutionary and phylogenetic relationship. This is considerably modified from Ozawa et al. (1990), and the southwestern North American column is after Ross and Ross (1987a, b).

Redefinition of the Upper Pennsylvanian Virgilian Series in Kansas

D. L. Baars[1], Scott M. Ritter[2], C. G. Maples[1], and Charles A. Ross[3]

Abstract

The Virgilian Series was defined nearly 60 years ago to include those rocks lying between the Missourian Series and the base of the Permian System. In the type area in east-central Kansas, the Virgilian Series comprised the Douglas, Shawnee, and Wabaunsee Groups. In Kansas, the upper boundary of the Virgilian (Pennsylvanian–Permian boundary) was placed at the top of the Brownville Limestone Member on the basis of what was then believed to be a regional disconformity rather than on paleontological criteria. Recent advances in fusulinid and conodont biostratigraphy provide tentative criteria upon which to effect a change in the placement of the Virgilian–Permian boundary. It is now generally agreed that the base of the Permian System is approximated by the first occurrence of *Pseudoschwagerina*, an inflated schwagerinid. Furthermore, the Subcommission on Permian Stratigraphy has informally agreed that the base of the Permian should coincide with the first occurrence of the conodont species *Streptognathodus barskovi*. Inflated schwagerinids (*Paraschwagerina kansasensis*) first occur along with evolutionary changes in the Conodonta in the Neva Limestone of the Council Grove Group. Consequently, the Virgilian Series is herein redefined to include rocks present between the top of the Missourian Series and the base of the Neva Limestone.

To increase compatibility between chronostratigraphic and lithostratigraphic nomenclature, the following changes are made: 1) the Admire Group is redefined to include rocks between the base of the Onaga Shale and the base of the Neva Limestone; 2) the Admire is reassigned to the upper Virgilian Series; 3) the Neva Limestone is elevated to formational status; 4) the Grenola Limestone is redefined to include strata between the top of the Roca Shale and the base of the Neva Limestone; 5) the overlying Council Grove Group is redefined to include strata lying between the base of the Neva Limestone and the base of the Chase Group; and 6) regionally the base of the emended Council Grove Group marks the base of the Permian System. The emended Council Grove Group is lower Wolfcampian in age and is time equivalent with the Neal Ranch Formation of the west Texas type Wolfcampian.

Introduction

As originally defined, the Virgilian Series comprised the youngest rocks of Pennsylvanian age in the midcontinent (Moore, 1932, 1949). Boundaries of the chronostratigraphic unit were defined at regional disconformities, rather than by biostratigraphic zonations. The lower boundary was placed at the disconformity developed at the top of the Missourian Series (base of the Stranger Formation). However, placement of the upper boundary, or base of the Permian System, has been in dispute for decades. After numerous vascillations, Moore (1940) concluded that the top of the Virgilian sequence (base of the Permian System) should be placed at what he believed to be a major disconformity immediately above the Wood Siding Formation, the uppermost unit in the Wabaunsee Group (fig. 1). Mudge and Yochelson (1962) coordinated an exhaustive study of stratigraphy and paleontology of the Pennsylvanian–Permian boundary in Kansas. However, they did not examine the paleontology in detail above the Americus Limestone Member, and they eventually reached the conclusion that: "As there is no clear agreement as to what constitutes the Permian, especially in regard to definition on the basis of fossils, any boundary established in Kansas must be regarded as tentative and subject to change when more is known of the type area in Russia or of the standard sequence for North America" (Mudge and Yochelson, 1962, p. 127). That arbitrary stratigraphic position of the Pennsylvanian–Permian boundary at the base of the Admire Group has since been followed by the Kansas Geological Survey (O'Connor and others, 1968; fig. 2).

Much of the early confusion resulted from lack of agreement by Russian geologists on what rocks were to be included in the type Permian (Baars, 1990). Since Likharev (1959) placed the Carboniferous–Permian boundary at the base of the Asselian in Russia, most stratigraphers followed this practice (Waterhouse, 1978; Chuvashov, 1989). Confusion existed also regarding critical fusulinid nomenclature that clouded the issue. "Many European fusulinid specialists retain the name *Schwagerina*, in the sense of Möller (1878) and so apply this name to species which . . . should by placed in *Pseudoschwagerina*" (Ross, 1963, p. 45). General agreement exists among fusulinid paleontologists that the base of

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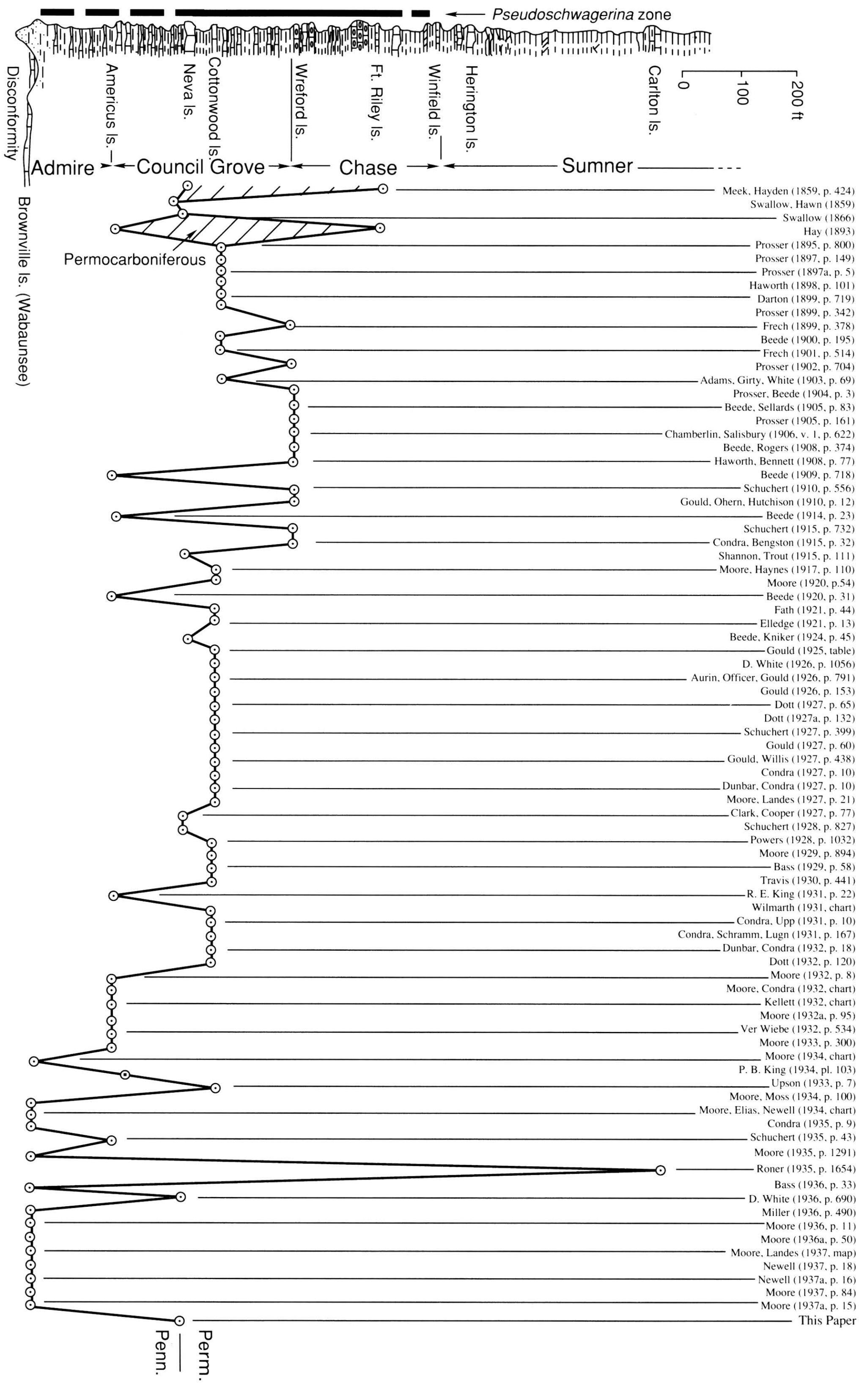

FIGURE 1—DIAGRAM TAKEN FROM MOORE (1940), SHOWING THE HISTORY OF PLACEMENT OF THE CARBONIFEROUS–PERMIAN BOUNDARY RELATIVE TO THE ROCK SECTION OF KANSAS BETWEEN 1859 AND 1937. Moore (1940) concluded that the boundary should be placed at a disconformity *below* the first occurrence of the *Pseudoschwagerina* biozone, which is present in the Neva Limestone.

the *Pseudoschwagerina* biozone marks the base of the Permian System (Ross, 1989), although not adopted by the International Commission on Stratigraphy. "The *Pseudoschwagerina* zone is characterised by *Pseudoschwagerina* and *Paraschwagerina*, but it includes other genera such as *Schwagerina* and *Triticites* . . ." (Ross, 1963, p. 45. Ammonoid (Furnish, 1989) and conodont (Wardlaw, 1989; Ritter, 1989) paleontologists tend to generally concur with that selection. This biozone first occurs in Kansas in the Neva Limestone, which contains *Paraschwagerina kansasensis* (Ross, 1963; King, 1988).

Placement of the base of the Permian at the base of the Neva Limestone necessitates repositioning the top of the Pennsylvanian upward stratigraphically to that boundary. A section including the Admire Group and the lower formations of the Council Grove Group necessarily must be reassigned to the upper Pennsylvanian System. This section has traditionally been considered as early Wolfcampian in North America for decades, and includes the Bursum and Pueblo intervals in Texas and New Mexico (Ross, 1963), and the Elephant Canyon Formation of eastern Utah. Microfaunas in this Admire–Bursum–Pueblo interval include the *Triticites–Schwagerina* biozone that predates the zone of *Pseudoschwagerina*, and is considered to be latest Carboniferous in Europe. This reassignment makes the top of the Pennsylvanian in North America coincident with the top of the Carboniferous in Europe. Ross and Ross (1987, 1988) showed these correlations, but did not formally propose a change. The same authors indicated the age of the Carboniferous–Permian boundary is 286±6 Ma (Ross and Ross, 1987, p. 145).

O'Connor et al., 1968			This report				Ural Mtns. Russia (Chuvashov, 1989)	
Permian System	Gearyan Stage	Chase Group	Wreford Limestone	Chase Group	Wolf-campian Series	Permian System	Asselian Series	Permian System
		Council Grove Group	Speiser Shale Funston Limestone Blue Rapids Shale Crouse Limestone Easly Creek Shale Bader Limestone Stearns Shale Beattie Limestone Eskridge Limestone **Neva Limestone**	**Council Grove Group**	**Wolf-campian Series**			
			Grenola Limestone Roca Shale Red Eagle Limestone Johnson Shale Foraker Limestone Janesville Shale	**Admire Group**	**Virgilian Series**	Pennsylvanian System		Upper Carboniferous
		Admire Group	Falls City Limestone Onaga Shale					
Pennsylvanian System	Virgilian Stage	Wabaunsee Group	Wood Siding Formation Severy Shale	Wabaunsee Group			Gzhelian Series	
		Shawnee Group	Topeka Limestone Oread Limestone	Shawnee Group				
		Douglas Group	Lawrence Formation Stranger Formation	Douglas Group				
	Missourian Stage	Lansing Group	Stanton Limestone	Lansing Group	Missourian Series			

FIGURE 2—STRATIGRAPHIC COLUMN SHOWING PREVIOUS ASSIGNMENTS UNDER THE COLUMN LABELLED O'CONNOR ET AL., 1968, COMPARED WITH THE PROPOSED USAGE OF THIS REPORT, relative to generally accepted standard Russian terminology.

Conodonts

Conodonts are important index fossils in most systems from the Cambrian to the Triassic; however, they have played only a minor role, subordinate to that of the fusulinids and ammonoids, in determination of the Carboniferous–Permian (C–P) boundary. Latest Carboniferous to Early Permian conodont faunas are low in diversity and consist of elements of two evolutionary cycles. Holdovers from the Late Carboniferous include *Idiognathodus*, *Streptognathodus*, and *Cavusgnathus*. The Early Permian is ushered in by the inception of *Sweetognathus* and novel species of *Neogondolella*. Because conodonts undergo a faunal replacement, two approaches to a conodont-based boundary have been advocated. Some workers have suggested using the first occurrence of uniquely Permian *Sweetognathus whitei* to define the C–P boundary at the base of the Sakmarian Stage. During the past 15 years, Soviet workers have established a reliable biostratigraphic zonation for the Gzhelian and Asselian Series based upon speciation events in the genus *Streptognathodus*. Conodonts are present and often abundant in at least select lithofacies within the Wabaunsee, Admire, and Council Grove Groups. These faunas are dominated by species of *Streptognathodus*, with modest but significant occurrences of *Sweetognathus*. These faunas indicate that the beginning of the *Sweetognathus–Neogondolella* provides a sound conceptual and practical basis for placing the C–P boundary at the level of the Neva Limestone.

The first occurrence of *Sweetognathus* in the midcontinent is within the Neva Limestone in both northern Oklahoma and southern Nebraska. The Neva specimens have an adenticulate carina and are assigned to *Sweetognathus expansus* (Perlmutter), the founding species of the genus. In the midcontinent this species is joined or succeeded stratigraphically by *Sw. merrilli* (Kozur), *Sw. inornatus* (Ritter), and *Sw. whitei* (Rhodes) in the overlying Council Grove and Chase Groups. *Sweetognathus expansus* has not been recovered, however, from the Neva Limestone in Kansas nor has it been reported from sections outside of the United States. Hence, this seminal species may have only limited application as an indicator of the C–P boundary.

The appearance of *Sw. expansus* is preceded and accompanied by important changes in the more widespread holdover genera *Idiognathodus* and *Streptognathodus*. Evolutionary trends within these genera in the midcontinent are similar to those reported from the type Permian of Russia. We recognize four nearly identical conodont faunal intervals in Gzhelian to Asselian rocks of both Russia and the midcontinent. A straw vote of the Working Group on the C–P Boundary on July 13, 1989, tentatively established the first occurrence of *Streptognathodus barskovi* accompanied by the base of the *Schwagerina moelleri–Pseudofusulina fecunda* (*Pseudoschwagerina*) fusulinid zone as the base of the Permian System.

In the midcontinent, the base of this interval is characterized by a sharp decline in the relative abundance of *S. wabaunsensis*, the appearance and predominance of narrow elongate streptognathodids with extremely short carina, and the appearance of *Sweetognathodus expansus*. These changes are first noted in the lower part of the Neva Limestone. The exact time of these changes is obscured by the near absence of conodonts in the Howe Limestone through Salem Point Shale Member. *S. barskovi* has its earliest occurrence in the Bennett Shale Member but constitutes less than 2% of the total fauna. *S. barskovi* is present in the Neva Limestone where it is slightly more common.

Virgilian Series Redefined

The Virgilian Series was defined originally to include all rocks from the top of the Missourian Series to the base of the Permian System. As such, the top of the Virgilian must now be placed at the base of the Neva Limestone of the Council Grove Group that contains fusulinids of the *Pseudoschwagerina* biozone, the first appearance of the conodont genus *Sweetognathus*, and the species *Streptognathodus barskovi* (Ritter, 1989). The base of the Virgilian remains unchanged at the base of the Stranger Formation.

The reference section of the series is exposures along the Verdigris River in Greenwood County, Kansas. The top is here extended stratigraphically upward to the base of the Neva Limestone. This revised Virgilian section is, in many respects, more in line with Moore's (1932) original definition of the Virgilian, the top of which he placed at the Americus Limestone in Kansas. Thus the Admire Group and lower Council Grove Group, as previously defined, are of latest Virgilian age. Regionally, the controversial Bursum–Pueblo–Elephant Canyon intervals, containing the *Triticites–Schwagerina* biozone, are here included in the latest Virgilian.

Admire Group Redefined

To compartmentalize and simplify lithostratigraphic nomenclature accompanying redefinition of the Virgilian Series, the Admire Group is here redefined to include all strata from the base of the Onaga Shale to the base of the Neva Limestone. Thus, the Admire Group now includes (ascending) the Onaga Shale, Falls City Limestone, Janesville Shale, Foraker Limestone, Johnson Shale, Red Eagle Limestone, Roca Shale, and the Sallyards Limestone, Legion Shale, Burr Limestone, and Salem Point Shale Members of the Grenola Limestone. The base of the Neva Limestone, as here redefined, will constitute the base of the Council Grove Group and the base of the Wolfcampian Series (Lower Permian) (fig. 2).

The Admire Group (revised) now comprises a thicker series of cyclical carbonates and fine clastics, but still displays approximately the same geographic distribution and significance as the former group. It overlies the Wabaunsee Group and underlies the Council Grove Group as previously used, but is reassigned to the latest Virgilian Series.

Council Grove Group Redefined

To accommodate changes in latest Pennsylvanian nomenclature, the Council Grove Group, as here redefined, is proposed to consist of all strata from the base of the Neva Limestone to the base of the Wreford Limestone Formation. The Neva Limestone is elevated to formation status to simplify lithostratigraphic terminology and to begin the redefined Permian System and Council Grove Group with a sequence boundary. As a lithostratigraphic unit, the Neva is an excellent marker bed throughout the subsurface of Kansas and is readily mapped at most surface exposures. The Neva Limestone contains the first occurrences of fusulinids of the *Pseudoschwagerina* biozone.

Thus, the Council Grove Group consists of (ascending) the Neva Limestone, Eskridge Shale, Beattie Limestone, Stearns Shale, Bader Limestone, Easly Creek Shale, Crouse Limestone, Blue Rapids Shale, Funston Limestone, and Speiser Shale (fig. 2). It is underlain by the Admire Group and overlain by the Chase Group, and is of lower Wolfcampian (Lower Permian) age, biostratigraphically equivalent to the Neal Ranch Formation of the type Wolfcampian (Ross, 1963).

Conclusions

1) The Neva Limestone contains the first occurrences of the *Pseudoschwagerina* biozone, and thus constitutes the base of the global Permian System. It is here elevated to formation status.
2) To accommodate the relocated base of the Permian System, the Virgilian Series is extended stratigraphically upward to include all rocks above the Missourian Series and below the Neva Limestone.
3) The Admire Group is here redefined to include strata between the base of the Onaga Shale up to the base of the Neva Limestone. The group is latest Virgilian (latest Pennsylvanian and latest Carboniferous) in age.
4) The Council Grove Group is redefined to include all strata between the base of the Neva Limestone and the base of the Chase Group. The group is earliest Wolfcampian (Lower Permian) in age.

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A Reference Section for the Pennsylvanian Lorton Coal Bed (Root Shale: Wabaunsee Group) in Kansas

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Abstract

The Lorton coal bed (Wabaunsee Group: Virgilian) of Late Pennsylvanian age is formally recognized as a bed-level stratigraphic unit in the Root Shale in Kansas. A stratigraphic reference section in Lyon County, Kansas, is given for the Lorton coal bed.

Introduction

The Wabaunsee Group (Pennsylvanian:Virgilian) in Kansas is notable for its general historical lack of coal-mining activity compared with older, Desmoinesian coals of the Cherokee Group. Over the years, the most consistently mined coal from the Wabaunsee Group in Kansas has been the Nodaway coal bed (Howard Limestone). Whitla (1940) and Schoewe (1946) provided excellent summaries of mining efforts and nomenclatural histories for many of the Wabaunsee Group coal beds.

During work on a stratigraphic lexicon for the state of Kansas, it became apparent that the informally named Lorton coal in the Wabaunsee Group was laterally extensive enough to form a coal horizon of stratigraphic importance and sufficiently easy to recognize to justify formal bed status. It is the purpose of this paper to assign formal bed status to the Lorton coal bed in the upper part of the Root Shale. In addition, a measured reference section of the Lorton coal bed in Kansas is given.

Lorton Coal Bed

The Lorton coal bed has been well known in an informal sense in Kansas for most of this century. Moore (1935 [1936], p. 240) noted that the Lorton coal bed was one of the most persistent and well-known late Paleozoic coal beds in the midcontinent, with exposures from Oklahoma to Nebraska. Schoewe (1946, p. 49) noted that the Lorton coal was one of the few Wabaunsee Group coals that had been mined in more than one county (Greenwood, Pottawatomie, Lyon, and Wabaunsee). In Nebraska, the Lorton Coal, one of only three Wabaunsee Group coals formally recognized (Burchett, 1977, p. 23), occurs in the French Creek Shale Member (Root Shale), immediately below the Nebraska City Limestone Member of the Wood Siding Formation.

The Lorton coal bed can be observed in Kansas where the upper 10-ft (3-m) interval of the Root Shale (=French Creek Shale Member) is exposed. Overlying the Root Shale is the Nebraska City Limestone Member of the Wood Siding Formation. The Lorton coal bed commonly is at least 1–3 inches (2–8 cm) thick throughout the outcrop belt of the Root Shale in Kansas, however a maximum thickness of 17 inches (43 cm) has been reported for the Lorton coal bed in Lyon County, Kansas (Schoewe, 1946, p. 100–102). Mohler (1891) reported a coal in Greenwood County near the Greenwood–Lyon County line that was 37 inches (94 cm) thick, which was noted by Schoewe (1946, p. 93) as possibly being the Lorton coal. We selected a reference section for the Lorton coal bed in Kansas along the Kansas Turnpike in Lyon County, Kansas (figs. 1 and 2), because of the unusually good quality of this exposure (which generally is poor in the Root Shale), ease of accessibility, and typical thickness for the Lorton coal bed (fig. 3).

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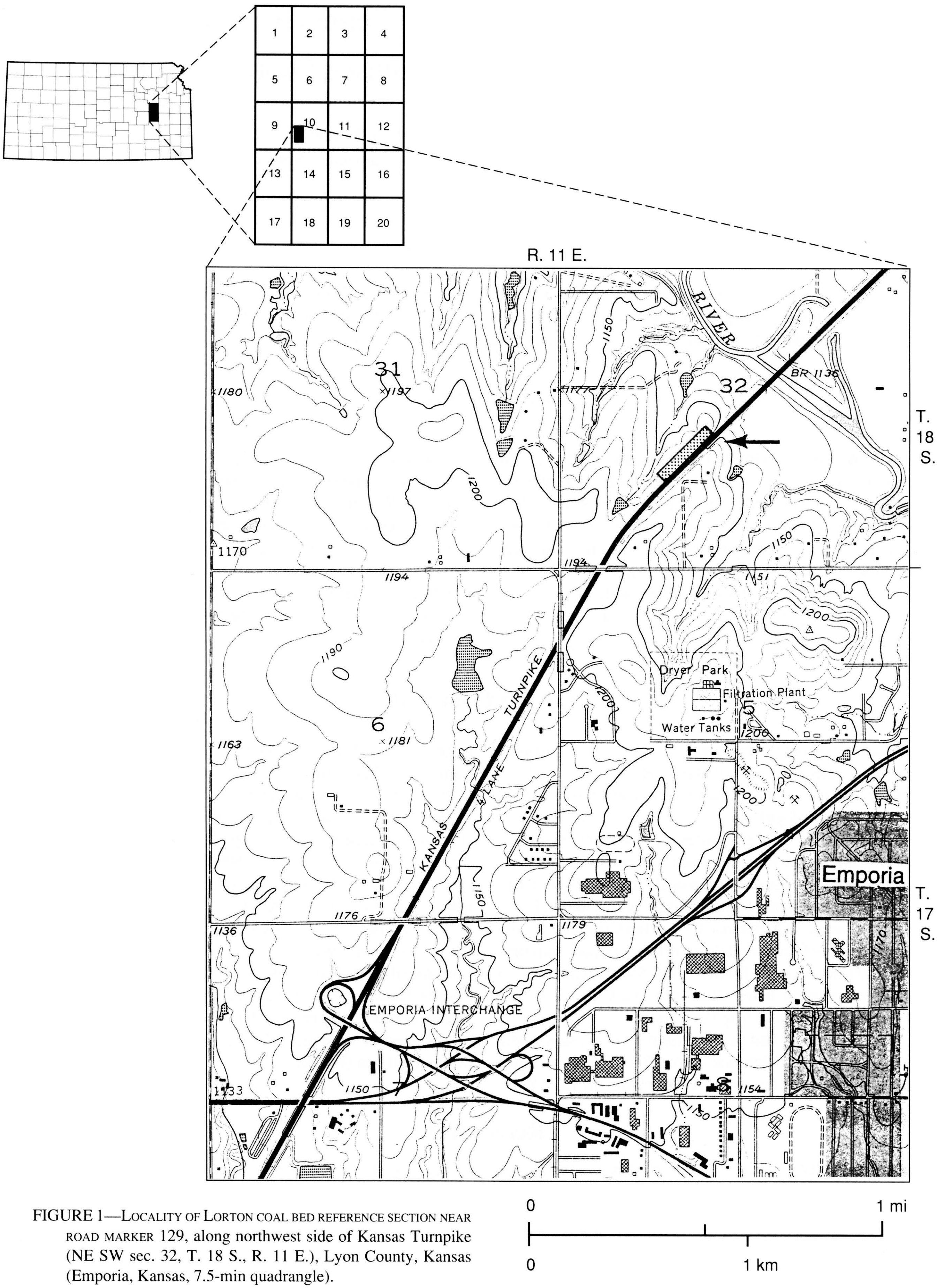
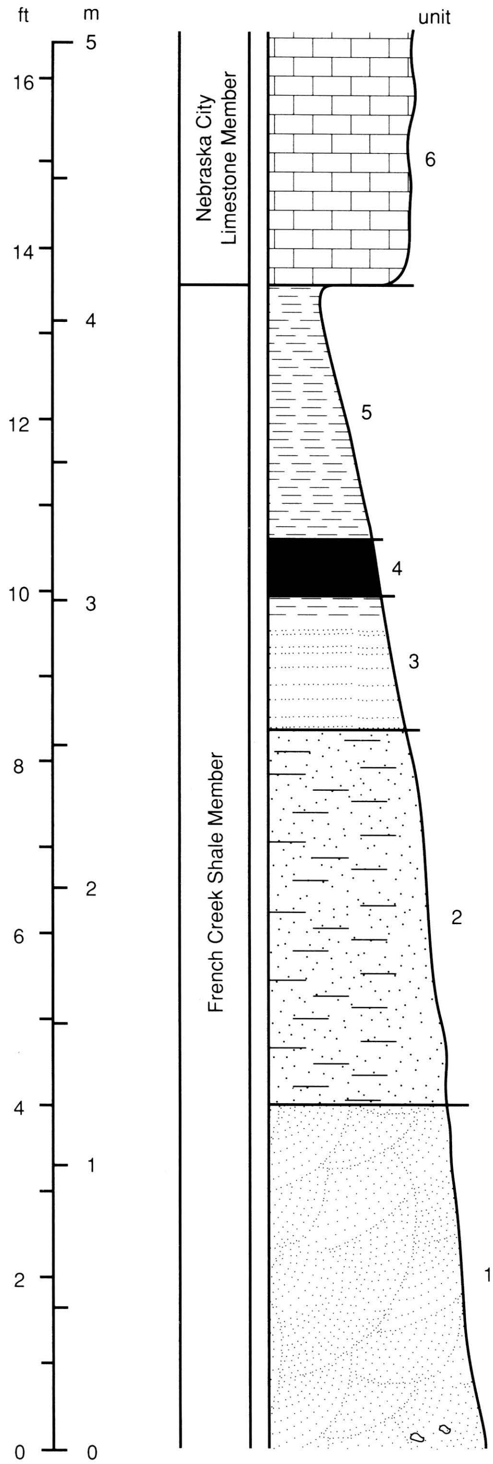


FIGURE 1—LOCALITY OF LORTON COAL BED REFERENCE SECTION NEAR ROAD MARKER 129, along northwest side of Kansas Turnpike (NE SW sec. 32, T. 18 S., R. 11 E.), Lyon County, Kansas (Emporia, Kansas, 7.5-min quadrangle).

FIGURE 2—L. L. BRADY INDICATES THE BASE OF THE LORTON COAL BED AT ITS PRINCIPAL REFERENCE SECTION IN LYON COUNTY. Note the crossbedded sandstone (unit 1 in fig. 3) at the base of the exposure.



6. Limestone (Nebraska City Limestone Member, Wood Siding Formation), argillaceous, and calcareous shale, weathered to yellowish gray (5Y7/2); contains *Myalina* (*Orthomyalina*), *Derbyia*, productid brachiopods, and crinoid debris; section incomplete—[>2.0 ft (>60 cm)].

5. Claystone (uppermost part of Root Shale), dark-gray (N3), grades upward to medium-gray (N5); contains plant debris; partially slump covered, but can be exposed with digging—[3.0 ft (91 cm)].

4. Coal (Lorton coal bed, French Creek Shale Member, Root Shale), black (N1), banded, mainly fusain and clarain, with shaly laminae in upper 0.1 ft (3 cm); 1-inch (2-cm)-thick clay ironstone zone at base—[0.7 ft (21 cm)].

3. Shale, light-olive-gray (5Y6/1) with thin siltstone to very fine grained sandstone laminae (lenticular bedding); grades upward into clay shale near base of Lorton coal bed; upper 0.5 ft (15 cm) carbonaceous with plant fossils; thickness variable—[1.0–3.5 ft (30–106 cm)].

2. Sandstone and shale, sandy to silty, light-olive-brown (5Y5/6) to light-olive-gray (5Y5/2); sandstone thin-bedded, fine to very fine grained, lenticular to flaser bedded depending on presence of shale; rare to common pyrite concretions up to 1 inch (2.5 cm) thick in sandstone—[4.3 ft (130 cm)].

1. Sandstone, light-olive-gray (5Y5/2), fine-grained, crossbedded, massive, micaceous, with pyrite nodules near base; basal part of section covered—[>4.0 ft (>120 cm)]. Elevation of base of exposed sandstone approximately 1,160 ft (estimated from Emporia, Kansas, 7.5-min quadrangle).

FIGURE 3—Reference section for the Lorton coal bed in Kansas.

Lithostratigraphy of the Shore Airport Formation (Chesterian), Southwestern Kansas

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Abstract

The Shore Airport Formation in the Hugoton embayment of the Anadarko basin is a new subsurface stratigraphic unit for peloid packstone and maroon calcareous shale of the previously unnamed strata in the Chesterian Stage. Shore Airport strata in southwestern Kansas are unconformably underlain by the Ste. Genevieve Limestone (Chesterian) and unconformably overlain by the Kearny Formation (Morrowan). Argillaceous Shore Airport strata are distinct from Ste. Genevieve quartzose carbonates that typically contain little shale. Lower Kearny strata generally contain increased percentages of siliciclastic and sandy marine carbonates. The unit is named for the Shore Airport SW 7.5-min quadrangle, Morton County, Kansas. A core from the Amoco #1 Breeding F (sec. 34, T. 31 S., R. 40 W.) contains 40.6 ft (12.4 m) of Shore Airport strata and is designated as the type section.

Two facies are recognized from the type section. Peloid packstone is greenish-gray to maroon in color and is the dominant facies. Paucity of stenohaline marine allochems, fine grain size, and micrite matrix indicate deposition in a low-energy, restricted-shelf environment. Rhizoliths, drab-haloed root traces, and glaebules suggest reddish color in maroon peloid packstone intervals accumulated in a B_s soil horizon (zone of illuvial accumulation of sesquioxides). These paleosols are interpreted as inceptisols (sesquioxide-rich, clay-poor paleosols).

Peloid packstone is intercalated with maroon calcareous shale. Slickensides, glaebules, drab-haloed root traces, rhizocretions, and blocky peds indicate these maroon shale intervals formed in a B_t soil horizon (zone of illuvial accumulation of clay and sesquioxides). The paleosols are interpreted as alfisols (sesquioxide-rich, clay-rich paleosols).

Introduction

Mississippian strata in Kansas are confined to the subsurface, with the exception of outcrops of Burlington–Keokuk Limestone and Warsaw (Osagean) in two townships in Cherokee County, in the extreme southeastern corner of the state (Thompson and Goebel, 1968; Kammer et al., 1990; Maples, this volume). In nearby states, Chesterian strata crop out in southwestern Missouri (Thompson, 1986), northwestern Arkansas (Glick, 1979), and northeastern Oklahoma (Frezon and Jordan, 1979). Outcrops of Chesterian strata are absent from Colorado, with the exception of the extreme northwestern part of the state (DeVoto, 1980).

Little detail is known about the lithology and deposition of the previously unnamed portion of the Chesterian in southwestern Kansas. Amoco #1 Breeding F is proposed as a type section for the Shore Airport Formation (Chesterian, new name), because it contains contacts with the underlying Ste. Genevieve Limestone and the overlying Kearny Formation. In the type section, the Shore Airport Formation consists of peloid packstone and maroon calcareous shale. Argillaceous Shore Airport strata are distinct from underlying Ste. Genevieve quartzose carbonates that typically contain little shale. Overlying lower Kearny strata generally contain increased percentages of siliciclastic and sandy marine carbonates. Core study of the Shore Airport is important in increasing our understanding of sedimentation of Upper Mississippian strata.

Previous Investigations

Most previous authors refer to Chesterian strata in southwestern Kansas as all Mississippian strata above the Ste. Genevieve Limestone. In this report, however, the Ste. Genevieve is also considered to be Chesterian (Maples and Waters, 1987). In discussion of previous works, however, the reference to Chesterian strata excludes the Ste. Genevieve.

Strata of Chesterian age were first recognized, but not described, by Robert Roth (in McClellan, 1930, p. 1,548) from samples of the uppermost 400 ft of the Mississippian from Watchorn Oil and Gas Company #2 Morrison in Clark County (Lee, 1940). Chesterian strata in southwestern Kansas were originally described by McClellan (1930). Dille (1932) identified Chesterian strata from northwestern Oklahoma, southwestern Kansas, and southeastern Colorado. Chesterian strata also have been reported from southeastern Kansas (Lee, 1940; Goebel, 1968). The identification of Chesterian strata in southeastern Kansas, however, was probably erroneous (Maples, this volume).

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Clair (1948, 1949) provided details on the lithology of Chesterian strata in southwestern Kansas. Based on cuttings, Clair recognized three lithologic groups in southwestern Meade and southeastern Seward counties (in ascending stratigraphic order): 1) variegated maroon and green shales or sandy limestones; 2) finely crystalline, very finely sandy limestone intercalated with variegated gray, green, and maroon shales; and 3) slightly porous oolitic and fossiliferous limestone. The Shore Airport Formation in the Amoco #1 Breeding F is lithologically similar to the interstratified fine-grained limestones and variegated shales described by Clair (1948, 1949) and Beebe (1959a, 1959b). Although absent in the Amoco #1 Breeding F, sandstones occur locally at the base of the Shore Airport in Haskell, Stevens, and Seward counties (Clair, 1948, 1949; Veroda, 1959; Fugitt and Wilkinson, 1959; Shonfelt, 1988). In addition, Goebel (1968) and Goebel and Stewart (1979) provided generalized descriptions of Chesterian strata.

Oolites at the top of the Shore Airport are petroliferous and comprise the reservoir beds of the Adams Ranch Pool in Meade County, Kansas (Clair, 1948, 1949). Oolitic grainstones are productive from uppermost Chesterian strata in the panhandle of Oklahoma (Asquith, 1984). This facies is absent from the type section of the Shore Airport Formation in Morton County. Oolitic grainstones may have been removed by Late Mississippian–Early Pennsylvanian erosion associated with the sub-Pennsylvanian unconformity.

Regional Geology and Stratigraphy

Shore Airport strata in Kansas are presently restricted to the southwestern part of the state (fig. 1). The original extent of Shore Airport strata is unknown due to erosion associated with subaerial exposure during Late Mississippian–Early Pennsylvanian time.

Mississippian carbonates in Kansas were deposited on a shelf that extended southward from the Transcontinental arch. Deposition of argillaceous carbonates and siliciclastics of the Shore Airport marks the termination of dominantly carbonate deposition that continued throughout much of Mississippian time (Lane and De Keyser, 1980).

Shore Airport strata are underlain by the Ste. Genevieve Limestone (Chesterian) (fig. 2). Many of the quartzose grainstones in the Ste. Genevieve of southwestern Kansas are eolian in origin (Handford, 1990; Handford and Francka, 1991; Abegg, 1991, this volume). These eolianites are interbedded with subtidal strata (Abegg, 1991, this volume). Shore Airport strata are truncated at the sub-Pennsylvanian unconformity and are overlain by Morrowan strata. In Clark County, the informal "Gray group" (cf. Youle, 1991) and locally the Cherokee Group overlie the Shore Airport Formation (Goebel and Stewart, 1979).

Methods

This report stems from a more comprehensive study (Abegg, 1992) that examines Upper Mississippian strata in the Hugoton embayment of the Anadarko basin (fig. 3) in southwestern Kansas. The Amoco #1 Breeding F core was described at a scale of 1:12. Carbonate textures were described using the classification scheme of Dunham (1962). A total of 61 thin sections were examined from the Breeding core. Stratigraphic cross sections of Shore Airport, Ste. Genevieve, St. Louis, and Salem strata will be presented separately (Abegg, 1992).

Shore Airport Formation (Chesterian, New Name)

The core proposed for the type section of the Shore Airport Formation is from the Amoco #1 Breeding F, located in SW sec. 34, T. 31 S., R. 40 W., Morton County, Kansas (fig. 4). The type section is located in and named for the Shore Airport SW 7.5-minute quadrangle. The core is currently stored at the Kansas Geological Survey core facility in Lawrence, Kansas. This well was selected as the type section because it is the most complete Shore Airport core available and it contains the contacts with both the underlying Ste. Genevieve Limestone and the overlying Kearny Formation (Morrowan). Stratigraphic names from Chesterian outcrops in nearby regions were not applied because they generally represent different facies than those present in southwestern Kansas.

Type Section Facies

The Shore Airport Formation is 40.6 ft (12.4 m) thick in the Amoco #1 Breeding F; it extends from 5,282.05 to 5,322.65 core depth (fig. 5). Comparison of gamma ray peaks and porous intervals in core and logs indicate log depths are approximately 10 ft deeper than corresponding core depths (fig. 6). Peloid packstone and maroon calcareous shale are the two lithofacies recognized in the type section of the Shore Airport Formation.

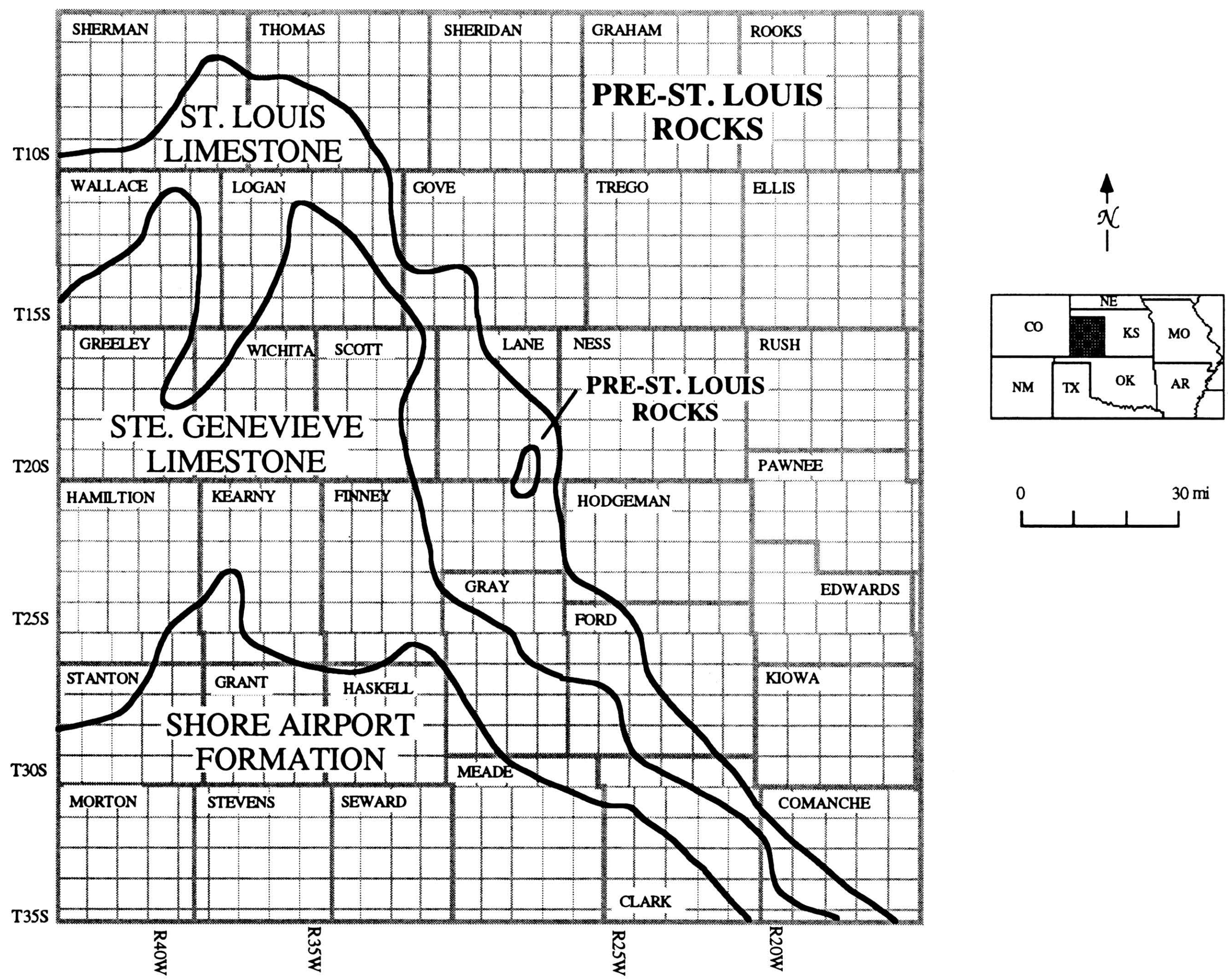


FIGURE 1—Subcrop map of Mississippian strata beneath the sub-Pennsylvanian unconformity in Kansas (modified from Thompson and Goebel, 1968). St. Louis strata are eroded from southeastern Lane and adjacent Finney counties.

Peloid Packstone Facies

This facies consists of greenish-gray to maroon packstones. Peloids are common to abundant and are the dominant allochem in this facies. Rare to common grains include echinoderms, lithoclasts (intraclasts?), and ooids. Many of the ooids are extensively micritized. Rare allochems include fragments of brachiopods and bryozoans, foraminifera, ostracodes, and sponge-spicule casts. Detrital quartz of silt to very fine sand size comprises approximately 10–40% of the peloid packstone facies. Muscovite, feldspar, zircon, and amphibole are minor constituents. Peloid packstones are typically argillaceous with maximum clay concentrations along microstylolite swarms. Clays exhibit moderate to low birefringence and have refractive indices lower than quartz. This suggests much of the clay is smectite.

Peloid packstone is commonly laminated (fig. 7). Laminae are the result of grain-size and compositional variations; finer laminae contain greater concentrations of silt and detrital quartz. Laminae are partially disrupted locally. Tubes in the shale, some filled with sparry calcite, are commonly rimmed by green haloes with diffuse outer boundaries. Greenish color is generally restricted to such haloes. The upper few centimeters of one maroon peloid packstone (5,287.2-ft [1,586-m] core depth) contained irregular patches of greenish-gray material. Rarely the larger spar-filled tubes are rimmed by vaguely laminated brownish micrite. Downward bifurcations with smaller diameters were not observed in any of the tubes. Well-indurated reddish grains occur locally.

Microstylolite swarms are common in most horizons. Often the limestone surrounding the calcite spar-filled tubes resists compaction, producing a nodular appearance. These nodules grade into stylolitized regions. Few interpenetrating grain contacts and abundant equant calcite cements in the nodules indicate compaction was minor. Calcite-cemented fractures that taper toward the center of nodules are common. Equant and syntaxial overgrowth calcite cements occur in the unstylolitized strata, but are nearly absent from microstylolitized intervals.

This facies is intercalated with the maroon calcareous shale facies of the Shore Airport (fig. 5). Peloid packstone is also interstratified with uppermost Ste. Genevieve quartzose grainstone, indicating an interfingering of Ste. Genevieve and Shore Airport facies.

Interpretation

Mud-poor packstones and rare stenohaline marine biota indicate peloid packstone was deposited in a shallow-water, restricted-shelf environment. Mud-poor packstones and ooids indicate winnowing in an intermittently agitated environment. Stenohaline marine organisms such as crinoids and brachiopods are rare, suggesting that salinities deviated from marine values. The restriction may be the result of poor circulation in shallow shelf waters. Alternatively, ooid shoals to the south (Asquith, 1984) may have provided a barrier to circulation with normal marine waters.

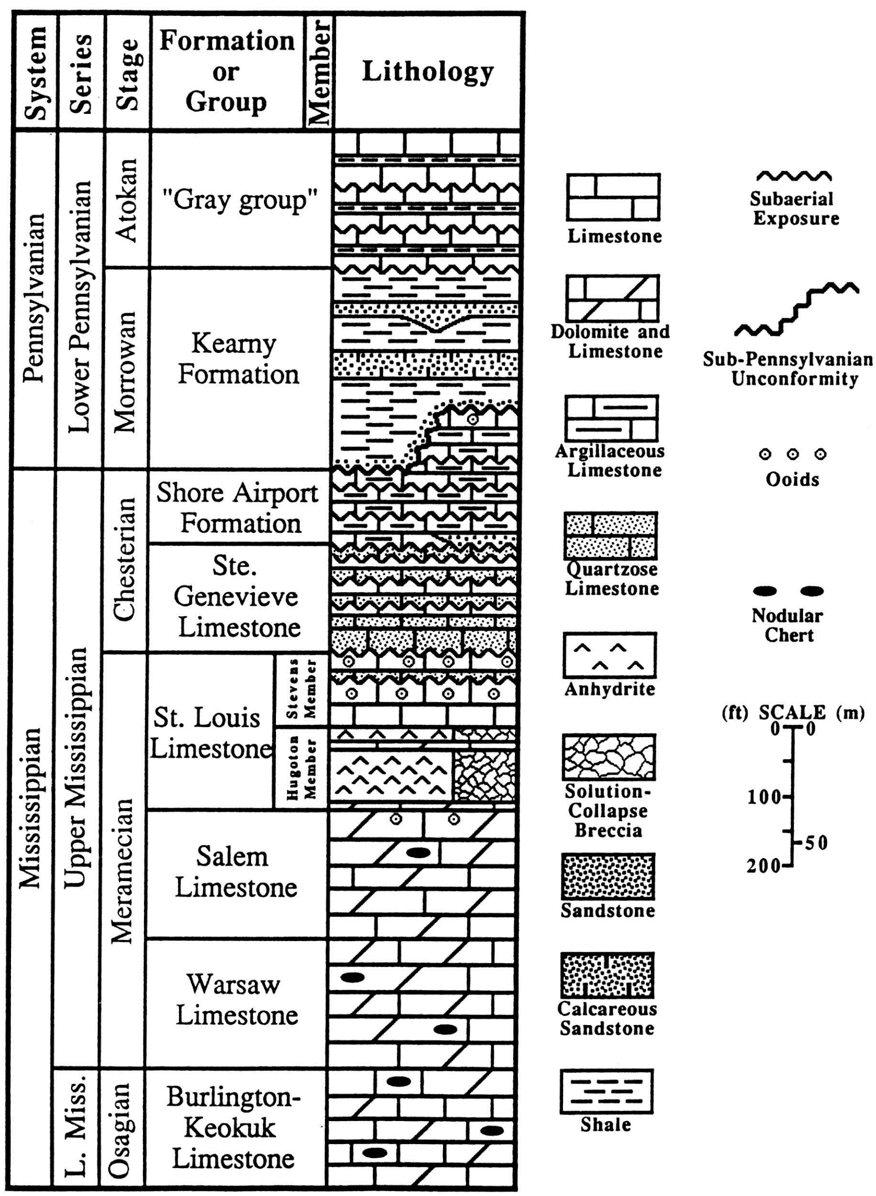


FIGURE 2—Upper Mississippian lithostratigraphic units in the Hugoton embayment of the Anadarko basin in western Kansas. Shore Airport Formation (Abegg, this paper), Hugoton and Stevens Members of the St. Louis Limestone (Abegg, this volume), and "Gray group" (Youle, 1991) are new names. The sub-Pennsylvanian unconformity erodes the entire Mississippian over the Central Kansas uplift and the Nemaha anticline. Meramecian–Osagean boundary after Kammer et al. (1990). Scale is approximate as thicknesses are variable.

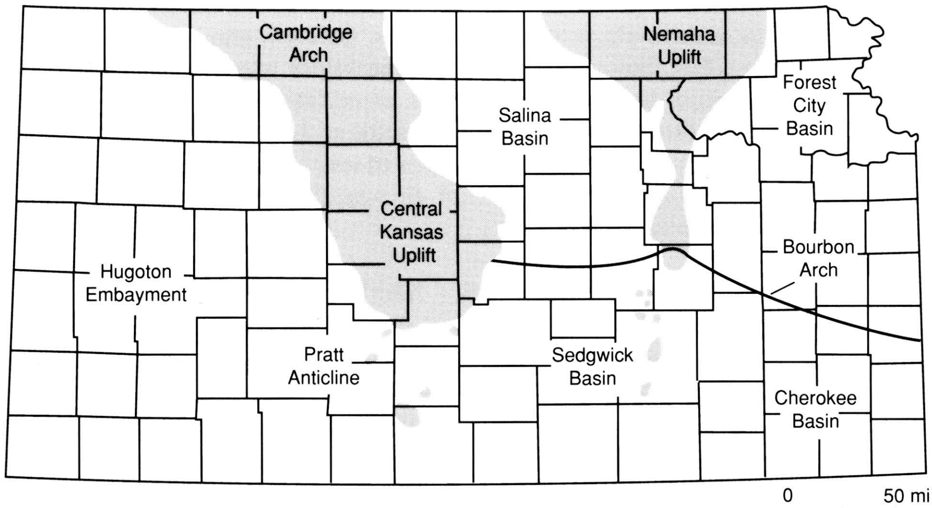


FIGURE 3—Late Mississippian–Early Pennsylvanian tectonic features (modified from Merriam, 1963; Ebanks et al., 1979). Shaded areas represent regions where Mississippian strata are absent due to Late Mississippian–Early Pennsylvanian erosion.

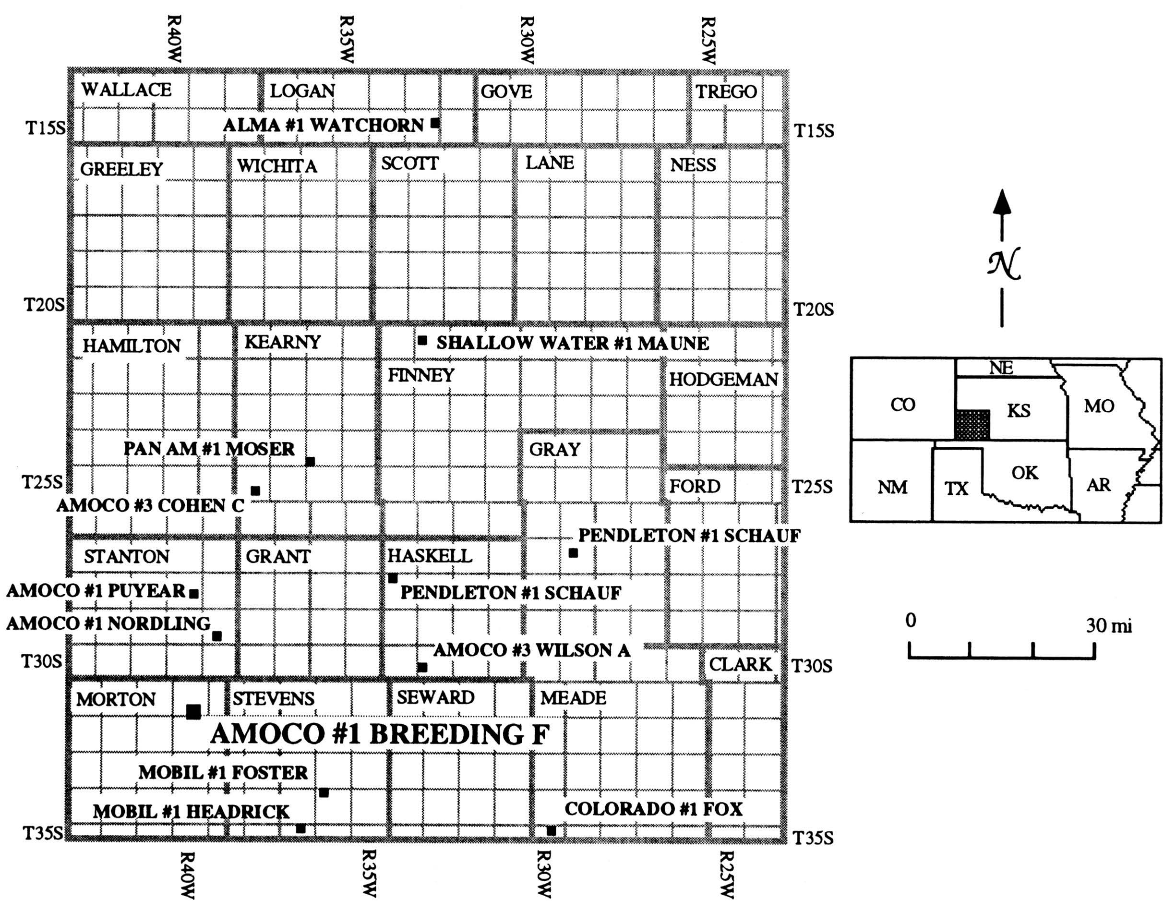


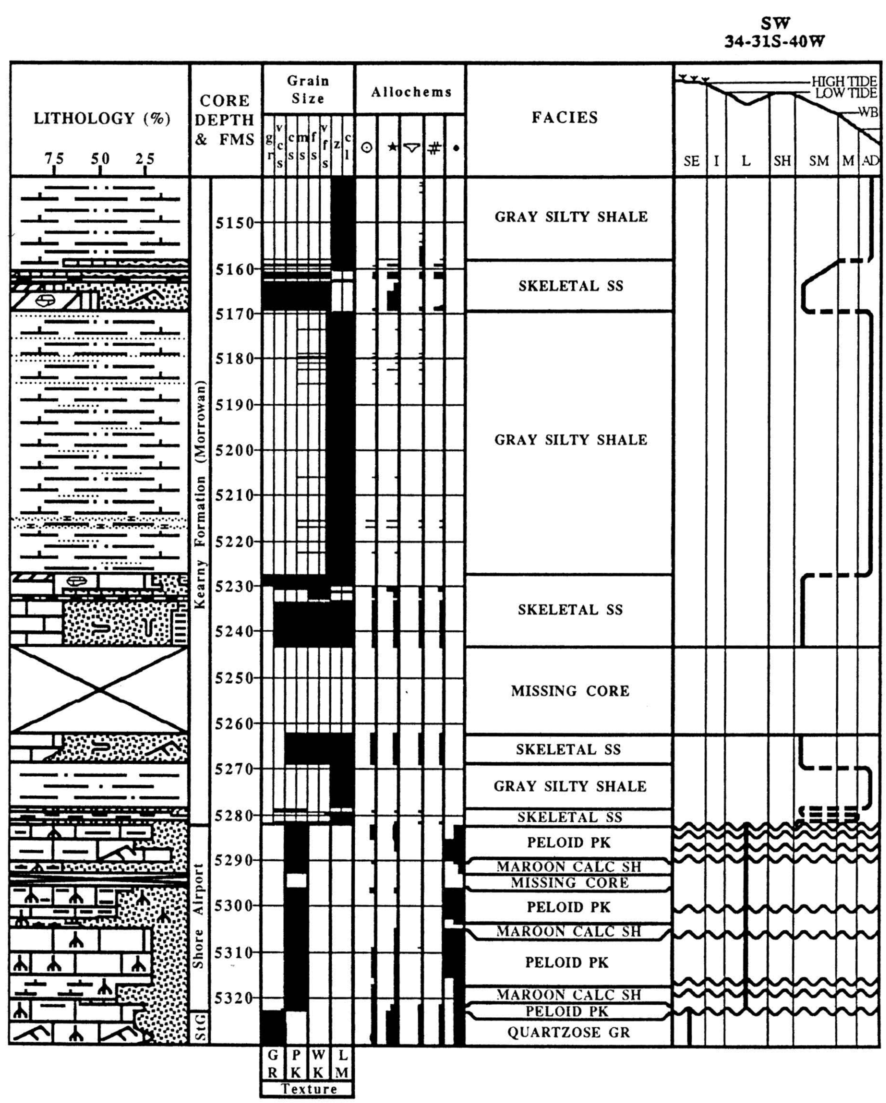
FIGURE 4—Map of southwestern Kansas showing location of Upper Mississippian cores logged. Amoco #1 Breeding F is located in northeastern Morton County (sec. 34, T. 31 S., R. 40 W.).

The spar-filled tubes and vaguely laminated brownish micrite are interpreted as root casts surrounded by rhizocretions (cf. Klappa, 1980). Many of the tubes, however, lack rhizocretions and a burrow origin cannot be discounted. Associated with rhizoliths, maroon color in clay-poor peloid packstones probably results from concentration of sesquioxides in the B_s horizon of poorly developed paleosols (see table 1 for definitions of soil terms). Greenish-gray color and rhizoliths above these B_s horizons suggest possible A horizons. Greenish-gray patches near the top of one maroon peloid packstone interval (5,287.2-ft [1,586-m] core depth) occur immediately below a transgressive surface and are interpreted to indicate subtidal reduction of iron. Well-indurated sesquioxide-rich grains are interpreted as glaebules (cf. Brewer, 1976; Retallack, 1990).

Maroon Calcareous Shale Facies

Clays in the shale have moderate to low birefringence and refractive indices less than quartz. This suggests much of the clay is smectite. Detrital quartz of very fine sand to silt size comprises up to 40% of this facies. Muscovite is rare and feldspar is extremely rare. Microspar is present locally. Maroon is the dominant color, although greenish-gray occurs locally, producing a variegated appearance. Maroon calcareous shale contains localized patches of slightly weathered limestone that are lithologically similar to interstratified peloid packstone (fig. 8). Borders of these peloid packstone patches are commonly stylolitized.

Tubes in the shale, some filled with sparry calcite, are often rimmed by a green halo with a diffuse outer boundary (fig. 8). Greenish color is generally restricted to such haloes. Well-indurated dark-maroon grains are rare. Many broken surfaces of the core are glossy and striated. Cores of this facies invariably are rubbly, breaking into roughly equant blocks.



Interpretation

This facies is interpreted as a clay-rich alfisol B_t horizon. Such reddish shaly intervals in limestone successions are commonly termed terra rossa paleosols (e.g., Goldhammer and Elmore, 1984). Clay and sesquioxides are interpreted to have been concentrated during paleosol development. The near absence of feldspar may be the result of weathering and subsequent breakdown to clays. The rubbly nature of the core is due to blocky peds and a high clay content.

The tubes are interpreted as roots (cf. Klappa, 1980). The greenish rims around many of these features are interpreted as drab-haloed root traces (Retallack, 1990). Diffuse outer boundaries indicate that drab-haloed root traces formed by the reduction of iron around roots during anaerobic decay (cf. Retallack, 1990). Glossy and striated surfaces are slickensides, which are common in clay-rich paleosols. Slickensides form by expansion and shrinkage due to alternating wet and dry periods or during compaction (Retallack, 1990). Well-indurated, dark-maroon grains are interpreted as glaebules (cf. Brewer, 1976). Slightly weathered peloid limestone patches are relatively unaltered parent material (lithorelicts of Brewer, 1976).

Shore Airport Paleosols

The two types of paleosols recognized in the Shore Airport type section are inceptisols and alfisols. The exact boundaries of A and C horizons within these paleosols are commonly difficult to recognize. Sesquioxide- and/or clay-rich B horizons, however, are easily identified. Figure 9 shows the distribution of horizons in paleosols in the Shore Airport Formation.

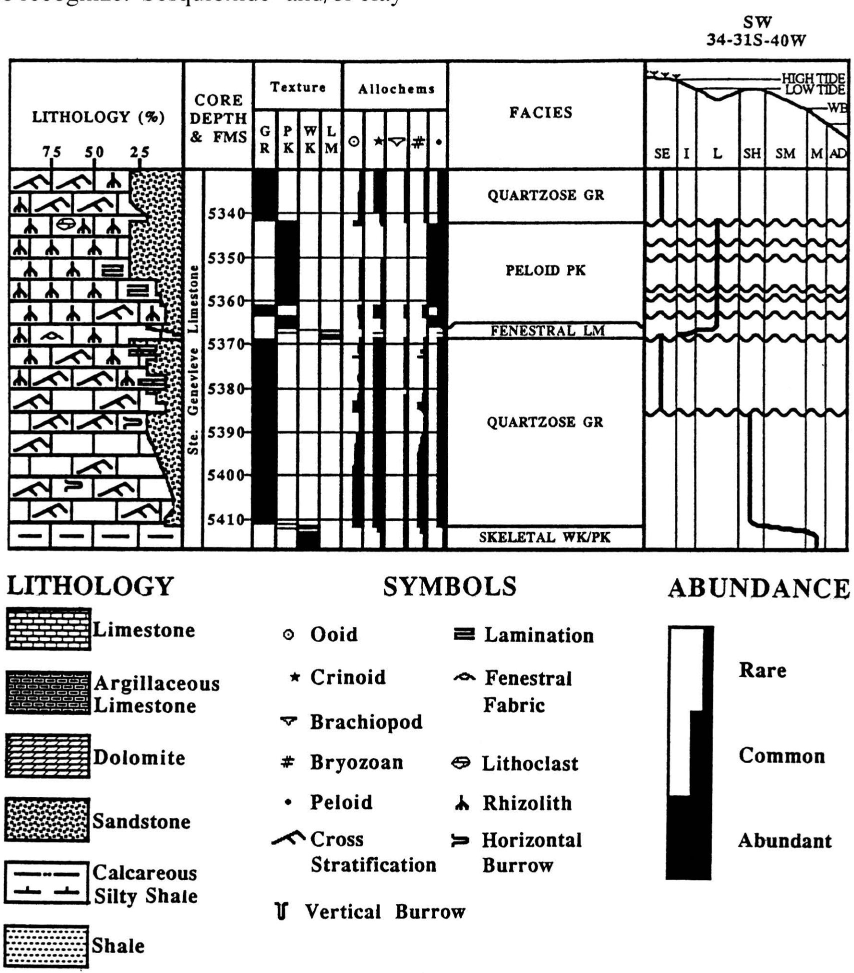


FIGURE 5 (above and left)—Description of core from the Amoco #1 Breeding F. Wireline log depths are roughly 10 ft deeper than core depths. Right-hand track shows interpretations of shifts in depositional environments. Dashed lines represent shifts without deposition. Horizontal wavy lines are subaerial exposure surfaces or surfaces bracketing eolian strata. Abbreviations used: SE—subaerial exposure; I—intertidal or tidally influenced; L—restricted lagoon/shelf; SH—oolitic or skeletal shoal; SM—shallow marine with evidence of at least intermittent agitation, above or near wave base (WB); M—marine with little winnowing, below wave base; AD—separates dysaerobic and anaerobic facies from overlying aerobic facies. Depositional textures are also abbreviated: GR—grainstone, PK—packstone, WK—wackestone, LM—lime mudstone. Formations (FMS) are listed in the depth track.

Inceptisols

Inceptisols are paleosols with relatively minor soil development (Retallack, 1990). Maroon color in the peloid packstone facies is the B_s horizon of inceptisols (fig. 10). Sesquioxides have accumulated in the B_s horizon, but signifi-

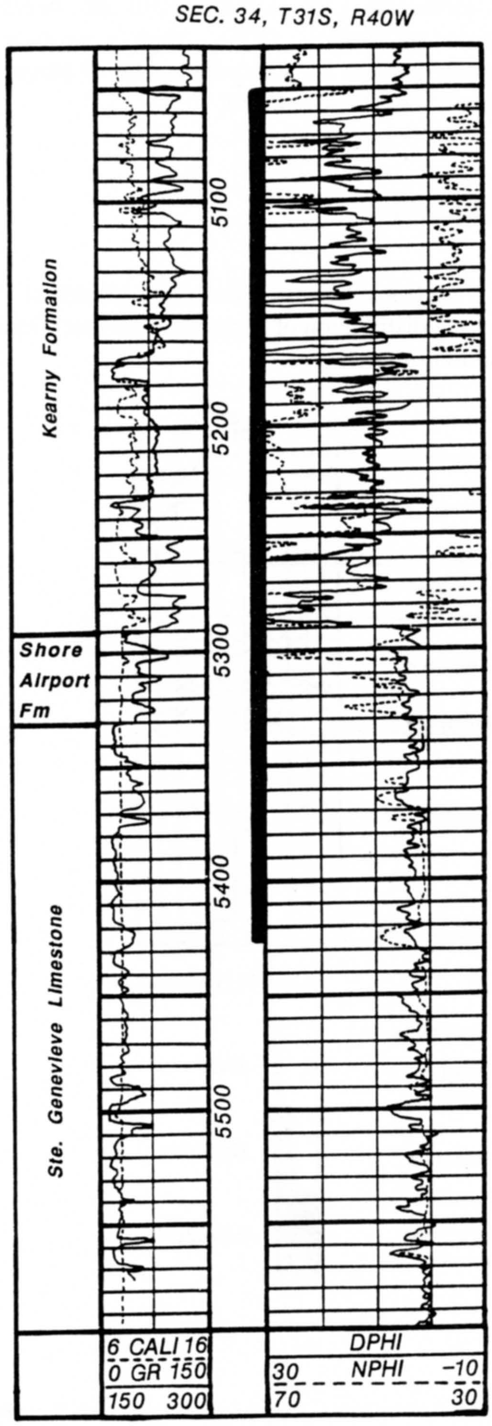


FIGURE 6—Gamma ray-neutron density log from the Amoco #1 Breeding F, Morton County, Kansas. Tops are picked from a combination of core analysis and cross section correlations. Cored interval is indicated by the thick line in depth track. Depths in feet.

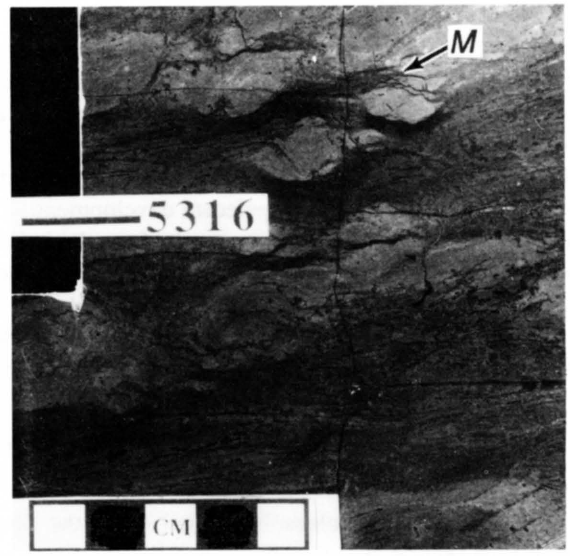


FIGURE 7—Peloid packstone with laminations and microstylolite swarms (M). 5,315–5,316-ft [1,595-m] core depth, Amoco #1 Breeding F.

FIGURE 8—Maroon calcareous shale (5,316.8–5,319.0 ft [1,595–1,596 m[and 5,319.5–5,320.2 ft[1,596 m]) interbedded with peloid packstone. Light patches (just above 5,320 ft [1,596 m]) are interpreted as drab-haloed root traces (D) formed by the reduction of iron during anaerobic decay. 5,315–5,321-ft (1,594–1,596-m) core depth, Amoco #1 Breeding F.

cant clay illuviation has not occurred. Rhizoliths, drab-haloed root traces, and glaebules also typify inceptisol B_s horizons. The maroon color suggests these paleosols were generally well drained and oxidized.

Possible A horizons of inceptisols consist of green, argillaceous peloid packstone. The green color suggests reduction of iron (gleying), possibly the result of near-surface anaerobic decay of organic material. The upper contact of the A horizon marks a transgression over the exposure surface. Reworked clasts from the underlying paleosol occur locally. This transgressive surface is typically difficult to recognize; sometimes it can be approximated by a change from unstratified intervals with roots to laminated peloid packstone. Because of the difficulty in recognizing a transgressive surface, some intervals tentatively interpreted as A horizons (fig. 9) may represent strata deposited following transgression.

The C horizon is a transitional zone from the overlying sesquioxide-rich B_s horizon to the underlying unweathered peloid packstones. Exact boundaries to the C horizon are arbitrary.

Alfisols

Alfisols are marked by a light-colored A horizon? underlain by a clay-rich B_t horizon. The red calcareous shale facies of the Shore Airport Formation is interpreted as an alfisol sesquioxide- and clay-rich B_t horizon (figs. 8 and 11). These B_t horizons also contain well-developed blocky peds, slickensides, drab-haloed root traces, and glaebules. Goldhammer and Elmore (1984) interpreted similar lithologies from the Pennsylvanian Black Prince Limestone in Arizona to be terra rossa paleosols resulting from the accumulation of insoluble residues with the dissolution of limestone. Relicts of argillaceous limestone indicate that dissolution may account for much of the silt and shale in the Shore Airport.

The A horizon is typically difficult to identify in the Shore Airport alfisols. The boundary with the B horizon is probably gradational, but this contact is difficult to observe in core because it is usually rubbly. Possible A horizons consist of unstratified gleyed shaly packstone with scattered rhizoliths, locally with well-developed root casts and rhizocretions.

TABLE 1—Definitions of soil terms used in this report; information modified from Retallack (1988, 1990) and additional sources cited.

Sesquioxide—oxides and hydroxides of iron or aluminum. The term indicates that compounds have one-half times as many O^{2-} ions as Fe^{3+} or Al^{3+} ions. In general, the most common sesquioxides are hematite, goethite, or gibbsite (Hausenbuiller, 1978). In this report, used for reddish intervals that are probably hematitic.

Glaebule—local concentrations of such minerals as sesquioxides (modified from Brewer, 1976).

Drab-haloed root trace—root surrounded by a rim of reduced iron.

Peds—aggregates of soil material between openings (e.g., cracks, roots, etc.) in the soil.

Blocky peds—equant peds with dull interlocking edges.

Illuviation cutans—cutans are a modification of soil material along natural surfaces caused by the concentration of a particular constituent. Illuviation cutans form by material washed down into cracks in the soil.

Slickensides—formed by expansion and contraction of soils due to alternating periods of wetting and drying or during compaction. Termed stress cutans in soil terminology.

A soil horizon—soil zone that contains roots and a mixture of mineral or organic matter.

B soil horizon—soil zone enriched in some material relative to or more weathered than adjacent horizons.

B_s soil horizon—B horizon marked by illuvial accumulation of sesquioxides.

B_t soil horizon—B horizon marked by accumulation of clay.

C soil horizon—slightly more weathered than underlying fresh bedrock.

R soil horizon—consolidated and unweathered bedrock.

Alfisol—soil with well-developed B_t horizon, often red with sesquioxides.

Entisol—very weakly developed soil, typically marked only by roots.

Inceptisol—weakly developed soil, typically marked by roots and an incipient clayey and sesquioxidic B_s horizon.

Overlying strata are commonly laminated. Similar to inceptisols, the difficulty in recognizing a transgressive surface suggests some intervals tentatively interpreted as A horizons (fig. 9) may represent strata deposited following transgression.

The C horizon is the transition from the overlying B_t horizon to underlying unweathered peloid packstones. Decreasing amounts of clay and sesquioxides occur toward the base of this horizon. The boundaries of the C horizon are gradational and arbitrary.

Ste. Genevieve Facies

The Ste. Genevieve Limestone consists of four facies: 1) skeletal wackestone/packstone, 2) quartzose grainstone, 3) fenestral lime mudstone, and 4) peloid packstone (fig. 5). The peloid packstone in the upper Ste. Genevieve is similar to that in the Shore Airport; it is included in the Ste. Genevieve because it is interstratified between two quartzose grainstone intervals. The upper boundary of the Ste. Genevieve is marked by the top of the uppermost quartzose grainstone. In order to define the lower contact, only the uppermost Ste. Genevieve quartzose grainstone and the peloid packstone facies need to be described below. Details of these and other Ste. Genevieve facies are included in Abegg (1992).

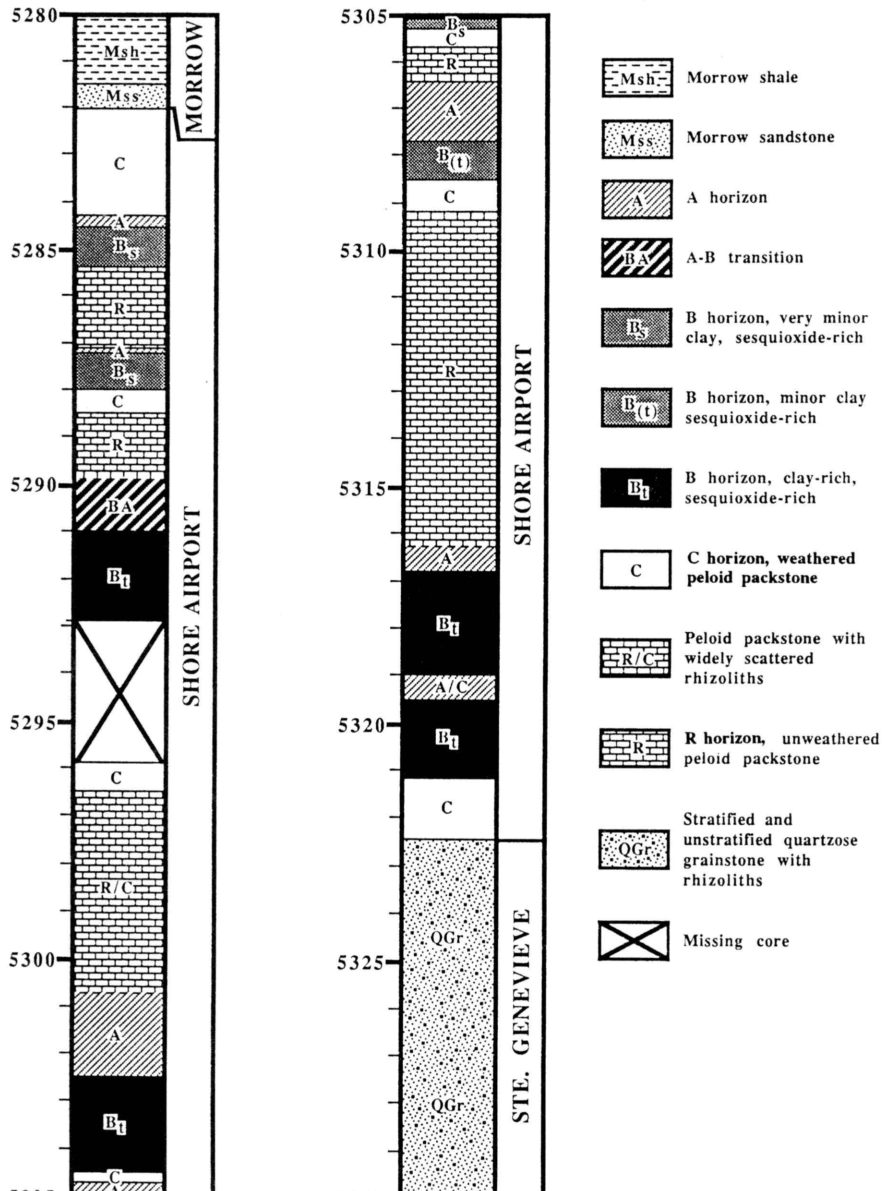


FIGURE 9—Soil horizons in the type section of the Shore Airport Formation. Identification of A horizons is often uncertain and boundaries of C horizons are gradational and thus arbitrary. Sesquioxide-rich and clay-rich B_t horizons along with sesquioxide-rich and clay-poor B_s horizons are easily identifiable.

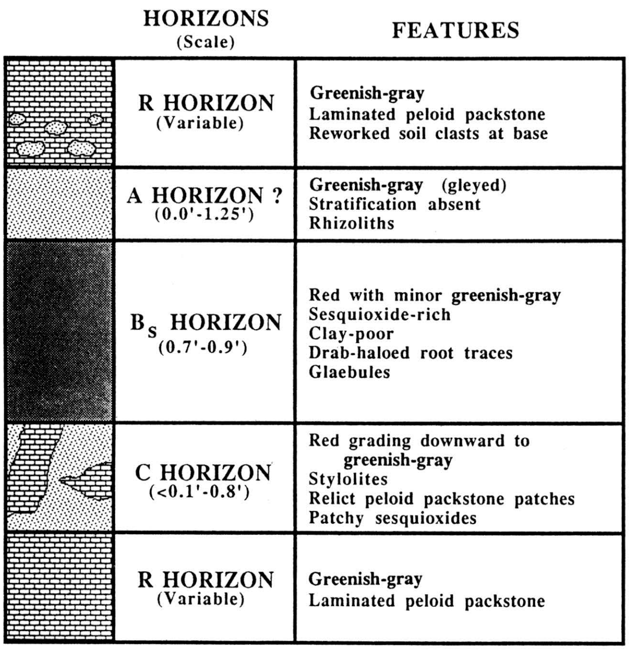


FIGURE 10—INCEPTISOLS SHOWING HORIZONS AND FEATURES IN THE SHORE AIRPORT FORMATION TYPE SECTION.

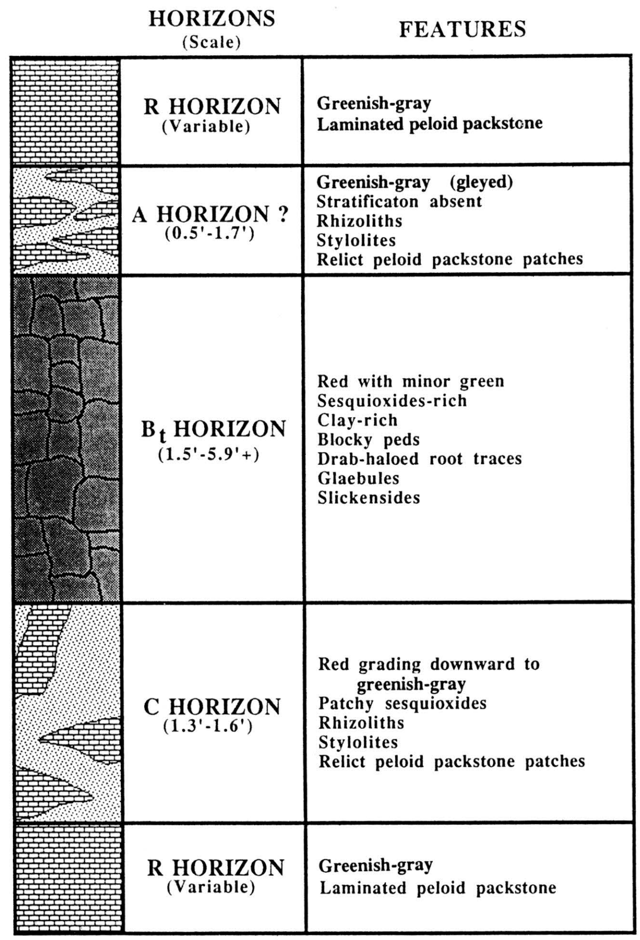


FIGURE 11—ALFISOLS SHOWING HORIZONS AND FEATURES IN THE SHORE AIRPORT FORMATION TYPE SECTION.

Quartzose Grainstone Facies

Allochems are almost invariably broken and well rounded, regardless of their original shape. Common grains include peloids and echinoderms. Bryozoans and ooids are common to rare. Brachiopods, trilobites, foraminifera, sponge spicule casts, and lithoclasts are rare. Glauconitic grains and cubic pyrite are scattered throughout. Detrital quartz sand varies between 5% and 30% and is mostly very fine grained, although grain size ranges from very coarse silt to medium sand. Quartzose grainstones often can be recognized on wireline logs by a crossover in the neutron and density curves with higher neutron porosities than density porosities (fig. 6). Other detrital grains are rare, including feldspar, zircon, and amphibole. Muscovite, detrital chert, and phosphatic grains are very rare. Cross stratification is typically less than 15°, but locally as high as 32°. Much of this facies is marked by climbing translatent stratification (fig. 12).

Interpretation

The majority of quartzose grainstone is interpreted as carbonate eolianites. Coarsening-upward grain size and rare ripple-foreset laminae indicate that the climbing translatent stratification (fig. 12) is of eolian origin (cf. Hunter, 1977, 1981; Kocurek and Dott, 1981; Kocurek, 1991). However, discontinuous and disrupted stratification in quartzose grainstone is interpreted as bioturbated subtidal deposits (fig. 5). Hunter (1989) described a quartz-rich limestone facies from the Illinois basin in southern Indiana. He also ascribed an eolian origin. Based on similarities with Hunter's examples, Handford (1990) and Handford and Francka (1991) interpreted the quartzose grainstone of southwestern Kansas as eolian in origin. Handford (1988), however, had previously interpreted these grainstones as subaqueous tidal channels. Eolian quartzose grainstones have been identified over much of the Hugoton embayment (Handford and Francka, 1991; Abegg, 1992).

Peloid Packstone Facies

The peloid packstone in the upper Ste. Genevieve Limestone is nearly identical to the same facies in the Shore Airport. The peloid packstone in the Ste. Genevieve includes the following features not observed in the peloid packstone in the Shore Airport: 1) very thin grainstone intervals, 2) possible *Microcodium* that is calcification of mycorrhizae (fungal and root associations) (Klappa, 1978), 3) absence of interbedded sesquioxide- or clay-rich intervals, 4) fewer microstylolite swarms, and 5) more abundant calcite cement-filled tubes, many with dark-brown, vaguely laminated micrite coatings (fig. 13). These tubes are concentrated at particular horizons. Tubes with well-developed micritic coatings typically grade downward to tubes lacking such coatings (fig. 14).

Interpretation

Rare stenohaline marine biota indicates peloid packstone was deposited in a restricted-shelf environment. Periodic winnowing and ooids indicate an intermittently agitated shallow-water environment. Stenohaline marine organisms such as crinoids and brachiopods are rare, suggesting that salinities deviated from normal-marine values or that environmentally stressed conditions existed. The restriction may result from poor circulation in shallow shelf water. Alternatively, ooid shoals also may have contributed to restricted circulation.

The calcite cement-filled tubes are interpreted as root casts and micritic coatings are rhizocretions (cf. Klappa,

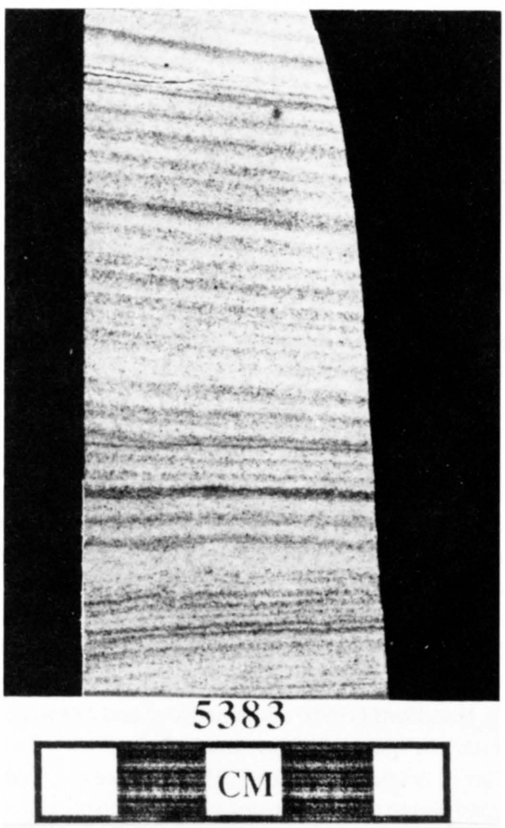


FIGURE 12—Climbing translatent strata, typically 2–5 mm thick, formed by the migration of climbing wind ripples from the Ste. Genevieve quartzose grainstone facies. Each climbing translatent stratum consists of a basal dark interval of mostly very fine sand that grades upward to a lighter interval that typically contains medium sand. 5,383-ft (1,615-m) core depth, Amoco #1 Breeding F.

FIGURE 13—Peloid packstone from the upper Ste. Genevieve. Tubes (arrows) surrounded by vaguely laminated micrite are interpreted as root casts and rhizocretions respectively, collectively termed rhizoliths. Rhizoliths are the only feature that marks these poorly developed paleosols (entisols). 5,342-ft (1,603-m) core depth, Amoco #1 Breeding F.

1980). Similar rhizoliths occur much less frequently in the peloid packstone facies of the Shore Airport. Upper Ste. Genevieve rhizoliths in peloid packstone intervals are concentrated near the top of paleosols. Rhizoliths with well-developed rhizocretions typically grade downward to root casts lacking rhizocretions; however, a burrow origin for tubes without rhizocretions cannot always be discounted. Because the only indications of paleosols are local concentrations of rhizoliths, these paleosols are interpreted as entisols (fig. 14). Entisols (table 1) characteristically contain parent lithologies that are nearly unaltered by soil processes due to a lack of time or unfavorable conditions for soil development (Retallack, 1990).

Kearny Formation (Morrowan) Facies

The basal Kearny Formation (Morrowan) in the Amoco #1 Breeding F consists of the skeletal sandstone facies and the gray silty shale facies (fig. 5).

Skeletal Sandstone Facies

Dark-gray silty shales of the Kearny are intercalated with fossiliferous sandstone generally containing greater than 50% detrital quartz plus feldspar and muscovite. Locally grainstones occur where carbonate allochem abundance exceeds quartz abundance. Common allochems include crinoids and limestone lithoclasts, and rare brachiopods, bryozoans, tabulate corals, ooids, foraminifera, bivalve? casts, and trilobite fragments. Phosphatic and glauconitic grains are common to rare. Planar cross stratification sets up to 10 cm are present at several horizons. Horizontal and vertical trace fossils occur locally. Grains are very poorly sorted with grain sizes ranging from clay to granule. Intergranular porosity is totally occluded by calcite cement and, less commonly, by saddle dolomite cement.

Interpretation

The coarse grain size, cross stratification, and stenohaline marine biota indicate fossiliferous sandstone accumulated in very shallow, highly agitated, normal-marine water. Vertical trace fossils suggest an abundance of suspension feeders that are typical of high-energy settings (Dodd and Stanton, 1981). The shallow-water setting and abundance of skeletal components, relative to the detrital fraction, suggest deposition in a delta-front setting (cf. Swanson, 1978) removed from areas of high detrital input.

Gray Silty Shale Facies

Dark-gray silty shale makes up the largest fraction of the Kearny Formation in the Shore Airport type-section core. Rare pyritized articulate brachiopods (and cephalopods?) are the only megafossils observed in these shales. Thin, typically discontinuous, silty laminae to 3.5 mm thick are common. These laminae fine upward and have sharp and locally irregular bases. Rare laminae with medium sand grains are typically thicker than laminae with fine to very fine sand; they contain ooids, crinoids, and bioclasts.

Interpretation

The high organic content, pyrite, stenohaline marine brachiopods, and low-diversity fauna suggest the dark-gray silty shale of the Kearny was deposited in a dysaerobic marine environment below normal wave base, probably in a prodelta setting (cf. Swanson, 1978).

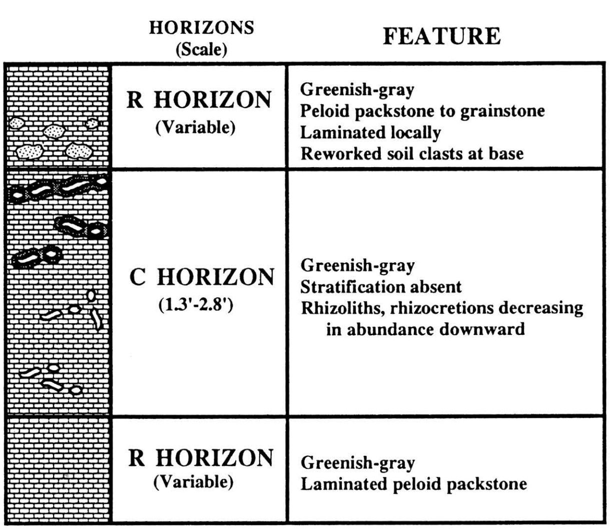


FIGURE 14—ENTISOLS SHOWING HORIZONS AND FEATURES IN THE SHORE AIRPORT FORMATION TYPE SECTION. Reworked soil clasts are rare. Root casts without rhizocretions grade upward to rhizoliths with increasingly thicker rhizocretions.

Formation Boundaries

Lower Boundary

The Shore Airport Formation is underlain by the Chesterian (Maples and Waters, 1987) Ste. Genevieve Limestone (fig. 2). The Shore Airport–Ste. Genevieve boundary is placed at the top of the uppermost quartzose grainstone.

Ste. Genevieve strata in the type section of the Shore Airport also are representative of the formation elsewhere in the Hugoton embayment. Quartzose grainstone is very distinct in both core (fig. 5) and logs (fig. 6) from the argillaceous strata of the Shore Airport. Additionally, Shore Airport strata contain shale interbeds that are recognizable in core and on gamma ray logs. Ste. Genevieve carbonates typically consist of 5% to 30% detrital quartz and generally lack shale. The absence of grain sizes less than sand results in a very clean gamma-ray signature. Detrital quartz produces a separation of the neutron to the right of the density curve (matrix calibrated for limestone). Shore Airport carbonates commonly contain detrital quartz with a significant silt and clay fraction. The argillaceous nature of many Shore Airport carbonates corresponds to a significantly higher gamma ray count and a separation of the neutron curve to the left of the density curve, opposite from Ste. Genevieve carbonates (fig. 6).

In the Shore Airport type section, a peloid packstone interval lithologically similar to Shore Airport limestones occurs between quartzose eolianites of the Ste. Genevieve. Similar interstratification of quartzose grainstone and peloid packstone in the uppermost Ste. Genevieve facies occurs locally in the Hugoton embayment. This indicates interfingering of Ste. Genevieve and Shore Airport strata.

Upper Boundary

Morrowan strata of the Kearny Formation in the type section of the Shore Airport consist of interbedded shale and calcareous sandstone. In many cases, the Shore Airport and Kearny Formations can be differentiated by the percentage of terrigenous siliciclastics (figs. 5 and 6). Shale commonly predominates in the Kearny, whereas shale typically occurs as thin interbeds in the Shore Airport. In the type section, the shales of the Shore Airport are maroon to greenish-gray whereas the Kearny shales are dark gray. Dark-gray shales, however, have been previously reported from the Shore Airport (e.g., Clair, 1948, 1949).

The boundary between the formations is part of a highly erosional unconformity that separates the Mississippian and Pennsylvanian systems over much of North America. The upper beds of the Shore Airport become increasingly eroded northward until erosion associated with the sub-Pennsylvanian unconformity has removed the formation entirely (fig. 1). Rare reworked lithoclasts of the Shore Airport are part of a thin transgressive lag at the base of the Kearny in the type section. Shore Airport strata up to 6 cm beneath the sub-Pennsylvanian unconformity contain solution-enlarged fracture and vuggy porosity filled with shaly, skeletal sandstones of Morrowan age (fig. 15). The sediment-filled porosity is interpreted as microkarst formed during Late Mississippian–Early Pennsylvanian subaerial exposure. Light-brown calcareous nodules occur up to 1.2 ft (0.4 m) below the sub-Pennsylvanian unconformity. These nodules show only minor compaction and contain rhizoliths, microspar, and approximately 10% detrital quartz. Greenish clay-filled fractures occur from 5,282.6 ft, 0.5 ft (0.2 m) below the unconformity, down to 5,284.7 ft; they are bordered by greenish halos. These fractures are interpreted as illuviation cutans (table 1) formed by clay that is washed into cracks (cf. Retallack, 1990). The calcareous nodules and illuviation cutans probably formed during Late Mississippian–Early Pennsylvanian subaerial exposure because they are best developed proximal to the sub-Pennsylvanian unconformity and are not well developed in any Shore Airport paleosols.

Where Morrowan strata are absent, the Shore Airport is overlain by the informal "Gray group" (Atokan?) (cf. Youle, 1991) and locally by the Cherokee Group (Desmoinesian) (Goebel and Stewart, 1979). Compared to Shore Airport strata, "Gray group" limestones are typically cleaner and are commonly interstratified with more radioactive shales. Log signatures of the Cherokee Group appear similar to strata of the "Gray group" but are typically more thinly bedded (Youle, 1991).

Lateral Variability

Very few cores of the Shore Airport are available for study. The majority of these cores are short, many only targeting the sandstone at the base of the unit in Seward and surrounding counties. Therefore, evidence of lateral variability of the Shore Airport relies heavily on log stratigraphic cross sections.

Maximum observed thickness of the Shore Airport Formation is 446 ft (136 m) in southwestern Meade County.

Thickness of the Shore Airport changes dramatically, largely in response to erosion associated with the sub-Pennsylvanian unconformity. In extreme southwestern Seward County, the thickness of the Shore Airport changes by as much as 247 ft (75 m) between two wells approximately 7 mi (11 km) apart. A structural cross section indicates this thickening of the Shore Airport is the result of erosion over a structural high.

Sandstones at the base of the Shore Airport are productive in Stevens, Seward, and Haskell counties (Clair, 1948, 1949; Veroda, 1959; Fugitt and Wilkinson, 1959; Shonfelt, 1988). Basal Shore Airport sandstone, limestone-lithoclast conglomerate, and coaly shale are present in Stevens County in cores from the Anadarko #2 Hitch G (sec. 3, T. 33 S., R. 34 W.), Anadarko #2 Etzold B (sec. 22, T. 33 S., R. 34 W.) and Anadarko #3 Cosgrove A (sec. 22, T. 33 S., R. 34 W.). These three basal Shore Airport and Ste. Genevieve cores are currently stored at the Kansas Geological Survey core facility.

Because Shore Airport cores are generally absent, lateral variability relies heavily on the calibration of logs to lithologies in the Amoco #1 Breeding F. These interpretations of log patterns are probably not unique solutions. Cuttings would be effective in calibrating these log patterns to lithologies throughout southwestern Kansas. Fragments of many paleosol features should be recognizable in cuttings, especially if thin sectioned.

Three log profiles are recognized in Shore Airport carbonates: 1) serrated, 2) blocky, and 3) funnel (fig. 16). Some of these names are borrowed from descriptive shapes of spontaneous potential curves (cf. Doveton, 1986). Serrated profiles are common and are well illustrated in the Amoco #1 Breeding F (fig. 6). Serrated profiles are interpreted as argillaceous limestones punctuated by alfisol clay-rich (B_t) soil horizons. It is likely, however, that not all the shales in the Shore Airport are paleosols. Thick intervals that lack interbedded shales produce blocky profiles. Blocky profiles are common and are interpreted as successions of argillaceous limestones that lack interbedded clay-rich (B_t) soil horizons. Blocky profiles may be punctuated by entisols or inceptisols. Blocky profiles are well illustrated in many wells (e.g. Douglas #1–18 Thomas, sec. 18, T. 34 S., R. 35 W.). Funnel profiles are rare in most Shore Airport sections. Mobil #1 Foster (sec. 5, T. 34 S., R. 36 W.) illustrates several funnel profiles. Funnel profiles are difficult to interpret because they have not been calibrated to core lithologies, but they may represent shoaling-upward cycles from argillaceous peloid packstones to high-energy peloid ooid grainstones.

Blocky and serrated types commonly occur in the same well. Serrated profiles are most abundant in Morton County. To the east, blocky profiles become more abundant. Funnel profiles occur locally. This trend in log patterns may suggest that the Shore Airport in Morton County contains numerous alfisols, and successions that lack paleosols or are punctuated by entisols and inceptisols (clay-poor paleosols) become more abundant eastward. Additional work on Shore Airport lateral variability is needed.

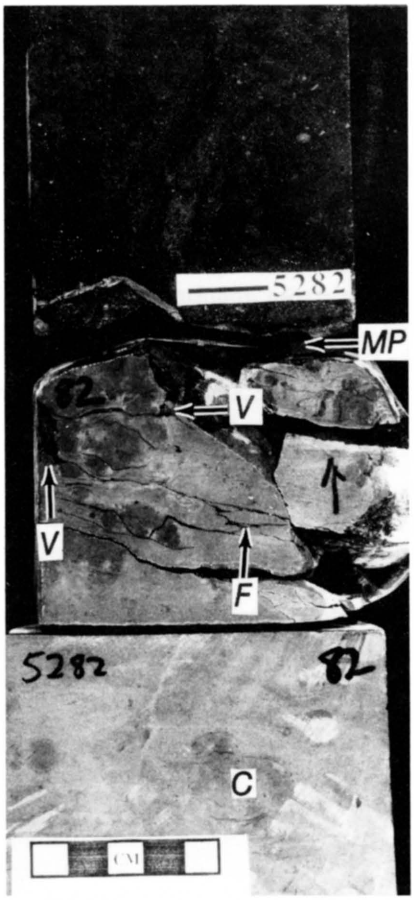


FIGURE 15 —MISSISSIPPIAN–PENNSYLVANIAN UNCONFORMITY (MP) AT 5,282.05-FT CORE DEPTH IN THE SHORE AIRPORT TYPE SECTION. Solution-enlarged fractures (F) and vuggy (V) porosity are filled with Morrowan sediment indicating microkarstification. Underlying Shore Airport has calcareous nodules (C) and greenish clay-filled illuviation cutans (not shown) that decrease in abundance from the unconformity and are not present in other Shore Airport paleosols. 5,181–5,182-ft core depth, Amoco #1 Breeding F.

Sedimentology

Shore Airport strata cap an overall regressive sequence that was deposited during the Late Mississippian. In southwestern Kansas, Meramecian strata generally consist of middle to outer shelf deposits consisting largely of normal-marine limestones. The uppermost Meramecian and Chesterian strata contain increasing influence of eolian deposition and paleosol formation. Subtidal intervals are typically thin and consist largely of oolitic grainstone and peloid packstone. Relative sea-level rises in the Late Mississippian rarely flooded this portion of the shelf completely enough to deposit widespread normal normal-marine limestones.

Asquith (1984) reports crinoid-bryozoan wackestone and packstone and porous oolitic grainstone from the Chesterian of northwestern Oklahoma. Normal-marine limestone in northwestern Oklahoma may be correlative to restricted peloid packstone in southwestern Kansas. Oolitic shoals may have been barriers to circulation with open-marine waters to the south. Alternatively, restricted conditions may be the result of poor circulation across a shallow shelf. Biostratigraphy and correlation of paleosols (sequence stratigraphy) is needed to help determine facies transitions in the Shore Airport.

Conclusions

1. The Shore Airport Formation in the Hugoton embayment of the Anadarko basin is a new stratigraphic unit for previously unnamed Chesterian strata. The Shore Airport–Ste. Genevieve boundary is defined at the top of the uppermost quartzose grainstone. Overlying Pennsylvanian strata typically have an increased siliciclastic fraction relative to Shore Airport strata. The Shore Airport Formation is named for the Shore Airport SW 7.5-minute quadrangle, Morton County, Kansas. The type section is a core from the Amoco #1 Breeding F (sec. 34, T. 31 S., R. 40 W.) that contains 40.6 ft (12.4 m) of Shore Airport strata. Peloid packstone and maroon calcareous shale are the two facies recognized from the type section of the Shore Airport.
2. Peloid packstone is greenish-gray to maroon in color and is the dominant facies. Paucity of stenohaline marine allochems, fine grain size, and micrite matrix indicate deposition in a low-energy, restricted shelf environment. Local winnowing and rare ooids suggest waters were periodically agitated. Maroon color formed by illuvial accumulation of sesquioxides in a B_s soil horizon.
3. Peloid packstone is intercalated with maroon calcareous shales. Clay and sesquioxides accumulated in the B_t horizon. Slickensides, glaebules, drab-haloed root traces, rhizocretions, and blocky peds indicate these reddish intervals are paleosols.
4. Two types of paleosols are present in the Shore Airport Formation in the Amoco #1 Breeding F. Inceptisols are marked by sesquioxide-rich B_s horizons that contain little clay. Alfisols are marked by sesquioxide-rich and clay-rich B_t horizons. Paleosols are spaced 2.8–10.8 ft (0.9–3.3 m) apart and are interstratified with restricted peloid packstone.

ACKNOWLEDGMENTS—Amoco Production Company graciously donated the Amoco #1 Breeding F core to the Kansas Geological Survey for use as a type section for the Shore Airport. I would like to thank Amoco Production Company and the Kansas Geological Survey for providing access to numerous Upper Mississippian cores. Thanks are extended to Amoco's Van Leighton for his kind assistance and consideration.

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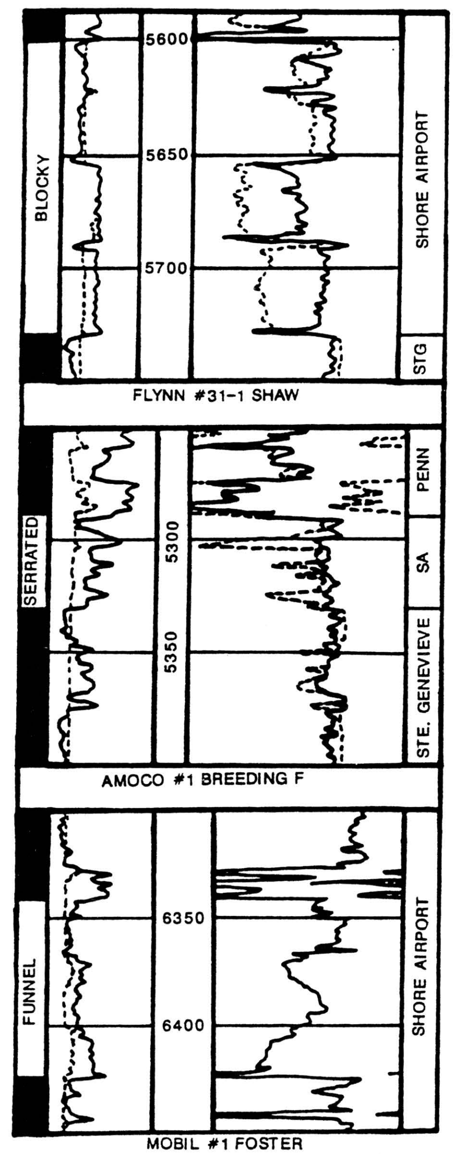

FIGURE 16—LOG PROFILES OBSERVED IN THE SHORE AIRPORT IN SOUTHWESTERN KANSAS. Serrated profiles are interpreted to result from subtidal peloid packstones punctuated by clay-rich alfisols. Blocky profiles are interpreted to result from subtidal strata, possibly punctuated by clay-poor entisols or inceptisols. Peloid packstones with entisols from the upper Ste. Genevieve result in a log pattern similar to observed blocky profiles. Funnel profiles have not been observed in core, but may represent high-energy shoaling-upward cycles from argillaceous peloid packstone to peloid ooid grainstone.

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Lithostratigraphy of the Hugoton and Stevens Members of the St. Louis Limestone and the Ste. Genevieve Limestone (Upper Mississippian), Southwestern Kansas

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Abstract

The Hugoton and Stevens Members are new lithostratigraphic units of the St. Louis Limestone in the Hugoton embayment, southwestern Kansas. A core from the Mobil #1 Foster (sec. 5, T. 34 S., R. 36 W.) is proposed as the type section for both members.

The Hugoton is the lower member and at the type section contains primarily dolomitic peloidal grainstone/packstone, dolomite, and anhydrite. Breccia, algal boundstone, and dolomitic lime mudstone are common facies elsewhere in southwestern Kansas. The Hugoton Member is easily differentiated from skeletal and oolitic limestones of the uppermost Salem Limestone. Abundant peloids, anhydrite, and paucity of stenohaline marine organisms in the Hugoton Member indicate deposition in a restricted lagoon. Restricted conditions probably resulted from oolite-skeletal shoals in the underlying Salem.

Strata of the Stevens Member contain dominantly skeletal packstone/wackestone. Periodic winnowing, intercalated oolites, and a diverse and abundant assemblage of stenohaline echinoderms, brachiopods, and bryozoans indicate Stevens skeletal packstone/wackestone was deposited in a normal-marine shelf environment at or near fair-weather wave base. Stevens Member oolitic grainstone/packstone, the reservoir facies, accumulated in a highly agitated, marine-shoal environment, probably at depths less than 15 ft (5 m). A quartzose grainstone 3.8 ft (1.2 m) thick in the Stevens Member contains abundant rhizoliths and ubiquitous climbing translatent strata with dips less than 7°, indicating deposition in a vegetated eolian sand sheet.

Ste. Genevieve strata are recognized by the lowest prominent quartz-rich grainstone. In the Mobil #1 Foster, the basal quartzose grainstone is 9.4 ft (2.9 m) thick, lacks rhizoliths, and consists of abundant climbing translatent, common grainfall, and minor grainflow stratification in crossbed sets up to 1.5 ft (0.5 m) thick with dips as high as 24°. This crossbedding, climbing translatent strata, and the apparent absence of vegetation indicate deposition by eolian dunes. The overlying Shore Airport Formation typically contains argillaceous limestone and intercalated calcareous shale.

Introduction

Ooid grainstones in the St. Louis and Ste. Genevieve Limestones are important hydrocarbon reservoirs. Despite the economic importance, the lithostratigraphy of these units in southwestern Kansas has not been updated since the work of Goebel (1968a) and Thompson and Goebel (1968). Mississippian strata in Kansas are confined to the subsurface, with the exception of outcrops of Burlington–Keokuk and Warsaw Limestones (Osagean to Meramecian) in two townships of Cherokee County, in the extreme southeastern corner of the state (Thompson and Goebel, 1968; Kammer et al., 1990; Maples, this volume). Upper Mississippian lithostratigraphic nomenclature of the Mississippi Valley region was originally extended to the subsurface of Kansas by Lee (1940) and Clair (1948, 1949).

Most previous studies of Upper Mississippian strata in southwestern Kansas used insoluble residues and biostratigraphy extensively to define lithostratigraphic units. It is more practical to base definitions on the more abundant carbonate fraction that is observable in cores and cuttings, or indicated with certain wireline logs. Formations are rock-stratigraphic units (i.e. lithofacies); accordingly biostratigraphic data should serve to constrain lithostratigraphic correlations, but not to delineate formations. Recent advances in carbonate petrology, sequence stratigraphy, and subsurface data warrant an update of existing lithostratigraphic definitions and interpretations of depositional history of the Upper Mississippian in southwestern Kansas. Increased understanding of Upper Mississippian facies, lithostratigraphy, and depositional history should enhance hydrocarbon exploration and production from these strata.

Ste. Genevieve and St. Louis strata of the Illinois basin and southwestern Kansas share many similarities; however, differences between the two areas exist. Lithologic similarities and entrenched usage in the literature and in the petroleum industry warrant continued use of these formational names in Kansas. This paper aims to update facies descriptions and standardize stratigraphic terminology, as well as increase our understanding of the depositional history for the St. Louis and Ste. Genevieve Limestones.

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The core from the Mobil #1 Foster (fig. 1, sec. 5, T. 34 S., R. 36 W., Stevens County, 6 mi (10 km) southeast of Hugoton, Kansas) is proposed as the type section for the Hugoton and Stevens Members of the St. Louis Limestone (fig. 2). In addition, this well will also serve as a reference section for the Ste. Genevieve Limestone in southwestern Kansas. A core is designated as the type and reference section because both the Ste. Genevieve and St. Louis do not crop out anywhere in the state. The Foster core contains facies that are representative of these lithostratigraphic units over much of the Hugoton embayment of southwestern Kansas.

The Mobil #1 Foster core contains 285 ft (87 m) of the Hugoton and Stevens Members of the St. Louis and the Ste. Genevieve (6,625 to 6,910 ft [1,987–2,073 m]). The core is currently housed at the Kansas Geological Survey core facility in Lawrence, Kansas. The base of this core was incorrectly identified as Salem on the scout card and by Abegg (1991). Stratigraphic cross sections indicate the basal 56 ft (17 m) of the core is the marine carbonate unit between the E1 and E2 evaporite of the Hugoton Member (Abegg, 1992). Log depths and core depths are approximately coincident (fig. 3). Neither the Salem–St. Louis nor the Ste. Genevieve–Shore Airport boundaries were cored. In addition to length, this core was selected because it is available to the general public and contains facies representative of these lithostratigraphic units over much of the Hugoton embayment.

The type section of the Hugoton Member does not contain the Salem–St. Louis boundary. Principal reference cores, therefore, are needed to facilitate recognition of this boundary. The lower boundary of the Hugoton Member is cored in the Atlantic #1 Mark A, sec. 28, T. 20 S., R. 33 W., Scott County, Kansas (Thompson and Goebel, 1968), and is currently housed at the Kansas Geological core facility in Lawrence, Kansas. Amoco #1 Nordling and Amoco #3 Wilson A (Abegg, 1992) cores also contain the Salem–St. Louis boundary and are currently housed at Amoco's core facility in Denver, Colorado.

Previous Investigations

According to Lee (1940), upper Meramecian and Chesterian strata of southwestern Kansas were first penetrated by the Watchorn Oil and Gas Company #2 Morrison in Clark County in 1931. Strata of "late Meramecian age" in southwestern Kansas were initially grouped into the Watchorn Formation "where subdivision of... the Spergen [Salem], St. Louis, and possibly Ste. Genevieve limestones is impracticable" (Lee, 1940, p. 84-85). Lee relied heavily on insoluble

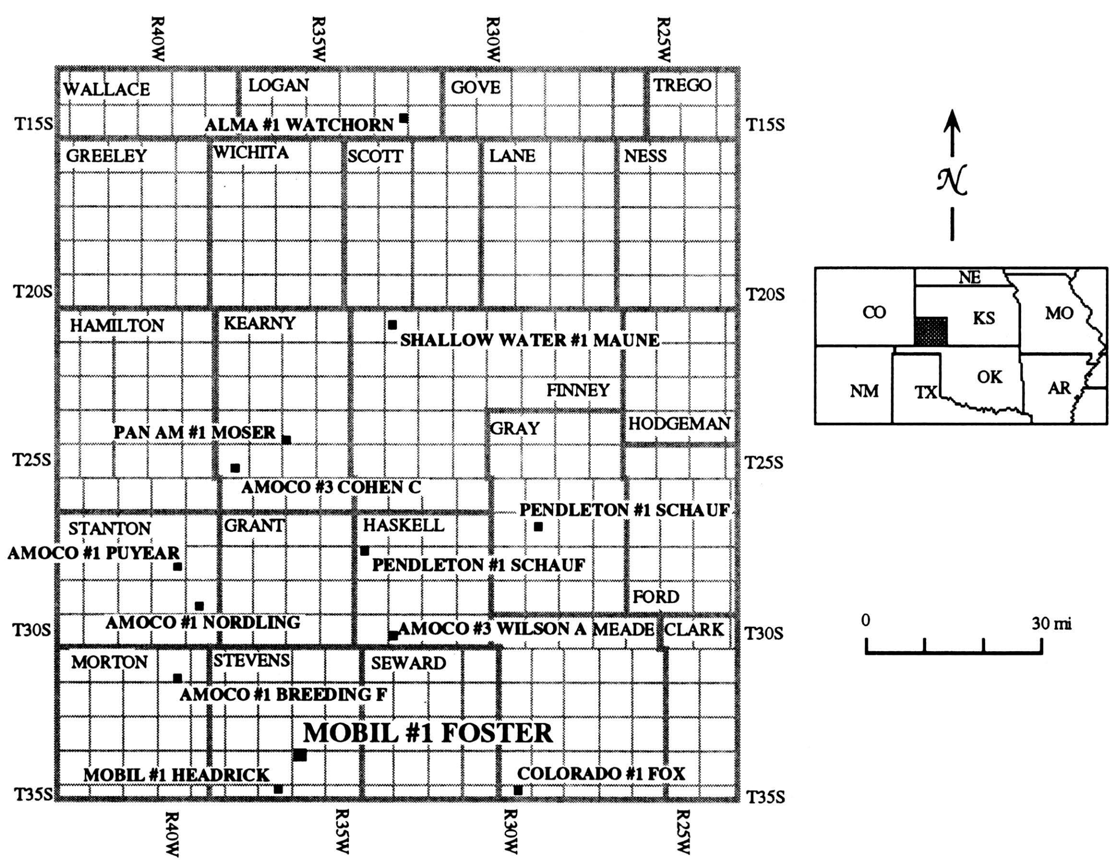


FIGURE 1—Location of the Mobil #1 Foster (sec. 5, T. 34 S., R. 36 W., southern Stevens County) and other cores used in research of Upper Mississippian strata in southwestern Kansas (cf. Abegg, 1992).

residues to assist in recognition of Mississippian units. In the same report, Girty (1940) reported on the megafossils of the Watchorn and unnamed Chesterian strata.

Clair (1948, 1949) subsequently divided the Watchorn into three formations using Mississippi Valley nomenclature. Recognition of the Ste. Genevieve, St. Louis, and Spergen (Salem) Limestones was based primarily on lithologic criteria. Chesterian strata (above the Ste. Genevieve) were not named due to lithologic heterogeneity (Clair, 1948, 1949; Beebe, 1959a, 1959b). Thompson and Goebel (1963, 1968) and Goebel (1968a) defined Mississippian strata using a combination of lithologic criteria, insoluble residues, and conodont biostratigraphy.

The Ste. Genevieve Limestone was placed within the Meramecian Stage (e.g., Merriam, 1963; Thompson and Goebel, 1963, 1968; Goebel, 1968b). Recently, however, Maples and Waters (1987) redefined the Meramecian–Chesterian boundary, placing the Ste. Genevieve at the base of the Chesterian Stage, a usage followed in this report (fig. 2).

Regional Geology and Stratigraphy

The St. Louis and Ste. Genevieve Limestones are most completely preserved in the Hugoton embayment of the Anadarko basin (figs. 4 and 5). Ste. Genevieve is also preserved in the Forest City basin in northeastern Kansas

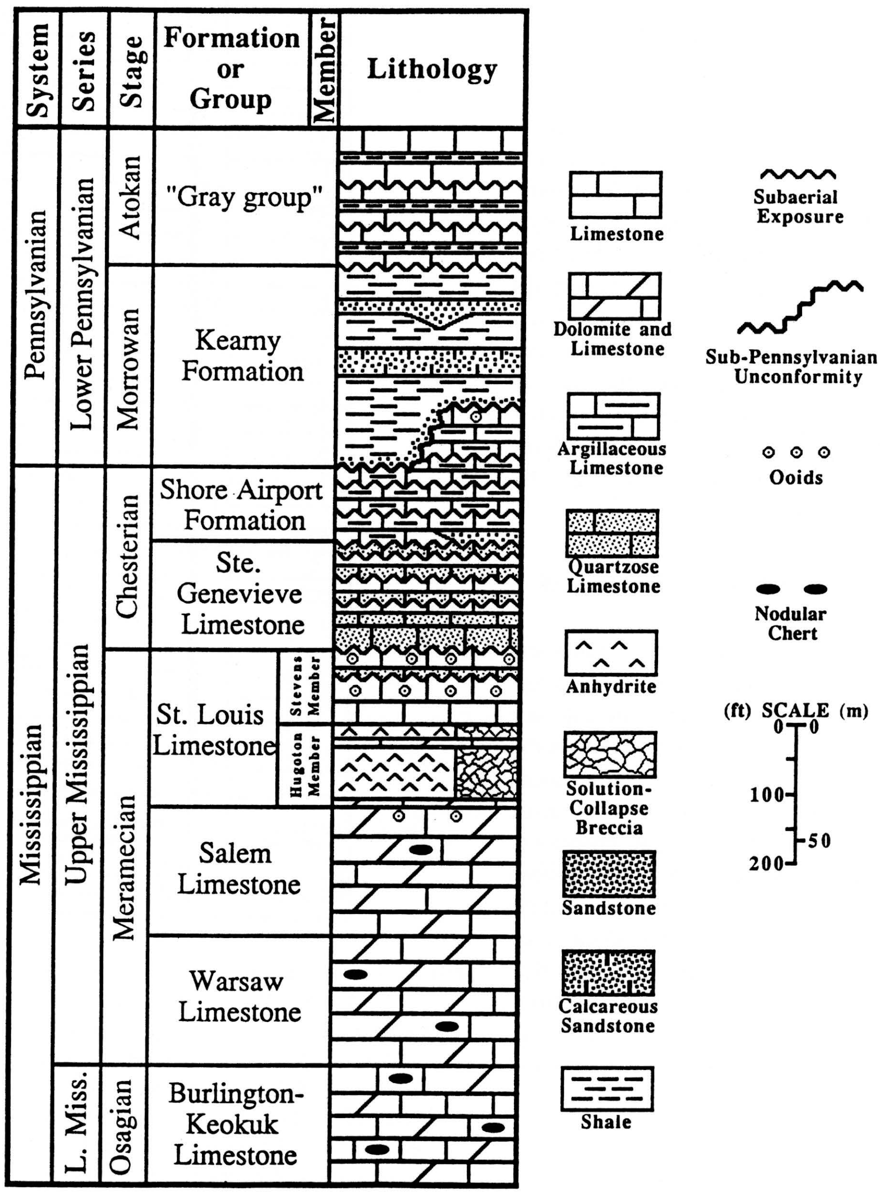


FIGURE 2—Upper Mississippian lithostratigraphic units in the Hugoton embayment of the Anadarko basin in southwestern Kansas. Stevens and Hugoton Members of the St. Louis Limestone, Shore Airport Formation (Abegg, this volume) and the informal "Gray group" (Youle, 1991) are new names. The sub-Pennsylvanian unconformity erodes the entire Mississippian section over structural highs (cf. fig. 5). Scale is approximate as thicknesses are variable.

(Thompson and Goebel, 1968). The St. Louis is more widespread than the Ste. Genevieve and is also preserved in the Forest City, Cherokee, Salina, and Sedgwick basins (Thompson and Goebel, 1968). The nearest St. Louis outcrops are in a downfaulted block along the Chesapeake fault in southwestern Dade and eastern Barton counties, southwestern Missouri (Clark, 1937; Thompson, 1986; personal observation). The nearest outcrops of Ste. Genevieve strata are in the Mississippi Valley, the type area in eastern Missouri (Thompson, 1986).

Ste. Genevieve and St. Louis strata in Kansas were deposited on a carbonate shelf that extended southward from the Transcontinental arch. The shift to argillaceous carbonates and siliciclastics in the overlying Shore Airport Formation marks the termination of dominantly carbonate shelf deposition that continued throughout much of Mississippian time (Lane and De Keyser, 1980). Mississippian strata in Kansas were subaerially exposed and extensively eroded prior to deposition of Lower Pennsylvanian strata.

The Ste. Genevieve (Shumard, 1859) and St. Louis (Engleman, 1847) Limestones were named for exposures in eastern Missouri in the western Illinois basin. In the Mississippi Valley type area, the St. Louis Limestone is primarily a mud-rich carbonate, generally interpreted to have been deposited in restricted lagoonal to tidal flat or sabkha settings (Jorgensen and Carr, 1973; Martorana, 1987). The overlying Ste. Genevieve is oolitic. Ste. Genevieve oolitic carbonates of the Illinois basin are a primary hydrocarbon target, whereas the St. Louis is generally unproductive. In the Hugoton embayment of southwestern Kansas, however, Stevens Member oolites are a major hydrocarbon reservoir, whereas the Ste. Genevieve is less productive.

Definitions of Lithostratigraphic Units

As used in this report, the Salem Limestone is characterized by dolomitic skeletal and oolitic limestones. The overlying St. Louis Limestone is commonly divisible into the Hugoton and Stevens Members (fig. 2). The Hugoton is the lower member and contains primarily peloidal limestone, dolomite, anhydrite, breccia, and algal boundstone. Strata of the Stevens Member are dominantly skeletal limestone. Additionally, uppermost St. Louis strata contain oolitic limestone. This usage differs from the type area where oolitic limestone is included in the Ste. Genevieve. Ste. Genevieve strata are recognized by the lowest prominent quartz-rich limestone, a boundary easily recognized on many neutron-density logs. The overlying Shore Airport Formation (Abegg, this volume) consists primarily of argillaceous limestone and intercalated calcareous shale.

Methods

This report stems from a more comprehensive study (Abegg, 1992) that examines Upper Mississippian strata in the Hugoton embayment of the Anadarko basin (Fig. 1) in southwestern Kansas. The Mobil #1 Foster was originally described at a scale of 1:12. Carbonate textures were described following Dunham (1962). Anhydrite textures were

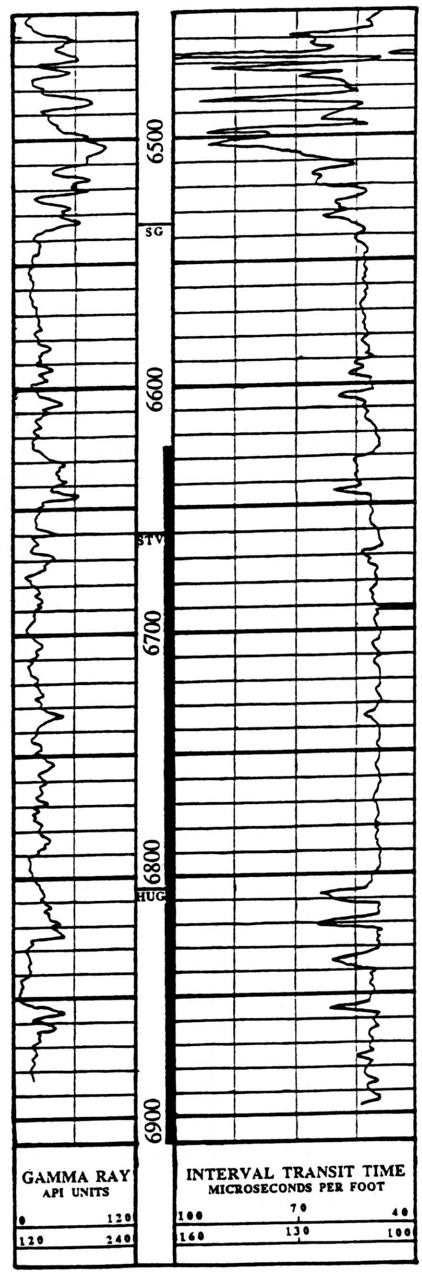


FIGURE 3—GAMMA RAY-SONIC LOG FROM THE MOBIL #1 FOSTER (sec. 5, T. 34 S., R. 36 W.), Stevens County, Kansas. Lithostratigraphic boundaries are picked from a combination of core studies and cross section correlations (SG, Ste. Genevieve; STV, Stevens Member of the St. Louis Limestone; HUG, Hugoton Member of the St. Louis Limestone). Shore Airport (Chesterian) overlies the Ste. Genevieve. Note the extremely clean gamma ray response of the E1 anhydrite (6,854–6,842 ft [2,056–2,053 m]). The St. Louis–Ste. Genevieve boundary is marked by an uphole increase in interval transit time corresponding to an increase in detrital quartz. Cored interval is indicated in depth track. Core and log depths are approximately equal. Depths in feet.

described following Maiklem et al. (1969). A total of 100 thin sections were examined from the Foster core. Stratigraphic cross sections of Shore Airport, Ste. Genevieve, Stevens, Hugoton, and Salem strata will be presented separately (Abegg, 1992).

Type and Reference Section Lithofacies and Depositional Environments

Six lithofacies are recognized in the Mobil #1 Foster core (fig. 6): 1) dolomitic peloid grainstone/packstone, 2) anhydrite, and 3) dolomite, 4) skeletal packstone/wackestone, 5) oolitic grainstone/packstone, 6) quartzose grainstone. Breccia, algal boundstone, and dolomitic lime mudstone facies are not present in the type section, but are present elsewhere in the Hugoton embayment (Abegg, 1992). Sedimentology of the St. Louis and Ste. Genevieve Limestones is detailed in Abegg (1992).

Dolomitic Peloid Grainstone/Packstone

Peloids are abundant to common. Partially micritized allochems suggest that some peloids are micritized grains. Ellipsoidal shape of others suggest they are fecal pellets. Echinoderms are rare to common. Other allochems are rare and include brachiopods, bryozoans, ostracodes, calcispheres, sponge spicules, and intraclasts. Detrital quartz of very fine sand size comprises 5 to 10% of this facies; feldspar, muscovite, glauconite, amphibole, and organic fragments are rare. Dolomite replaces up to 5 to 70% (most commonly 5-30%) of peloid grainstones and packstones. Dolomitization is typically fabric selective, preferentially replacing the micritic fraction. Bluish-gray chert is present in some horizons and is

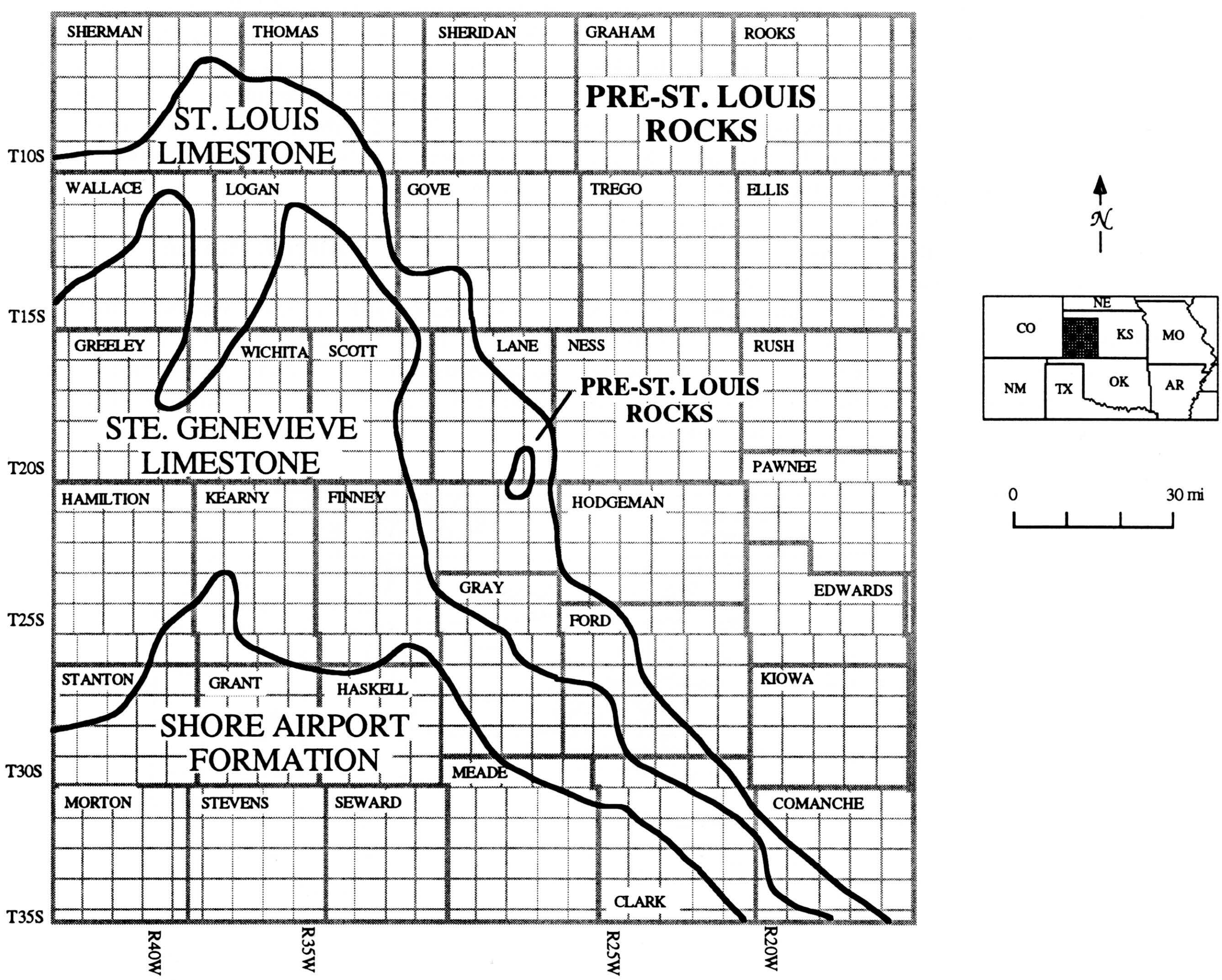


FIGURE 4—Subcrop map of Mississippian strata beneath the sub-Pennsylvanian unconformity in Kansas (modified from Thompson and Goebel, 1968).

commonly associated with casts of sponge spicules. This suggests a local biogenic source for much of the silica. Cubic pyrite, typically 10 to 50 mm, is scattered throughout much of the facies.

Many intervals are marked by parallel laminae. Some strata are ripple cross laminated (fig. 7). In the Ste. Genevieve at 6,637 to 6,638 ft (1,991.1–1,991.4 m), laminae rhythmically thicken and thin (fig. 8). Horizontal trace fossils are present in some horizons. Possible cryptalgal laminae, oncolites, microfenestral porosity, and autoclastic breccias are present where rocks of this facies occur underneath the anhydrite facies.

In the Foster core, peloid grainstone/packstone is interstratified with ooid grainstone/packstone, anhydrite, skeletal packstone/wackestone, or quartzose grainstone (fig. 6).

Interpretation

The abundance of peloids, paucity of stenohaline marine organisms, and association with anhydrite suggest peloid packstone and grainstone were deposited in a restricted-shelf setting. Subadjacent oolitic shoals are interpreted to have formed a barrier restricting connections with open-marine waters. Parallel lamination of packstones indicates low energy. Periods of increased agitation are indicated by ripple cross laminae. Alternating thick and thin laminae (fig. 8) appear similar to tidal rhythmites (A. W. Archer, pers. comm.). Possible cryptalgal laminae, oncolites, microfenestral porosity, and autoclastic breccia suggest shallow water or briefly emergent conditions. Diagnostic evidence for subaerial exposure (cf. Esteban and Klappa, 1983), however, is absent.

Anhydrite

Anhydrite occurs at two horizons in the Stevens Member of the St. Louis in the reference core (fig. 6). Anhydrite textures in the reference section are predominantly mosaic (e.g. 6,843.5 to 6,844.0 and 6,853 ft) and massive (e.g. 6,848.2 to 6,848.9 and 6,851 ft) (fig. 9, cf. Maiklem et al., 1969). Nodular-mosaic (e.g. 6849.3 to 6,849.5 ft), bedded-nodular (e.g. 6,826.85 to 6,827.0 ft), bedded-mosaic (e.g. 6,826.55 to 6,826.85 ft), and crystallotopic (e.g. 6,849.5 to 6,849.6 ft) textures also occur. In thin section, anhydrite textures are mostly felted, with lath-shaped texture occurring less frequently (cf. Maiklem et al., 1969). Blocky crystals are observed in anhydrite-filled fractures (6,839 to 6,840 ft). Much of the anhydrite contains little or no matrix. Anhydrite nodules are outlined by a matrix of thin, brown, dolomitic peloidal carbonates. Carbonates are typically interbedded with anhydrite intervals. Nodules are generally ellipsoidal and irregularly arranged, although vague upward-elongated nodules occur locally. Stratification or bedding were not observed. The edges of anhydrite nodules are commonly partially replaced by light-blue, length-slow, spherulitic chalcedony (cf. Folk and Pittman, 1971) and rarely by euhedral authigenic quartz. Highly birefringent anhydrite relicts are uncommon in the chalcedony and quartz.

Anhydrite in the Foster core is part of the E1 evaporite (fig. 10), the upper anhydrite interval in the Hugoton Member (Abegg, 1992). Interbedded lithologies include dolomitic peloid grainstone/packstone, dolomite, and skeletal packstone/wackestone (fig. 6).

Interpretation

The majority of Hugoton Member anhydrite is interpreted to have been deposited in a widespread shallow-subaqueous or saltern. Warren (1989) coined the term saltern to describe regions of evaporite deposition that are laterally

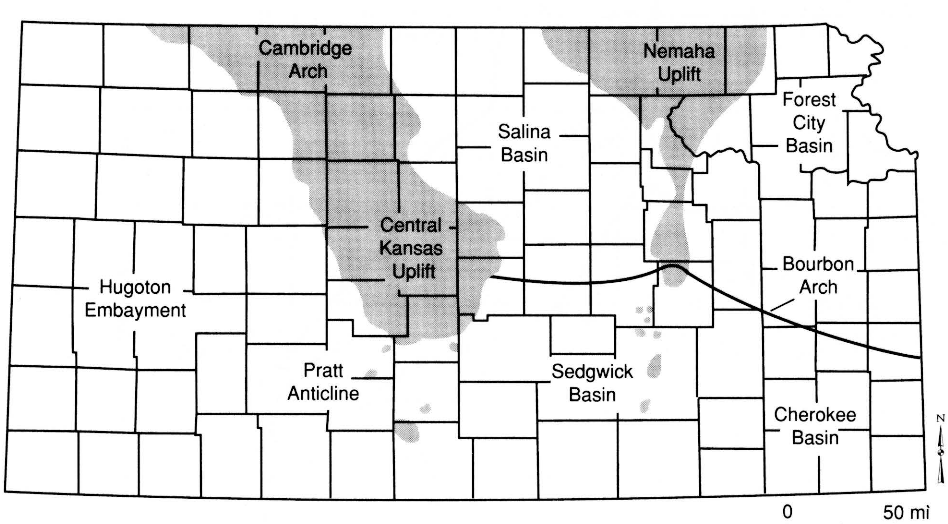


FIGURE 5—Late Mississippian–Early Pennsylvanian tectonic features in Kansas (modified from Merriam, 1963; Ebanks et al., 1979). Shaded areas represent regions where Mississippian strata are absent due to Late Mississippian–Early Pennsylvanian erosion.

more extensive than salinas or evaporating pans. Salterns have no known modern analog.

Mosaic, nodular-mosaic, and massive textures are abundant in the St. Louis Limestone evaporites. Such textures are commonly genetically associated with sabkha environments (Kerr and Thomson, 1963). Numerous authors, however, have indicated such associations are not always warranted (Dean et al., 1975; Warren and Kendall, 1985; Warren, 1989, 1991). Many differences exist between sabkha and saltern evaporites (table 1). The thickness, lateral extent, and lack of significant carbonate matrix of the anhydrite, as well as interbedded, shallow-water carbonate, indicate most of the anhydrite was originally deposited as gypsum in a saltern (table 1). Diagnostic supratidal features (cf. Shinn, 1983) are extremely rare.

Dolomite

Many carbonates in the Hugoton Member of the St. Louis are dolomitic (Abegg, 1992). However, only a few are extensively dolomitized. This facies is defined as rock containing greater than approximately 70% dolomite, which typically obscures the original depositional texture. Dolomitization is highly fabric selective, preferentially replacing the micritic fraction of the rock. The dolomite typically consists of finely crystalline (10 to 15 mm), limpid crystals with euhedral to planar-s texture (cf. Sibley and Gregg, 1987). Floating within this finely crystalline dolomite are dolomite rhombs up to 350 mm with planar-e texture (cf. Sibley and Gregg, 1987). Saddle-dolomite (nonplanar)

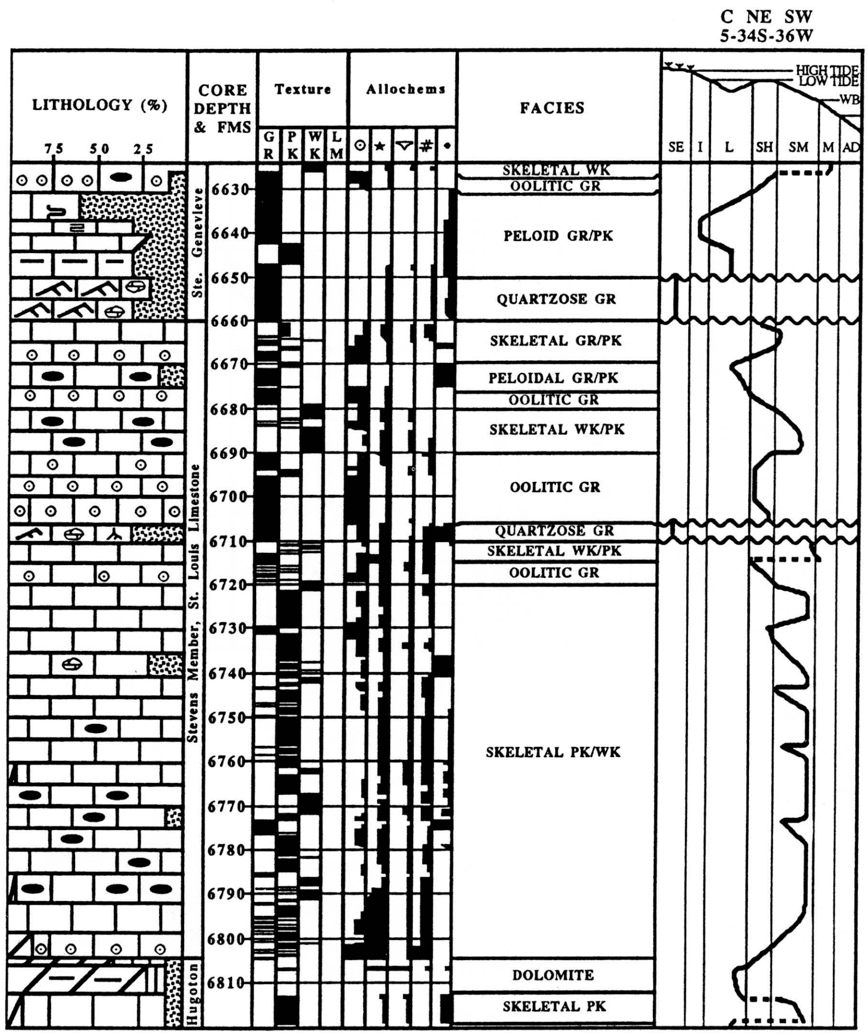


FIGURE 6 (above and following page)—Description of core from the Mobil #1 Foster. Wireline log and core depths are roughly equivalent. Right-hand track shows interpretations of shifts in depositional environments. Horizontal dashed lines represent shifts without deposition. Horizontal wavy lines are subaerial exposure surfaces or surfaces bracketing eolian strata. Abbreviations used include the following: SE - subaerial exposure, typically marked by calcretes or eolianites; I - intertidal or tidally influenced, fenestral porosity and tidal rhythmites occur locally; L - restricted lagoon/shelf, evidence of evaporites or absence of stenohaline marine fossils; SH - oolitic or skeletal shoal, grainstone to mud-poor packstone; SM - shallow marine with evidence of at least intermittent agitation, above or near storm wave base (WB); M - marine with little winnowing, typically wackestone deposited below storm wave base; AD - separates dysaerobic and anaerobic facies from overlying aerobic facies, only present in the Kearny Formation (Morrowan). Depositional textures are also abbreviated: GR - grainstone, PK - packstone, WK - wackestone, LM - lime mudstone. Formations and members are listed in the depth track.

cements are rare. Extensive dolomitization has obliterated most grains, but peloids, crinoids, brachiopods, and fenestrate bryozoans are preserved in a few beds. Interbedded less dolomitized carbonates contain peloids, crinoids, brachiopods, bryozoans, foraminifera, and intraclasts.

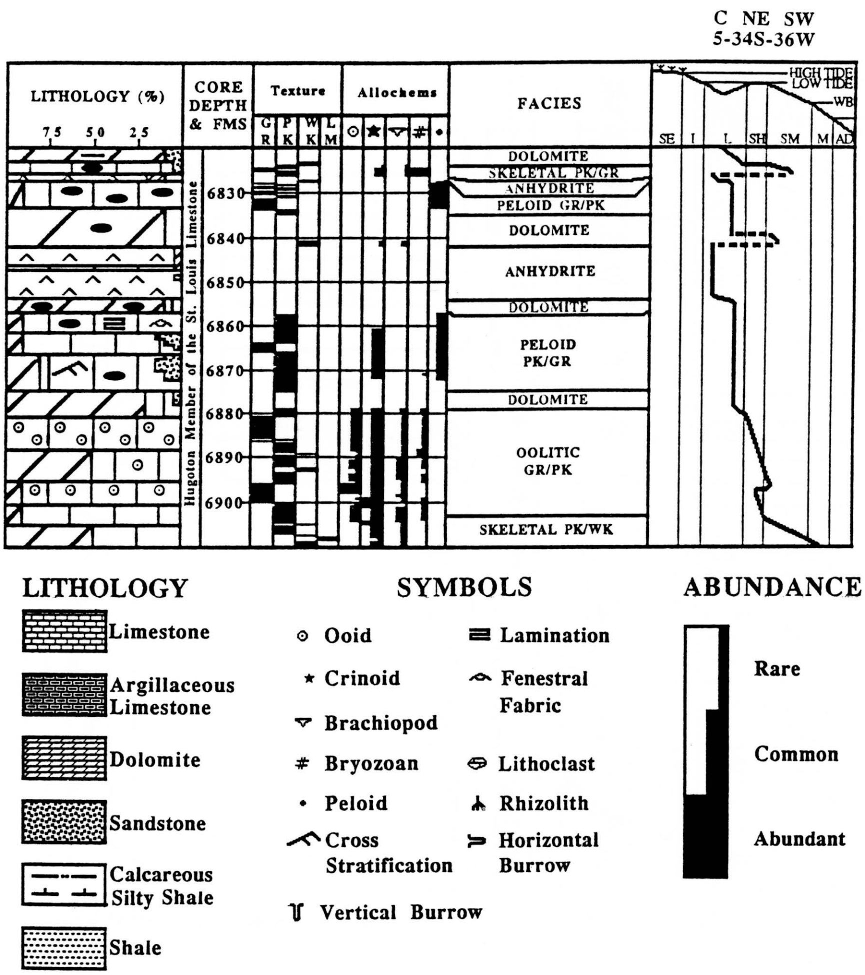
Up to 10% detrital quartz sand and silt is present in some dolomite horizons. Parallel lamination is common in many horizons and is locally disrupted by horizontal burrows (fig. 11). Sutured and unsutured stylolites, fractures, and chert nodules occur locally.

The dolomite facies is interbedded with the anhydrite, peloid grainstone/packstone, and skeletal packstone/wackestone facies (fig. 6). In addition, underlying Salem Limestone carbonates are also commonly dolomitic.

Interpretation

Rare stenohaline marine crinoids, brachiopods, and fenestrate bryozoans preserved in dolomite indicate local marine deposition of the precursor. Common laminations and detrital quartz suggest some dolomitized beds are altered peloid packstone. Because dolomitization is fabric selective for matrix, however, packstone and grainstone are likely to be less dolomitized. Therefore, extensively dolomitized facies probably had a micrite-rich precursor. The fine-grained nature of much of the dolomite supports such an interpretation.

Dolomitic carbonate is intercalated or laterally correlative to anhydrite and solution-collapse breccia in the Hugoton Member. Most strata in the overlying Stevens Member contain little or no dolomite, even though muddy facies are present. This relationship suggests evaporitic brines were responsible for much of the dolomitization, possibly due to refluxing lagoonal brines or connate brines expressed during compaction. Minor baroque dolomite indicates some deeper burial dolomitization. Additional investigation is needed to determine the genesis of dolomite in the Hugoton Member.



Skeletal Packstone/Wackestone

Skeletal packstone/wackestone is the most extensive facies in the Stevens Member of the St. Louis Limestone. Echinoderms and bryozoans are abundant to rare. Common to rare allochems include brachiopods and ooids. Rugose and tabulate corals, bivalve? and gastropod casts, trilobite fragments, foraminifera (mainly endothyrids), ostracodes, siliceous sponge spicules, and worm tubes are rare (fig. 12). Detrital quartz is generally absent to very rare, but makes up to 20% of the rock locally. Horizontal burrows are common in some intervals, whereas vertical burrows are rare. Truncated allochems, commonly capped by a vaguely laminated peloidal micritic crust, occur along subhorizontal surfaces locally in mud-poor packstones (fig. 13).

Skeletal packstone/wackestone is commonly gray to tan. Chert is generally rare and typically bluish-gray in color. Sponge spicules, now casts filled by sparry calcite and silica cement, provided a biogenic source for much of the silica. Absence of significant grain interpenetration within chert nodules and deflection of stylolites around chert nodules indicate that chert is precompactional. Dolomite is a minor constituent and is best developed proximal to Hugoton Member anhydrite. Microstylolites, and less commonly sutured stylolites, are present throughout much of this facies (fig. 12). Sutured and concavo-convex interpenetrating grain contacts indicate significant pressure solution locally.

Many skeletal packstone/wackestone intervals are overlain by oolitic grainstone/ packstone. The skeletal packstone/wackestone facies is also intercalated with the dolomite, anhydrite, and peloid grainstone/packstone facies of the St. Louis Limestone, and the quartzose grainstone of the Ste. Genevieve Limestone (fig. 6).

Interpretation

The diverse and abundant assemblage of stenohaline echinoderms, brachiopods, and bryozoans indicate deposition in a normal-marine environment. Periodic winnowing and intercalated oolites suggest deposition at or above fair-weather wave base. An abundance of horizontal trace fossils, characteristic of the Cruziana ichnofacies (Seilacher, 1967), is also consistent with shallow-marine deposition. Absence of subaerial exposure features (cf. Esteban and Klappa, 1983) suggest the truncation surfaces are marine hardgrounds.

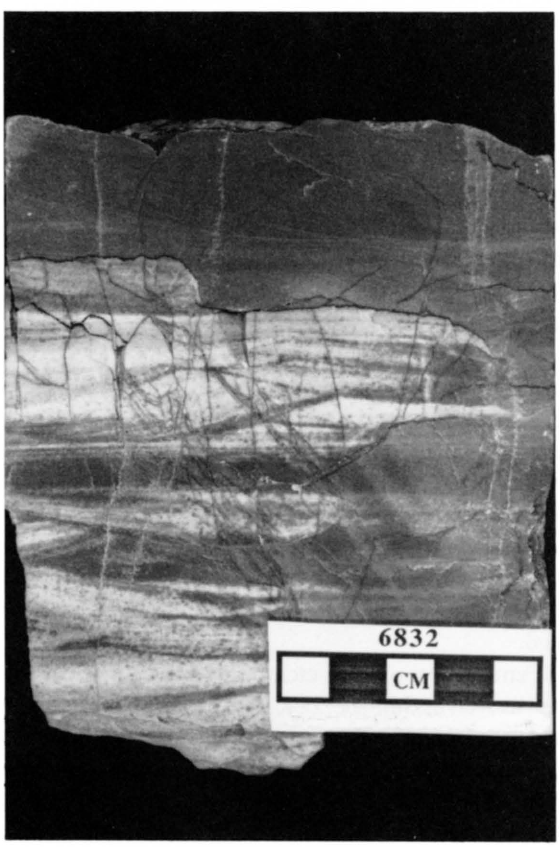


FIGURE 7—Peloid grainstone/packstone facies from the Hugoton Member in the Mobil #1 Foster. Ripple cross laminations highlighted by chert. 6,832 ft core depth.

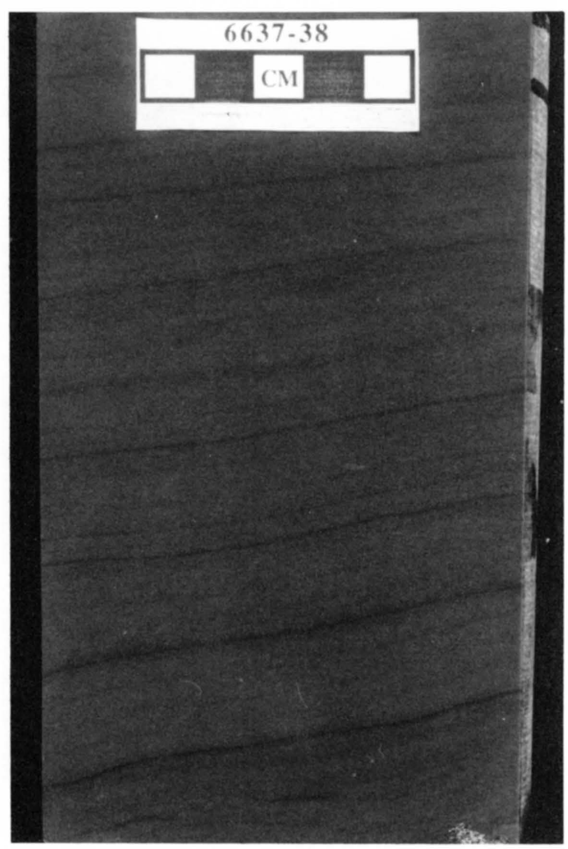


FIGURE 8—Peloid packstone from the Ste. Genevieve in the Mobil #1 Foster. Systematic thickening and thinning of laminae appear similar to tidal rhythmites (A. W. Archer, pers. comm.). 6,637–6,638 ft core depth.

Oolitic Grainstone/Packstone

Well-sorted, very fine- to coarse-grained ooids dominate this facies (fig. 14). Ooid cortices have a radial-concentric microstructure and are generally unbroken and relatively unabraded. Other allochems are rare and include echinoderms, brachiopods, bryozoans, gastropods, foraminifera, ostracodes, and lithoclasts. Detrital quartz is present only as nuclei of a few ooids.

Sedimentary structures are uncommon in many of the oolites. Unidirectional very low angle cross stratification to parallel lamination are present locally. Truncated ooids and bioclasts, commonly capped by a vaguely laminated peloidal micritic crust, occur along subhorizontal surfaces locally (fig. 13). Isopachous bladed cements are commonly well developed below the truncation surface, but are absent above.

This facies is the reservoir facies for most St. Louis Limestone producing intervals. Extant porosity is generally slightly solution-enlarged, cement-reduced interparticle.

The lower contact of the oolitic grainstones and packstones is typically gradational. Many oolites are underlain by skeletal packstone or wackestone. The upper contact of the ooid grainstone/packstone facies is either abrupt or somewhat gradational. Many oolites are overlain by skeletal packstone/wackestone, and rarely by quartzose grainstone and peloid grainstone/packstone (fig. 6). Oolitic grainstone or packstone is most abundant in the upper Stevens Member.

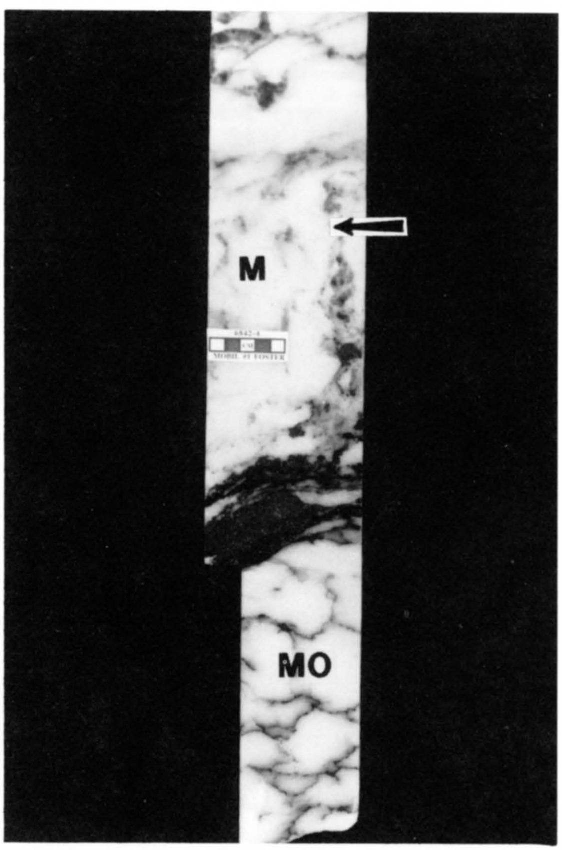


FIGURE 9—ANHYDRITE TEXTURES FROM THE E1 ANHYDRITE OF THE HUGOTON MEMBER IN THE MOBIL #1 FOSTER. Massive (M) and mosaic (Mo) (cf. Maiklem et al., 1969) are the most abundant structures. Possible vertically elongated anhydrite nodule (arrow) may represent a relict vertical gypsum crystal. 6,842–6,844 ft core depth.

Interpretation

The dominance of ooids and grainstone texture, minor cross stratification, and scattered stenohaline marine fossils indicate that oolitic grainstones and packstones accumulated in a highly agitated, marine environment. Modern ooids generally form at depths less than 6 ft (2 m), with the majority of ooid-rich facies being deposited in depths less than 15 ft (5 m) (Newell et al., 1960). Near absence of cross stratification may indicate bioturbation. Vaguely laminated, peloidal, micritic crusts with fenestral porosity on oolitic truncation surfaces (fig. 13) may be algal in origin, suggesting they formed with the aid of substrate-stabilizing algal mats (Gebelein, 1969). Absence of subaerial exposure features (cf. Esteban and Klappa, 1983) indicates the micritic crusts are not laminated calcretes. Dravis (1979) reports that algae were important in the formation of oolitic hardgrounds in the Bahamas. Isopachous bladed cements that are present only below the hardground may be marine in origin.

Quartzose Grainstone

Common grains include peloids, echinoderms, bryozoans, and ooids. Brachiopods, foraminifera, and lithoclasts are rare. Glauconitic grains are scattered throughout. Grain size ranges from very coarse silt to medium sand and varies with stratification type. Detrital quartz varies between 5 to 30%. Other detrital grains are rare, including feldspar, zircon, and amphibole.

Allochems are typically broken and well rounded, regardless of their original shape. Detrital quartz is not as well rounded as carbonate grains. In contrast to the ooid grainstone/packstone facies, ooid cortices are commonly noticeably abraded. This was originally reported by Clair (1948, p. 4; 1949, p. 61) as "elliptical rather than round" ooids. Syntaxial cement overgrowths of some echinoderm fragments are extremely well rounded. Quartzose grainstones are well to moderately sorted, but individual laminae are typically well sorted.

Petrography of acid etching and polishing of slabbed cores, as well as thin-sections, indicate grain types are grain-size dependent. The fine- to medium-sand fraction consists of common bioclasts and ooids with a relatively minor peloid and quartz abundance. The very coarse silt to very fine sand fraction consists primarily of detrital quartz and peloids with a relatively minor bioclastic fraction.

Three types of fine structure, the small discernible structural components of a deposit (Hunter, 1977, 1981, 1985,

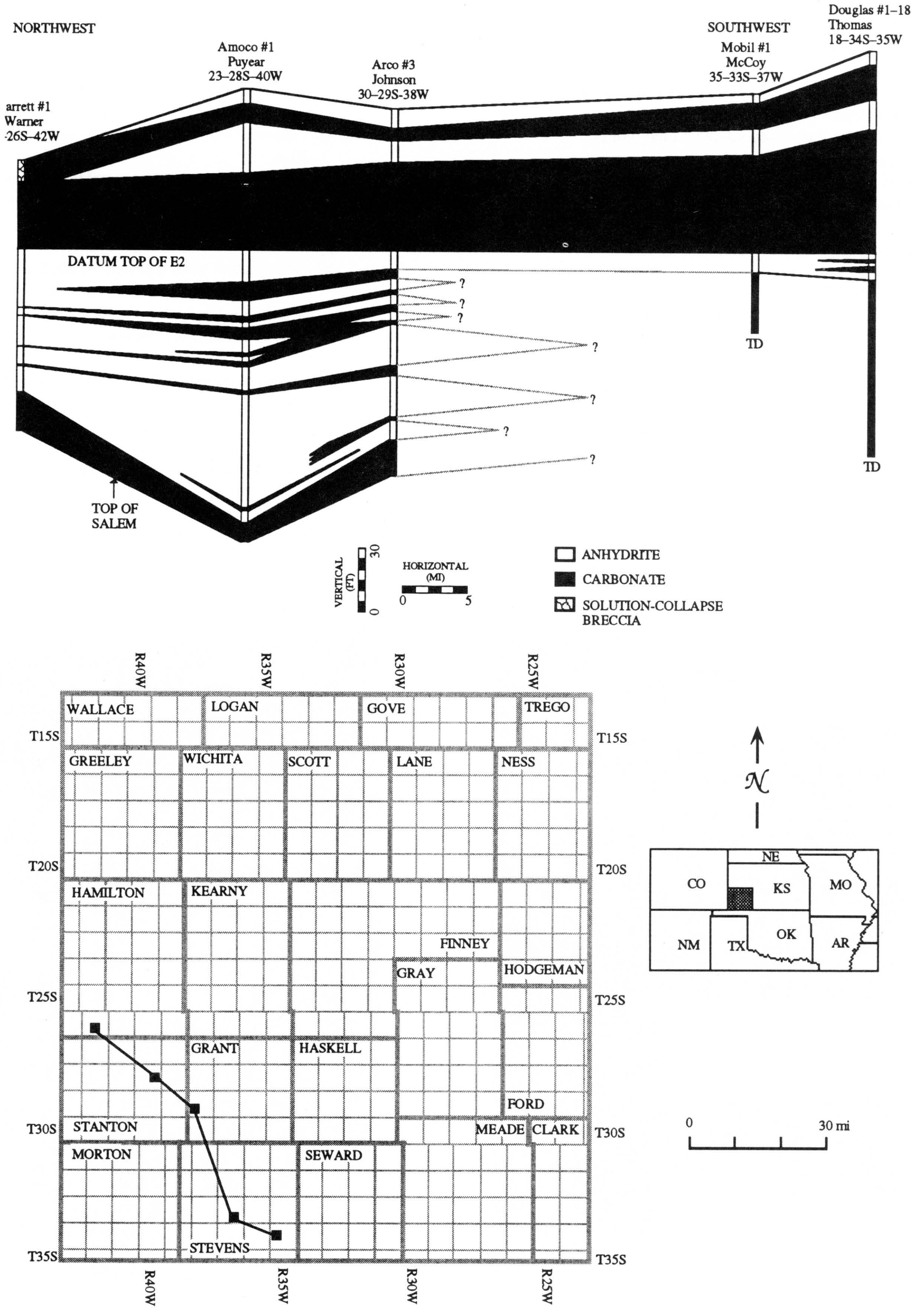


FIGURE 10—NORTH-SOUTH STRATIGRAPHIC CROSS SECTION OF THE HUGOTON MEMBER ANHYDRITE. Most E2 anhydrite beds do not extend as far south as E1 anhydrite.

TABLE 1—Distinguishing features of sabkha and saltern (extensive shallow-subaqueous) evaporites (modified from Warren, 1989, his table 3.1).

SABKHA	SALTERN
Evaporite units are supratidal, matrix dominated, usually <60% sulfate	Evaporite units are subaqueous, relatively pure, often >70% sulfate
Each evaporite (supratidal) depositional unit is thin, usually 1–2 m	Each evaporite (subaqueous) unit is thick, 1–20 m
Displacive and replacive nodular and enterolithic textures	Bottom-nucleated evaporite crystal textures; often laminated, laminae can be laterally continuous, but do not extend across the whole basin
Evaporite crystals are diagenetic	Deposition can be mechanical; evaporites contain clastic textures: wave and current ripples, crossbeds, rip-up breccias, reverse and normal graded beds
Associated with tepees, flat-laminated and mudcracked algal mats	Associated with tepees, laminar algal mats, and domal subaqueous stromatolites
Facies units tend to be laterally extensive, parallel to shoreline; deposition marked by subtidal, intertidal, and supratidal strata ("peritidal" trilogy of Warren and Kendall, 1985)	Facies often symmetric or asymmetric bull's-eye facies
Carbonate matrix washed in from lagoon during storms; quartz sands can be blown in from adjacent sand seas (ergs)	Carbonate facies outline areas of less saline water in basin
Dolomitization by storm recharge and shallow brine reflux	Dolomitization by evaporite drawdown and deeper brine reflux

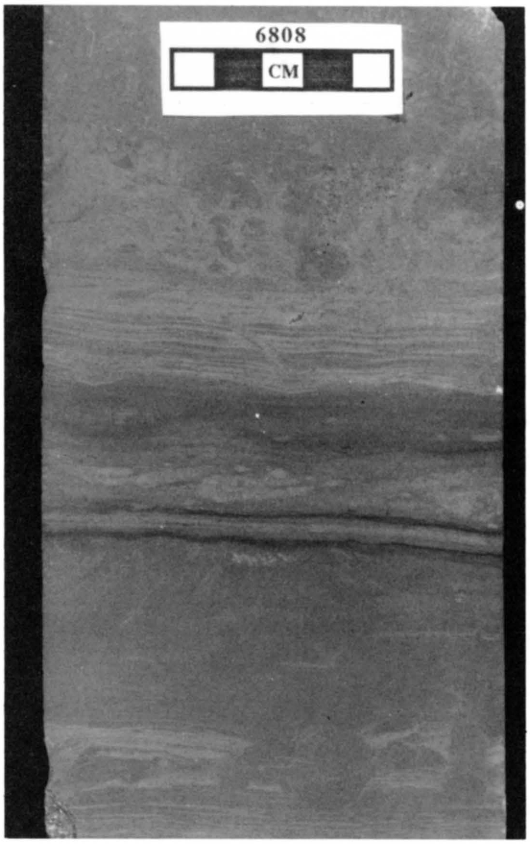


FIGURE 11—Dolomite facies from the Hugoton Member in the Mobil #1 Foster. Parallel laminae are partially to totally disrupted by burrows. 6,808 ft core depth.

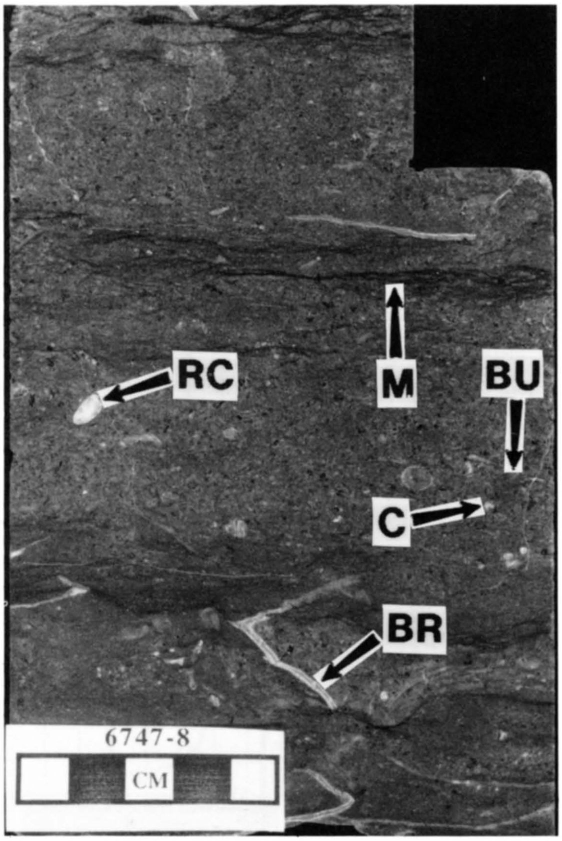


FIGURE 12—Skeletal packstone/wackestone from the Stevens Member in the Mobil #1 Foster. Microstylolites (M), burrows (Bu), bryozoans (Br), solitary rugose coral (RC), and crinoids (C) are indicated by arrows. 6,747–6,748 ft core depth.

1989), are recognized in the Mobil #1 Foster from this facies: 1) climbing translatent stratification, 2) indistinct stratification, and 3) structureless to fining-upward units.

Climbing Translatent Strata

The most common fine structure in the quartzose grainstone facies is marked by climbing translatent stratification. They are typically 2 to 5 mm thick, but some are as thick as 9 mm (figs. 15 and 16). Individual strata coarsen upward internally. Ripple foreset lamination is typically rare. Polishing or acid-etching surfaces enhances its recognition. Ripple foreset lamination and upward coarsening are best observed in the thickest strata. Coarsening-upward strata in the Mobil #1 Foster commonly dip at angles less than 7°. Best examples of coarsening-upward strata in the Mobil #1 Foster are at 6,706.3 to 6,706.7 and 6,659.2 to 6,659.9 ft.

Indistinct Stratification

The secondmost abundant type of fine structure is indistinct stratification (fig. 16), that typically dips 10° to 24°. Stratification, commonly highlighted by microstylolites, is difficult to distinguish because most of these deposits are very-well-sorted, very-fine sand, but grains up to medium sand are present. Indistinctly stratified units are most abundant in the more steeply dipping, upper portions of cross-strata sets. Best examples of indistinctly stratified intervals in the Mobil #1 Foster are at 6,658.25 and 6,657.6 ft.

Structureless to Fining-upward Units

Units that lack stratification or fine upward are rare (fig. 16). The bottom and top of an individual stratum are commonly sharp. The base is typically slightly irregular; underlying strata are locally truncated at a low angle. Thickness ranges from 2 to 16 mm, and individual units thin by as much as 4 mm across a 3.5-inch (8.9-cm) core. Several of these intervals fine-upward; the base is marked by a thin (< 1 mm thick) medium-sand layer that thickens as the stratum thins. Internal primary sedimentary structures are absent. Dips of fining-upward to structureless strata in the Mobil #1 Foster are as high as 24° and always exceed 20°. The best example of fining-upward to structureless strata in the Mobil #1 Foster is at 6,658.2 ft.

Quartzose Grainstone Deposits

Two quartzose grainstone deposits are present in the Mobil #1 Foster core (fig. 6). The lower deposit occurs in the Stevens Member of the St. Louis Limestone and is 3.8 ft (1.2 m) thick (fig. 17). This quartzose grainstone is included in the St. Louis because it is very thin and not easily recognized on logs. The upper deposit marks the base of the Ste. Genevieve Limestone and is 9.4 ft (2.9 m) thick (fig. 18).

Stevens Member Quartzose Grainstone

The Stevens Member quartzose grainstone deposit contains ubiquitous climbing translatent stratification dipping at less than 7°. Calcite-cemented tubes coated by indistinctly laminated, dark-brown micrite occur within and directly beneath this quartzose grainstone in the Stevens Member (fig. 17). The majority of these tubes are oriented subhorizontally. Some of these tubes bifurcate downward with smaller diameters in the branches, although this is rare. Rarely the calcite-filled tubes are divided by thin micritic walls (fig. 19). Brownish, bladed, sparry-calcite cement also

FIGURE 13—Two hardgrounds in skeletal and oolitic, mud-poor packstones from the Stevens Member in the Mobil #1 Foster. Note the relief on the upper hardground surface. The upper hardground is overlain by a vaguely laminated peloidal crust (arrow) that is possibly algal in origin. 6,715 ft core depth.

occurs within some intervals containing calcite-filled tubes. Brownish cement is upward-oriented (astropetal) (figs. 17 and 20) at 6,708.95 ft. This cement nucleates from the base of horizontal sheet cracks as thin semicontinuous layers extending laterally for up to 1.25 in (31 mm). Crystals grew upward into open pore space. Crystal terminations are commonly euhedral and rarely rounded. Compaction of crystal terminations against other grains, however, makes the rounded nature difficult to observe.

The base of the Stevens Member quartzose grainstone is marked by a lithoclastic conglomerate. Additionally, a conglomerate occurs within this quartzose grainstone (fig. 17). The thickness of these conglomerates range from 0.04 to 0.65 ft (0.01 to 0.2 m). Lithoclasts are up to 0.35 inches (0.9 cm) in size. Conglomerates contain lithoclasts with dark-brown micrite and calcite-filled tubes as described above.

Ste. Genevieve Quartzose Grainstone

The Ste. Genevieve quartzose grainstone contains all three types of fine structure, although structureless to fining-upward units are rare. Sets of cross stratification range from 0.3 to 1.5 ft (0.1 to 0.5 m) thick with dips up to 24°. Calcite-filled tubes and associated structures are absent in the Ste. Genevieve quartzose grainstone. The base of this quartzose grainstone deposit is marked by a lithoclast conglomerate similar to those in the Stevens Member. One lithoclast from the base of the Ste. Genevieve quartzose grainstone contains dark-brown, bladed and micritic pendant cements; geopetal internal sediment in a brachiopod within the clast indicates these were not upward-oriented cements (fig. 21). The basal Ste. Genevieve quartzose grainstone contains these brown lithoclasts, although the parent lithology is absent in the immediately underlying strata.

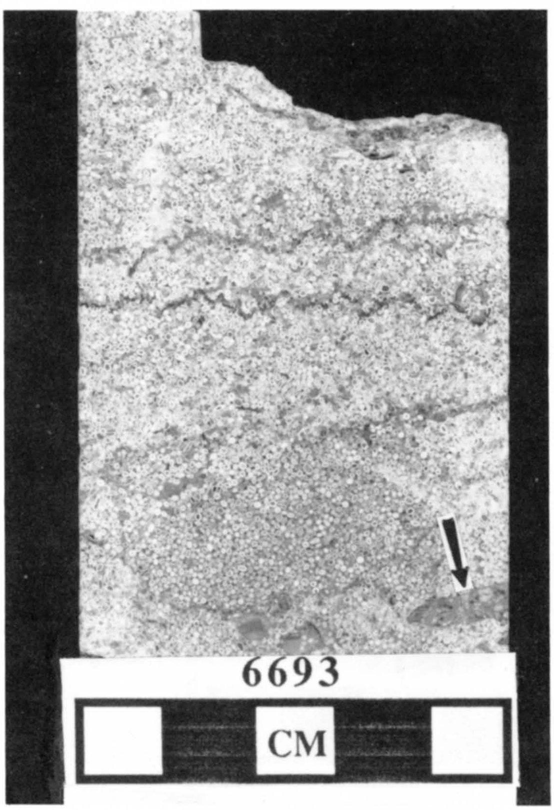


FIGURE 14—Ooid grainstone from the Stevens Member in the Mobil #1 Foster. Note scattered lithoclasts (arrow). Crinoids, and to a lesser degree brachiopods, nucleate cements more readily than ooids. Rare uncoated crinoids nucleate syntaxial cements that occlude much of the interparticle porosity. 6,693 ft core depth.

Interpretation

Based on multiple lines of evidence (table 2), quartzose grainstone in the Mobil #1 Foster core is interpreted as carbonate eolianites. Climbing translatent strata are generally considered diagnostic of eolian sedimentation (Hunter, 1977, 1981; Kocurek and Dott, 1981; Kocurek, 1991). Most other criteria indicative of an eolian interpretation are equivocal in isolation. Therefore, multiple lines of evidence are commonly required to affirm a wind-blown origin for carbonate grainstones.

Hunter (1989) ascribed a similar facies from the Illinois basin in southern Indiana to eolian origin. Handford (1990) and Handford and Francka (1991) interpreted the quartzose grainstone in the Damme field (Finney County) and the Big Bow Field (Stanton and Grant counties), Kansas, as eolian in origin. Handford and Francka (1991) recognized climbing translatent, grainfall, and grainflow stratification from cores in the Big Bow field in Stanton and Grant counties, Kansas.

TABLE 2—Contrasting features of eolian and subaqueous grainstones (based largely on Hunter, 1981, 1989). Boldface indicates features present in quartzose grainstones in the Mobil #1 Foster. Also refer to figs. 15–21.

EOLIAN	SUBAQUEOUS
Climbing translatent stratification	Subaqueous climbing ripples
Grainfall	Grainfall
Grainflow	Grainflow
Well to very well sorted	Moderate sorting
Typically very fine to medium sand, grains >4 mm extremely rare	Grains >4 mm common
Well-rounded and abraded allochems	Rounding variable
Frosted quartz grains1	Frosted grains absent
Absence of shale/micrite, and mica present (except in interdunes)	Mud or clay/micrite, and mica
Large-scale (>1 m) cross strata	Large-scale cross strata rare
Planar to wedge-planar cross strata	Wedge-planar less common
Tangential foresets	Tangential foresets less common
Straight-crested, low-amplitude ripples (high ripple indices) (cf. fig. 22)	Sinuous, high-amplitude ripples (low ripple indices) (cf. fig. 22)
Trace fossils absent to very rare	Trace fossils present
Adhesion ripples	Adhesion ripples absent
Calcrete (scattered rhizoliths, alveolar texture, etc.)	Calcrete present only at exposure surfaces
Vadose cements (scattered pendant, upward-oriented, and meniscus)	Vadose cements present only at exposure surfaces

Handford (1988) had previously interpreted quartzose grainstone from the Damme field as subaqueous tidal channels, illustrating that differences between eolian and subtidal strata are subtle.

Climbing Translatent Stratification

Climbing translatent stratification is considered the product of migration of wind ripples. Climbing wind ripples are distinct in form and appearance from climbing subaqueous ripples (fig. 22). Each millimeter-scale, coarsening-upward stratum forms from the migration of a single, climbing wind ripple. The coarsest grains are concentrated along ripple crests while finer grains are protected in the ripple troughs (Hunter, 1977; Fryberger and Schenk, 1988). In the ripple troughs, very fine sand and very coarse silt are protected from incoming saltating grains and from direct airflow across the ripple crests (Fryberger and Schenk, 1988). The thin layers of very fine sand and very coarse silt that are deposited in ripple troughs are typically less than 1 mm thick and produce a feature termed pin-stripe lamination (Fryberger and Schenk, 1988). Ripple-foreset laminae are not well developed in eolian climbing translatent strata due to an absence of avalanching on the gently sloping lee sides of wind ripples.

Climbing translatent strata are as thick as 9 mm (fig. 15). This unusual thickness might reflect damp conditions that would make the grains more cohesive, thus reducing the amount of the wind-ripple that is destroyed prior to its burial by the succeeding ripple train. According to Fryberger and Schenk (1981), increases in the rate of deposition and the rate of ripple-migration also can account for unusually thick climbing translatent strata.

Grainfall Strata

Indistinctly stratified units in quartzose grainstones are interpreted to have formed by grainfall in the flow separation on the lee side of dunes. Indistinct stratification is the result of excellent sorting of grains. Fine to very fine grains overrun the crest and are deposited on the lower slipface or apron as grainfall strata. Grainfall strata are distinguished from climbing translatent strata because wind-ripple stratification exhibits a coarsening-upward grain distribution, ripple-foreset laminae, and generally have lower dips, although some overlap exists.

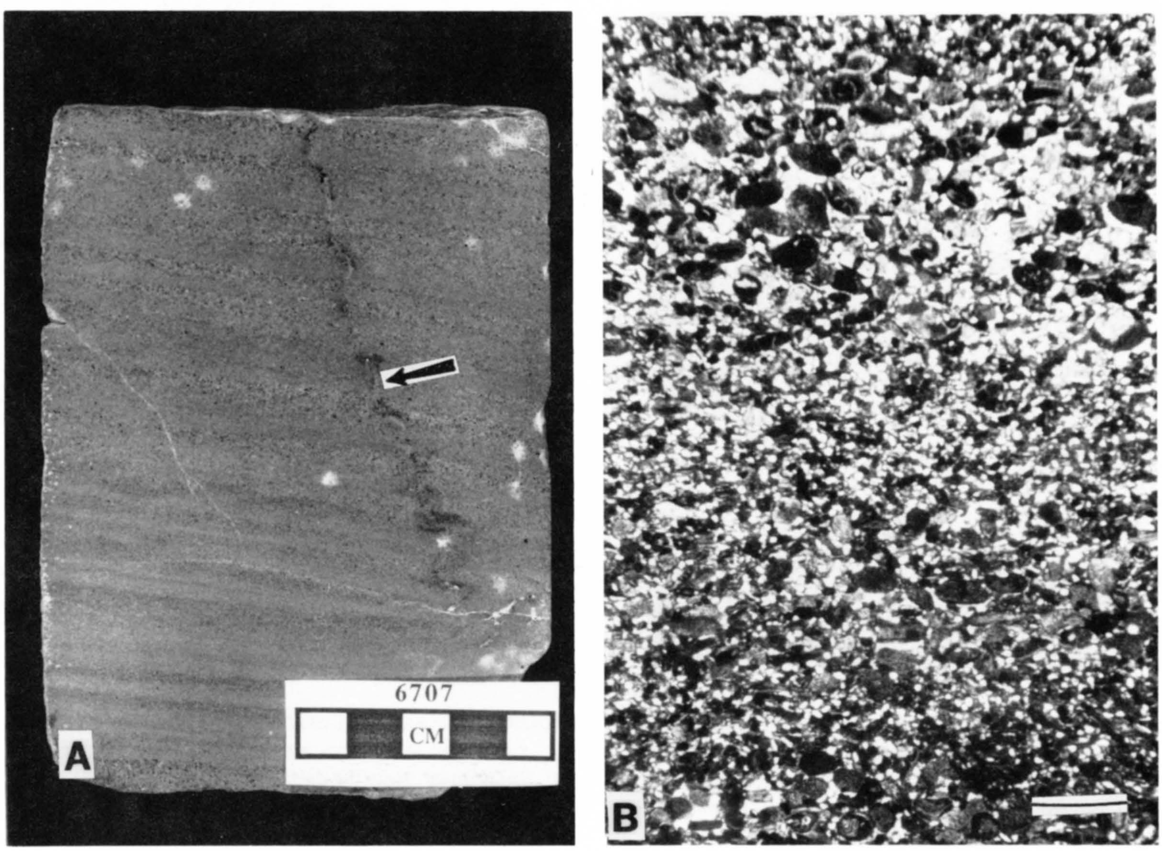


FIGURE 15—Quartzose grainstone in the Stevens Member from the Mobil #1 Foster. A) Climbing translatent strata, interpreted as eolian, dip at approximately 6°. The strata are unusually thick (up to 9 mm), coarsen upward, and contain well-developed ripple-foreset lamination. Direction of ripple migration is down the slope or to the right. Note the vertical rhizolith (arrow). B) Photomicrograph of climbing translatent stratification shown in 15A. Scale bar is 1 mm. 6,707 ft core depth.

Grainflow Strata

Structureless to fining-upward units are interpreted as grainflow deposits. Medium-sand grains that concentrate at the slipface crest subsequently avalanche, pick up finer grains by eroding underlying strata, and are deposited as grainflows. Structureless to fining-upward units are extremely rare in the quartzose grainstone facies. As other evidence suggests dunes were present. Either the upper parts of dunes were truncated by interdune erosion or avalanching on slipfaces was rare. Structureless to fining-upward deposits are intercalated with indistinctly stratified grainfall deposits and climbing translatent strata, as is common in small eolian dunes (Kocurek and Dott, 1981). Slipfaces in modern dunes commonly dip 33° to 34°, grainflows in the Mobil #1 Foster never exceed 24°. Dips angles of approximately 20° to 24° are consistent with grainflow deposition at the angle of repose and subsequent flattening through 35% compaction (cf. Rittenhouse, 1972). Compactional features are common and include stylolites and interpenetrating grain contacts. Erosion of steeper upper parts of slipfaces could also explain the low dips, as well as the scarcity of grainflow deposits (cf. McKee, 1979).

Basal contacts of grainflow deposits sometimes truncate underlying strata indicating scour. Thinning of as much as 4 mm across a 8.9-cm (3.5-in) core is observed, and is interpreted as wedging at the toe of a grainflow. The concave-upward nature of these units has been recognized at the toes of modern grainflows, possibly indicating the preflow depositional surface (cf. Hunter, 1977). Grainflows commonly coarsen upward because of dispersive pressures during flow (Bagnold, 1954; Hunter, 1977; Kocurek and Dott, 1981; Kocurek, 1991). Grain-size distribution, however, depends on the location in a grainflow. Upward coarsening is com-

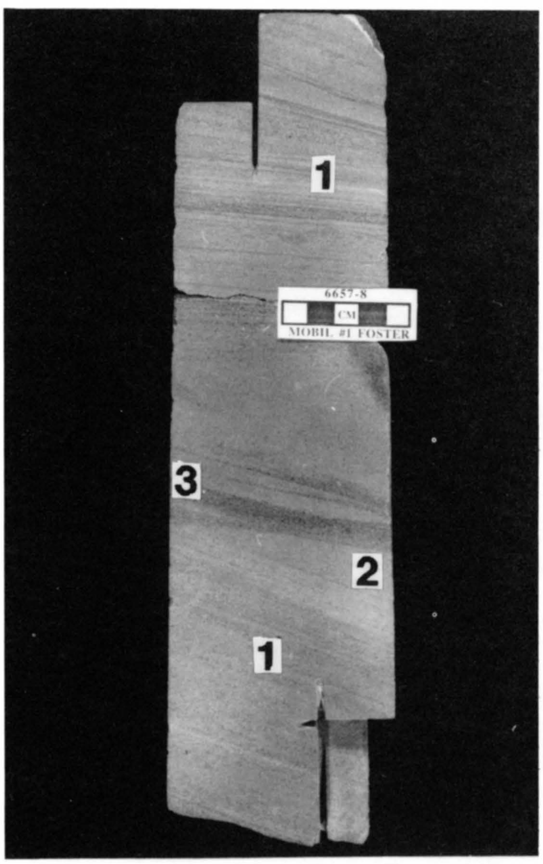


FIGURE 16 —Ste. Genevieve quartzose grainstone from the Mobil #1 Foster displaying three types of fine structure. Climbing translatent strata (1) are 2-5 mm thick and distinctly coarsen upward. Ripple-foreset lamination is developed only in the thicker strata. Grainfall units (2) consist of very fine to fine sand that is only vaguely stratified due to the excellent sorting. Grainflow (3) toes are fining upward to structureless, not as well sorted, and thin downward. The lower surface of the grainflows is concave-upward, possibly reflecting the preflow depositional surface. Dip of the grainflows is an apparent dip; true dip is slightly greater than 20°. 6,657–6,658 ft core depth.

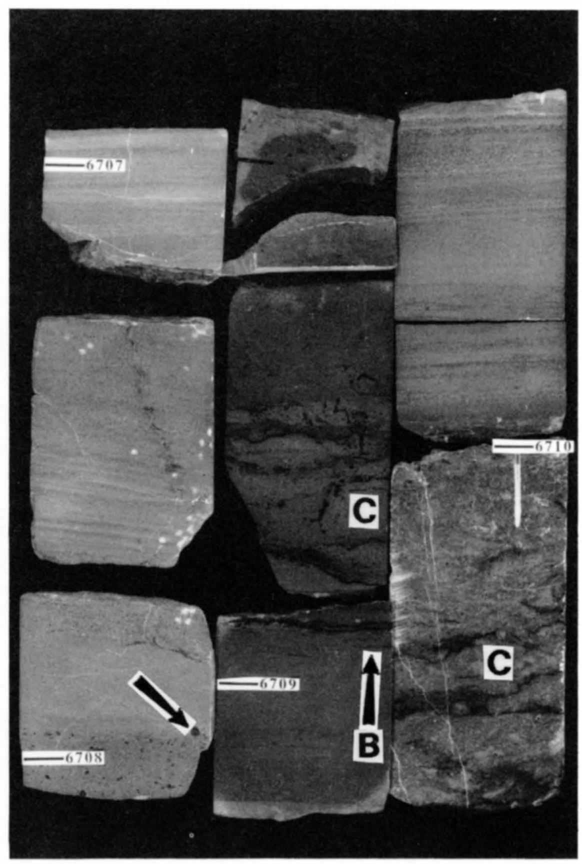


FIGURE 17—Quartzose grainstone from the Stevens Member in the Mobil #1 Foster was deposited as a vegetated eolian sand sheet. Note the dark brown rhizoliths in the two separate calcretes (C). Calcretes are overlain by lithoclast conglomerates containing reworked calcrete clasts (arrow). The strata are almost exclusively climbing translatent strata dipping at angles of less than 7°. Upward-oriented brownish spar (B) precipitated from the base of horizontal sheet cracks (see fig. 20). 6,706–6,710 ft core depth.

mon in proximal parts of grainflows (Fryberger and Schenk, 1981; Ahlbrandt and Fryberger, 1982). The mantle of coarser grains outruns the finer grains to the lower part of the grainflow and are later buried by finer-grained material, creating a fining-upward unit (Ahlbrandt and Fryberger, 1982).

Eolian Sub-environments

The Stevens Member and Ste. Genevieve quartzose grainstones in the Mobil #1 Foster core represent different environments of eolian accumulation. Low-angle-stratified deposits of the Stevens Member are formed as vegetated sand sheets. Cross stratified deposits of the Ste. Genevieve indicate dune fields. These successions illustrate two different styles of eolian sedimentation in these units over much of southwestern Kansas (figs. 15, 16, 17, and 18).

Vegetated Sand Sheet

The quartzose grainstone in the Stevens Member of the St. Louis is composed entirely of subcritically climbing

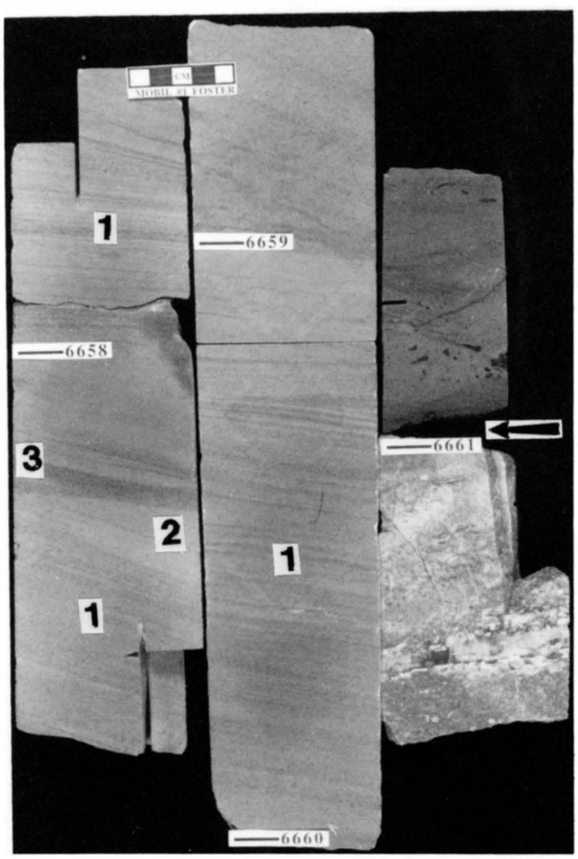


FIGURE 18—QUARTZOSE GRAINSTONE FROM THE STE. GENEVIEVE IN THE MOBIL #1 FOSTER. The base of the lithoclast conglomerate (arrow) at 6,661 ft core depth is the St. Louis–Ste. Genevieve boundary. Abundance of cross stratification sets and absence of rhizoliths indicates deposition took place in an active dune field. The majority of stratification is climbing translatent (1), but grainfall (2) and rare grainflow strata (3) also occur. 6,657–6,661 ft core depth.

translatent strata with dips less than 7° (figs. 15 and 17). The numerous calcite-filled tubes coated by indistinctly laminated (fig. 17), dark-brown micrite near the top of the underlying shoaling-upward succession are interpreted as rhizoliths with calcite-filled root casts and dark-brown rhizocretions (cf. Klappa, 1980). The ubiquitous climbing translatent strata and numerous rhizoliths indicate that the upper St. Louis eolianite was a vegetated sand sheet. The thin micritic bridges (fig. 19) associated with the rhizoliths are excellent examples of alveolar texture (cf. Esteban and Klappa, 1983). Upward-oriented (astropetal), bladed, brownish, sparry-calcite cement (fig. 20) is very similar to ribbon spar described from the Pennsylvanian Holder Formation in New Mexico (Goldstein, 1988). Goldstein reasoned that these cements precipitated in the capillary fringe at the base of the vadose zone. A similar origin for the brownish cements in the eolianites is likely, based on the preferred upward orientation. Possible rounded terminations of crystals may reflect a meniscus air-water contact.

Sand sheets are regions of predominantly eolian sedimentation where dunes with slipfaces are lacking (Kocurek, 1986; Kocurek and Nielson, 1986). Sand sheets commonly occur along the margins of dune fields (Kocurek, 1986). Conditions inhibiting the formation of dunes and favoring sand-sheet development are discussed in Abegg (1992). Handford and Francka (1991) recognized sand-sheet deposits from the Big Bow field in Stanton and Grant counties, but did not describe them.

Dune Field

The Ste. Genevieve eolianite contains higher-angle cross stratification in sets up to 1.5 ft (0.5 m) thick (figs. 16 and 18). Rhizoliths are absent. This indicates deposition in an unvegetated, active dune field. Cross strata sets are typically dominated by climbing translatent stratification, but the upper parts of the thickest sets contain grainfall and, rarely, grainflow stratification. The majority of cross strata dip less than 20°, suggesting that only dune aprons are commonly preserved. Compactional flattening could also help explain the low dip angles (cf. Rittenhouse, 1972). Thickness of eolian grainflows is proportional to slipface height (Hunter, 1977). Based on a plot of maximum thickness of eolian grainflow versus slipface height (Kocurek and Dott, 1981), the thickest eolian grainflow observed, 1.6 cm, corresponds to a slipface 0.9 m high. This is consistent with the maximum observed cross strata thickness, 0.8 m, from cores in southwestern Kansas. Interdune deposits are not recognized.

The base of each quartzose grainstone interval is marked by a lithoclast conglomerate (figs. 17 and 18). Dark-brown lithoclasts are reworked from the underlying paleosol. These conglomerates were formed in part by erosion of the underlying skeletal limestones and calcretes. The Ste. Genevieve eolian unit is not underlain by a calcrete, yet the basal lag contains calcrete lithoclasts. Either the calcrete was removed by erosion or the calcrete clasts were transported from nearby.

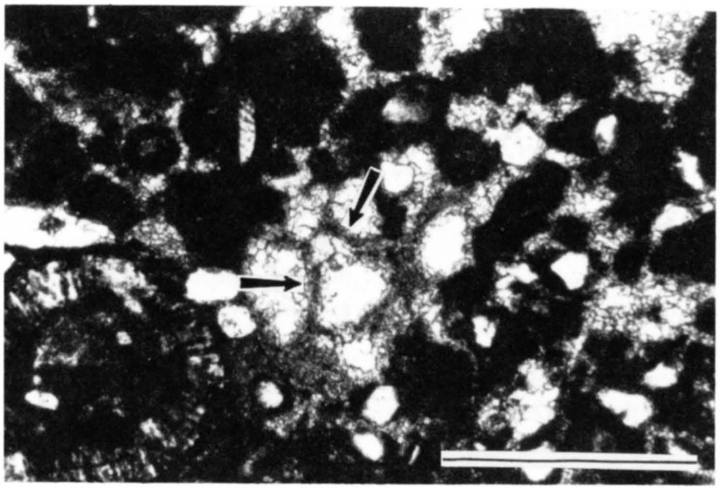


FIGURE 19—Thin micritic walls (arrows) that divide pores are interpreted as alveolar texture in a calcrete in the thin Stevens Member eolianite. Mobil #1 Foster, 6,709 ft core depth. Scale bar is 0.5 mm.

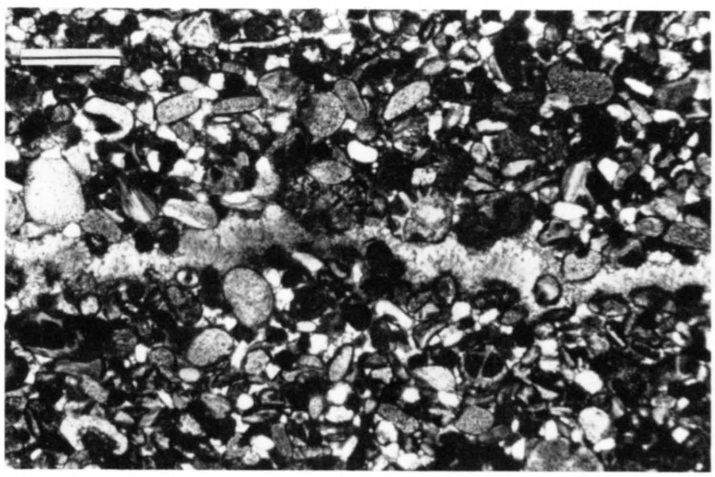


FIGURE 20—Upward-oriented brownish calcite cement formed along sheet cracks immediately below a calcrete (see fig. 17) in the Stevens Member eolianite. Possible rounded terminations, upward orientation, and proximity to a calcrete suggest cements may have precipitated in the capillary fringe (cf. Goldstein, 1988). Mobil #1 Foster, 6,709.0 ft core depth. Scale bar is 0.5 mm.

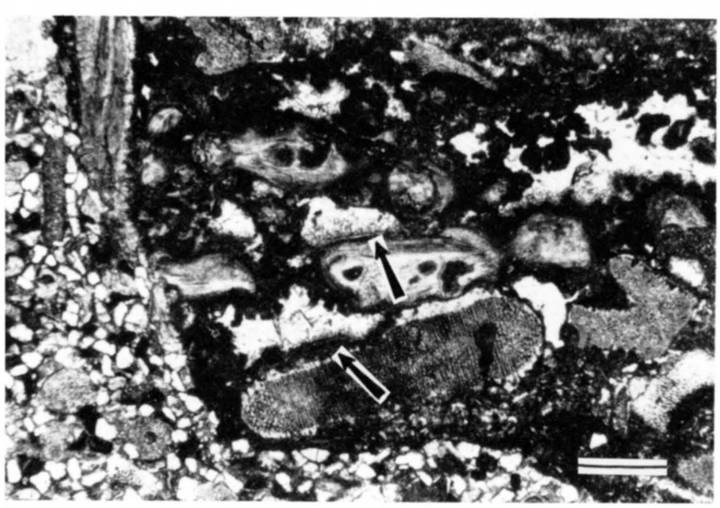


FIGURE 21—Brownish micritic and sparry calcite cement in a lithoclast at the base of the Ste. Genevieve eolianite in the Mobil #1 Foster. Rounded crystal terminations and geopetal sediment inside the brachiopod indicate the cement is a pendant cement formed in the meteoric vadose zone. 6,660.25 ft core depth. Scale bar is 0.5 mm.

Lateral Variability

Vertical successions of lithologies similar within the St. Louis and Ste. Genevieve Limestones occur over much of the Hugoton embayment. Log cross sections, calibrated by cores, permit characterization of lateral variability in facies and composition across southwestern Kansas.

Anhydrite, characteristic of the Hugoton Member of the St. Louis Limestone, is preserved in portions of Morton, Stanton, Stevens, Grant, Seward, Haskell, Hamilton, Kearny, and possibly Meade counties, southwestern Kansas (figs. 23 and 24). Many anhydrite units are laterally correlative over several counties, but some are discontinuous (figs. 10 and 24). Anhydrite is thin in southern Stevens County and is absent in southern Morton, southwestern Stevens, and southern Seward counties (fig. 24). To the north and east, recognition of characteristic anhydrite and slightly argillaceous dolomitic carbonate on wireline logs is difficult because of brecciation (figs. 10, 23, and 24).

The Stevens Member of the St. Louis Limestone consists largely of normal-marine skeletal packstone and wackestone in southwestern Kansas. Ooid grainstones are thickest near the top of the Stevens Member. A thin quartzose grainstone is interstratified with oolitic grainstone and packstone in the Stevens Member (fig. 6). This unit is very close to the base of the Ste. Genevieve Limestone in most cores, but in Stevens County it is separated by a thicker section of subtidal strata (Abegg, 1992).

Porous oolitic grainstones occur in many areas, but no regional trend has been recognized. Based on the location of oolite reservoirs, Handford (1988) concluded that oolite bodies are oriented northwest-southeast. Because these fields roughly parallel the Central Kansas uplift, Handford reasoned oolites developed parallel to depositional strike and are similar to Bahamian marine sand belts (Ball, 1967). However, local structure and diagenesis may also contribute to oolite reservoir distribution. Moreover, Youle (1990, his fig. 1) indicates a northeast-southwest orientation of Stevens Member oolites in the Wendel Pool in Gray County, Kansas. Additional work is needed to determine the controls on distribution of porous ooid grainstones in the Stevens Member of the St. Louis Limestone.

Quartzose grainstones interbedded with peloidal, oolitic, or skeletal carbonates comprise the Ste. Genevieve Limestone. As many as four quartzose grainstone units are recognized in the Ste. Genevieve in core. In some wells, quartzose grainstone is either poorly developed, absent, or simply not recognizable in the logs. This suggests that quartzose grainstone units are discontinuous or that quartz content is variable. Handford and Francka (1991, their fig. 11) illustrate quartz-poor and quartzose grainstones. Minor detrital quartz occurs in many interbedded peloidal and skeletal carbonates; some contain as much as 40% quartz. The presence of quartz in other facies, combined with the absence of significant quartz in some Ste. Genevieve sections, makes tracing of individual quartzose grainstones extremely difficult. This emphasizes the need for core to facilitate correlation. No consistent regional trends in quartz concentration have been recognized.

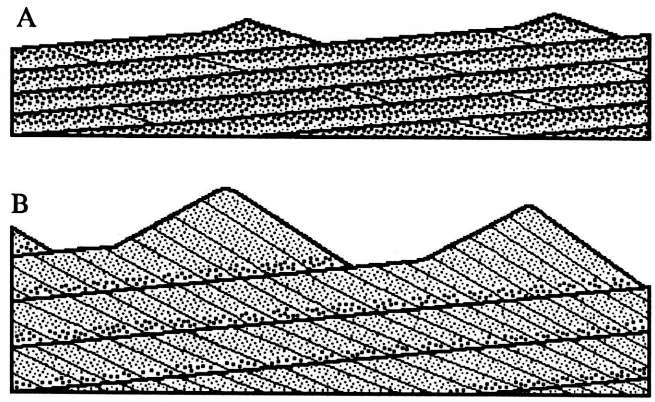


FIGURE 22—Features of eolian and subaqueous climbing ripples. Wind ripples (A) have low amplitudes and relatively long wavelengths with the coarser grains concentrated at the ripple crest. Low-angle foresets retard avalanching on lee sides of ripples. These features produce climbing translatent strata that are characteristically thin, of uniform thickness, commonly inversely graded, and contain few visible ripple-foreset laminae. In contrast, subaqueous ripples (B) have higher amplitudes with the coarser grains relegated to the ripple troughs. Avalanching is common on the steep lee sides of the ripples. These features produce climbing translatent strata that are typically thicker, normally graded, and contain well-developed ripple-foreset laminae (modified from Kocurek and Dott, 1981, their fig. 3)

Lithostratigraphic Boundaries

In order to facilitate consistent identification of Upper Mississippian lithostratigraphic boundaries, criteria for such picks need to be standardized. Facies changes make identification of Upper Mississippian units difficult locally. Facies changes are hard to recognize unless core or cuttings are utilized. Abegg (1992) used 13 cores covering much of the southern Hugoton embayment to calibrate log response to facies. This section discusses lithostratigraphic boundaries for the following units: 1) Salem Limestone, 2) Hugoton Member of the St. Louis Limestone, 3) Stevens Member of the St. Louis Limestone, 4) Ste. Genevieve Limestone, and 5) Shore Airport Formation (fig. 2).

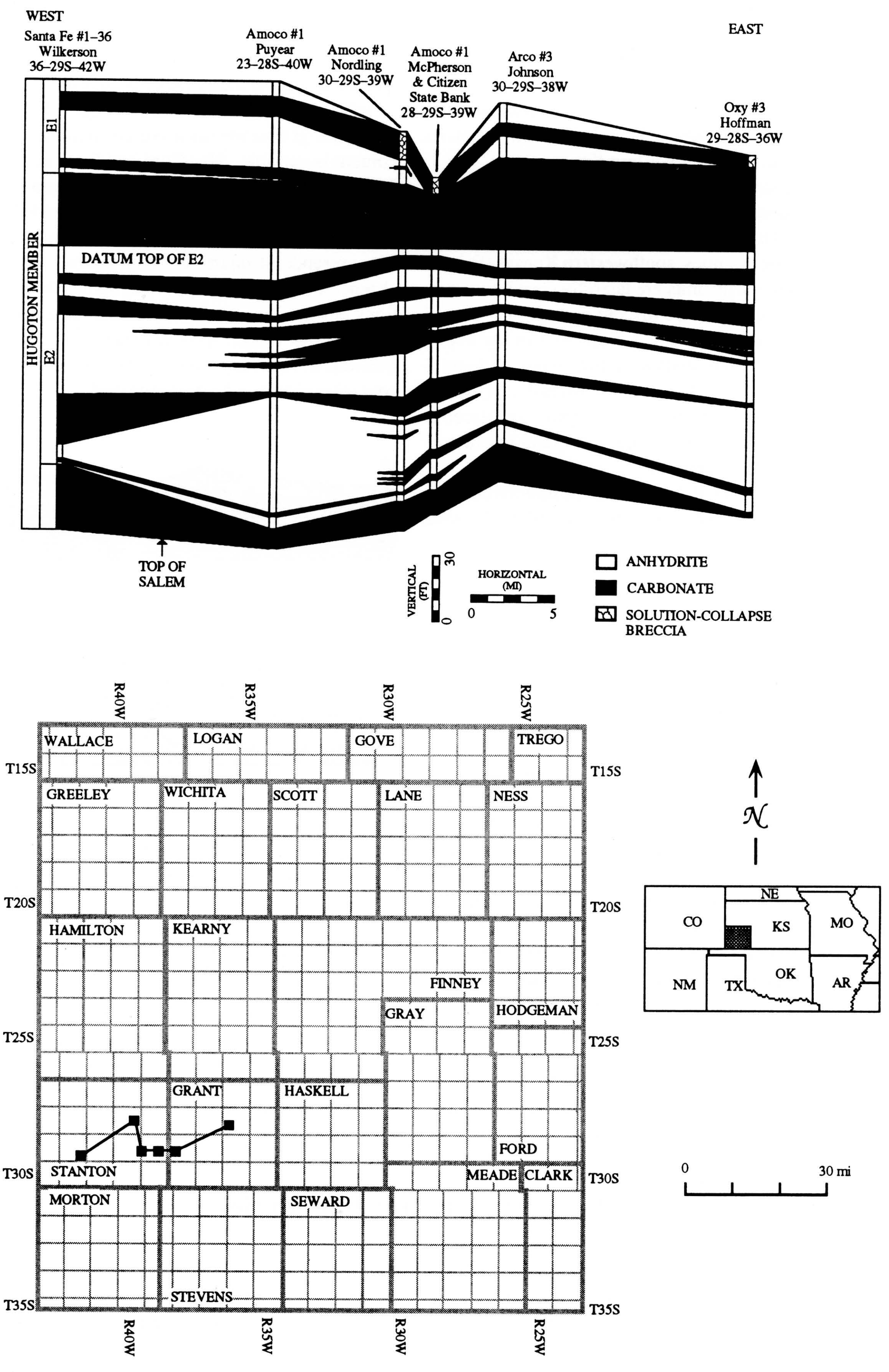


FIGURE 23—East-west stratigraphic cross section of Hugoton Member anhydrite. Many anhydrite beds are laterally correlative.

Salem–St. Louis Boundary

This boundary is absent in the Mobil #1 Foster. In other cores, the Salem–St. Louis boundary is marked by a change from ooid-skeletal grainstones of the Salem Limestone to algal boundstone and breccia of the Hugoton Member of the St. Louis (Abegg, 1992). On wireline logs, the exact placement of the boundary is difficult as both units are typically dolomitic. It is commonly possible to recognize a change from clean, porous dolomitic limestone of the upper Salem to slightly more argillaceous, dolomitic carbonate intercalated with anhydrite in the Hugoton (fig. 25). Cored breccias in the Hugoton Member consist of dolomitic carbonates that are typically less porous than the underlying Salem. Breccias can also be differentiated from the Salem Limestone using the gamma-ray log; cross stratified upper Salem grainstones are typically clean, whereas low-energy, dolomitic carbonates and breccias of the Hugoton Member are typically somewhat shaly (fig. 26).

Hugoton Member–Stevens Member Boundary

In the Mobil #1 Foster and elsewhere in southwestern Kansas, the boundary of the Hugoton and Stevens Members of the St. Louis Limestone is placed at the change from dolomitic carbonate and anhydrite to skeletal packstone/wackestone (figs. 25 and 26). This facies transition is commonly marked by a thin (≤ 3 ft) skeletal-ooid grainstone to packstone. Typical logs of the Hugoton Member indicate lower neutron porosity than density porosity, indicating dolomitic carbonates (figs. 25 and 26). Interbedded anhydrites have very low gamma-ray values and negative density porosities (fig. 25). In the Stevens Member the density and neutron curves are nearly coincident, indicating relatively pure limestones (figs. 25 and 26).

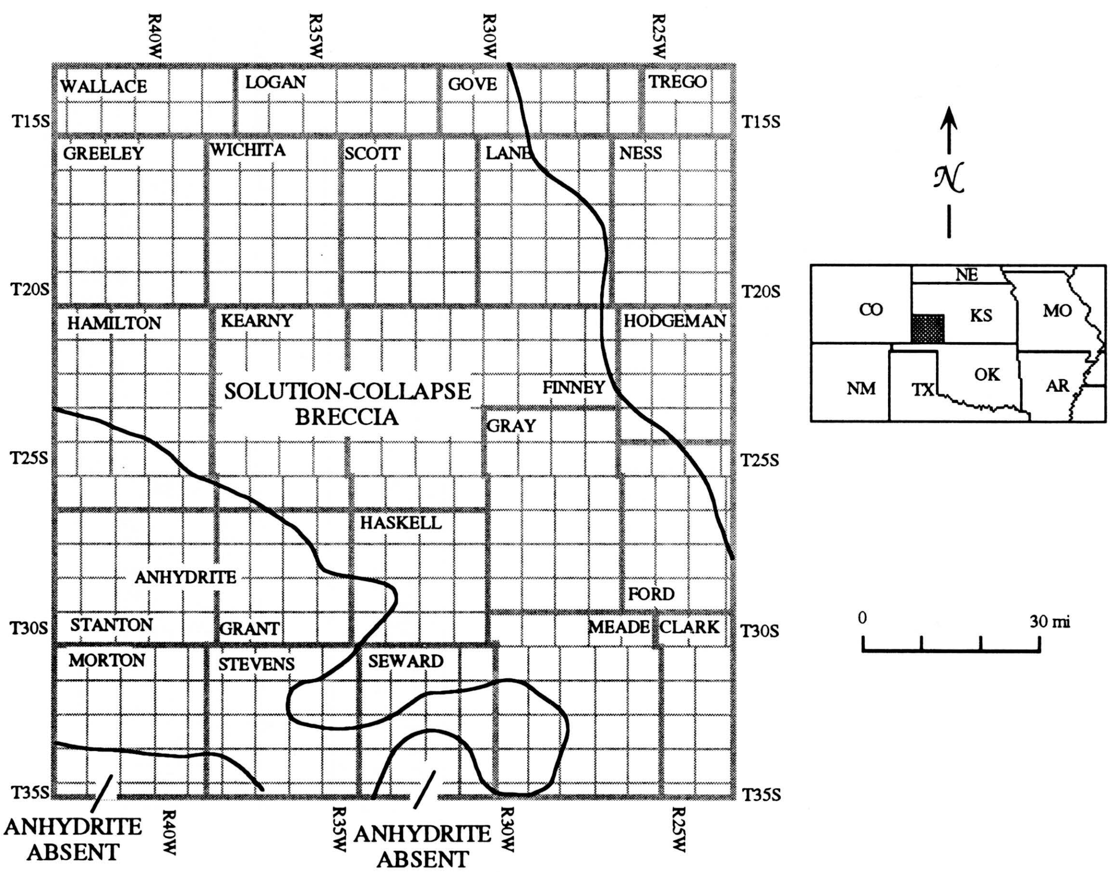


FIGURE 24—Location of preserved anhydrite in southwestern Kansas. To the north and east, evaporites were dissolved forming solution-collapse breccia. Anhydrite is thin to absent to the south in southern Morton and Stevens counties, suggesting increasing marine influence toward the Anadarko basin. Dashed lines indicate areas where well control is sparse or absent. Updip limit of St. Louis from Thompson and Goebel (1968, their fig. 3).

St. Louis–Ste. Genevieve Boundary

In southwestern Kansas, previous authors place oolitic limestones in the St. Louis Limestone (e.g., Clair, 1948, 1949; Thompson and Goebel, 1963, 1968). In the Illinois basin, however, the base of the Ste. Genevieve Limestone is generally placed at the stratigraphically lowest prominent oolitic (Atherton et al., 1975) and/or arenaceous limestone (Thompson, 1986). In order to be consistent with the original definition in the type area, a similar boundary could be adopted in the Hugoton embayment. However, several considerations argue against such a boundary.

The base of the stratigraphically lowest prominent oolite is difficult to pick without core or cuttings. Although many of the ooid grainstones are porous, intergranular porosity is occluded in many others by a combination of compaction and cementation, as in the Mobil #1 Foster (fig. 3). In wells without porous carbonates, this formation boundary would not be easily determined from wireline logs. Additionally, including oolites in the St. Louis Limestone in the Hugoton embayment is so entrenched by usage in industry and the literature that it is best not to change unless a more practical boundary can be determined.

In the Mobil #1 Foster and elsewhere in southwestern Kansas, the base of the Ste. Genevieve is herein placed at the stratigraphically lowest prominent quartzose grainstone. In order of decreasing reliability, the four most dependable ways to pick the St. Louis–Ste. Genevieve boundary in wireline logs include: 1) at the change from coincident neutron and density logs to a log crossover with lower neutron than density porosity, 2) at an uphole negative shift in the photoelectric (Pe) curve, 3) at an uphole positive shift in the interval transit time on sonic logs, and 4) at the top of the highest porous ooid grainstone. In many areas, the quartzose Ste. Genevieve Limestone is marked by a prominent crossover of the neutron and density log patterns, both calibrated for limestone (figs. 25 and 26) and also by shifts in the Pe and sonic logs. Where quartzose facies are absent or poorly developed, the Ste. Genevieve–St. Louis boundary can be placed at the base of a small positive gamma-ray shift immediately above the uppermost porous, presumably oolitic, limestone.

Ste. Genevieve–Shore Airport Boundary

The boundary between the Ste. Genevieve Limestone and the Shore Airport is one of the most consistent picks in the Mississippian section because of the increased argillaceous component in the Shore Airport Formation. This boundary is not present in the Mobil #1 Foster core. This boundary should be placed where neutron porosity lower than density porosity in the quartzose Ste. Genevieve changes to neutron porosity greater than lower density porosity in the argillaceous carbonates of the Shore Airport (figs. 3, 25, and 26). This boundary typically corresponds to the base of a shale observ-

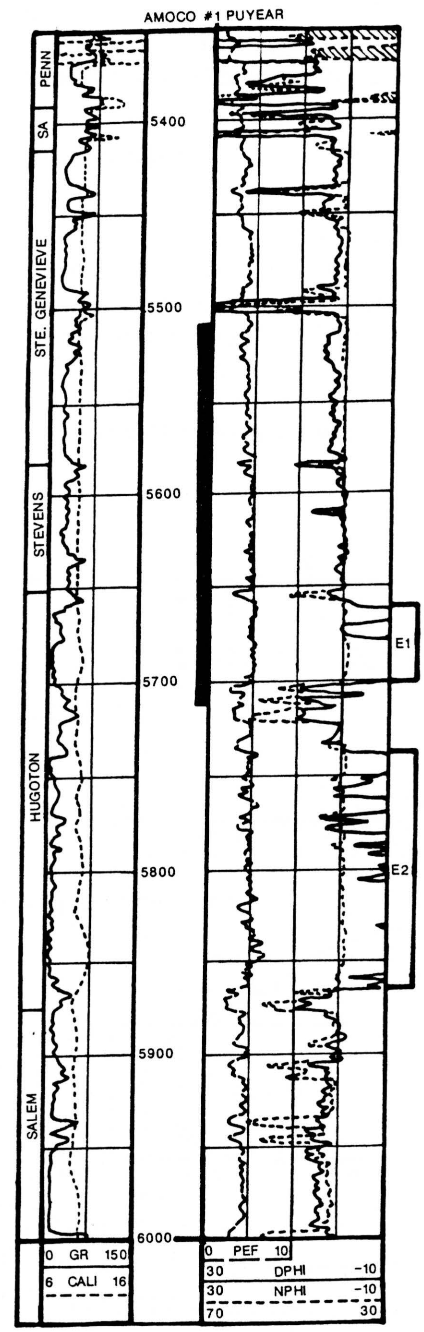


FIGURE 25—Typical gamma-ray and neutron-density log for Upper Mississippian strata from the Amoco #1 Puyear (sec. 23, T. 28 S., R. 40 W.). Note the extremely low gamma ray values and negative density readings for anhydrite beds (E1 and E2). See text for explanation. Compare with fig. 26.

able on the gamma ray log. Locally, however, the basal Shore Airport is a sandstone and conglomerate (Clair, 1948, 1949; Veroda, 1959; Fugitt and Wilkinson, 1959). In this case, the Shore Airport neutron-density logs are similar to those of the Ste. Genevieve, but the sandstone typically has higher porosity than the tight quartzose grainstone (e.g., Southland #1-19 Hampton, sec. 19, T. 34 S., R. 34 W.). In sonic logs, the top of the Ste. Genevieve is marked by low velocity of the first prominent shale bed (fig. 3).

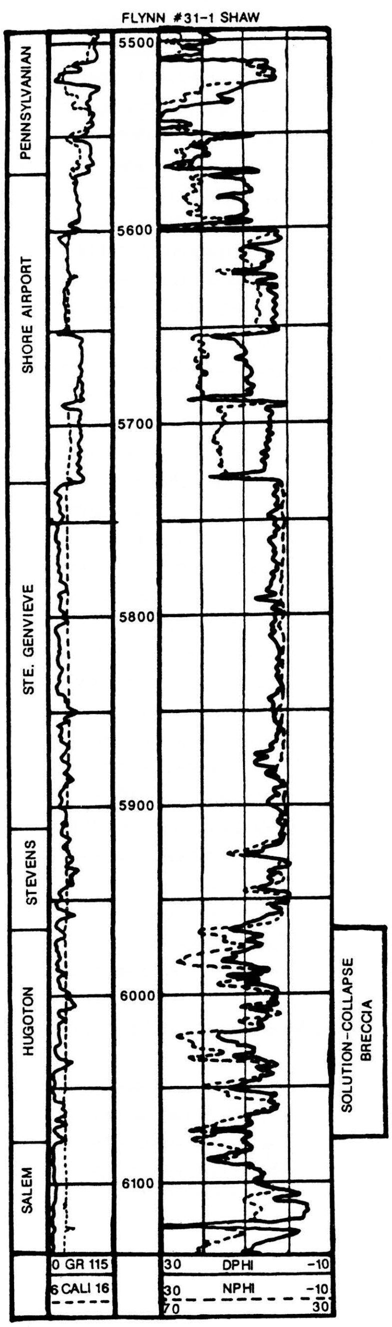


FIGURE 26—Gamma-ray and neutron-density logs from the Flynn #31-1 Shaw (sec. 31, T. 31 S., R. 34 W.). Note the fairly low gamma-ray values and numerous minor shale kicks of the breccia and the corresponding lower density readings relative to neutron readings. These log signatures are calibrated to the cored breccias in the Amoco #3 Wilson A (sec. 30, T. 30 S., R. 33 W.) approximately 9 miles (14.4 km) to the northeast.

Mississippian–Pennsylvanian Boundary

The Mississippian–Pennsylvanian boundary in southwestern Kansas is a highly erosional disconformity (e.g., Thompson and Goebel, 1968). The Shore Airport in the Mobil #1 Foster is overlain by the Kearny Formation (Morrowan) (cf. Swanson, 1978, his fig. 5). To the north and east, however, the Upper Mississippian is overlain by the "Gray group" (cf. Youle, 1991) and the Cherokee Group (Desmoinesian) (Goebel and Stewart, 1979).

The Kearny Formation consists of interbedded shales, sandstones, and carbonates (McManus, 1959; Swanson, 1978). The lower Kearny consists of shales interbedded with dolomitic calcareous sandstones and dolomitic arenaceous carbonates (McManus, 1959). Reworked Mississippian lithoclasts are common at the base of the Pennsylvanian. These conglomerates are interpreted as a transgressive lag that formed as the seas flooded the previously subaerially exposed shelf (cf. Youle, 1991). Log signatures of dolomitic sandstones and carbonates typically have low gamma-ray values and higher density porosity than neutron porosity (figs. 25 and 26).

The contact of the Kearny and Shore Airport Formations is locally difficult to place. Character of this boundary is variable because of the highly erosional unconformity that separates Mississippian and Pennsylvanian strata. Additionally, lower Kearny sandstones and carbonates are locally difficult to resolve from argillaceous limestones of the Shore Airport (McManus, 1959). The Kearny commonly contains significantly more shale and sandstone than the underlying Shore Airport.

In the eastern and northern Hugoton embayment, the Shore Airport is directly overlain by carbonates and thin shales of the Atokan? "Gray group"(Youle, 1991) (e.g., Pendleton #1 Schauf, sec. 16, T. 27 S., R. 29 W., Gray County) or the siliciclastic-dominated Desmoinesian Cherokee Group (e.g., Alma #1 Watchorn, sec. 13, T. 15 S., R. 33 W., Logan County). "Gray group" carbonates are commonly less argillaceous and the shales are more radioactive than are the limestones and shales of the underlying Shore Airport. This produces more contrast in "Gray group" gamma-ray log signatures relative to the Shore Airport. In cases where the Shore Airport has been eroded (fig. 4), the Ste. Genevieve or the St. Louis are directly overlain by Morrowan, Atokan, or Desmoinesian strata. The increased siliciclastic component of Pennsylvanian strata makes this a reliable log pick in many areas because Pennsylvanian strata typically have higher gamma-ray log values (figs. 25 and 26).

TABLE 3—CONODONTS RECOVERED AT VARIOUS INTERVALS FROM THE MOBIL #1 FOSTER (sec. 5, T. 34 S., R. 36 W.). Formation and member boundaries determined independently of conodont biostratigraphy. Conodont identification by Richard Lane of Amoco.

Interval (ft)	Identification	Number of Specimens
6909–6910.0	*Cavusgnathus altus*	1
	Taphragnathus 23360	3
	Spathognathodus eoscitulus	1
	Indeterminant conodonts	17
6906–6907	*Apatognathus* n. sp. A.	5
	Cavusgnathus altus	1
	Taphrognathus 23360	2
	Taphrognathus varians	2
	Spathognathodus penescitulus	1
	Spathognathodus eoscitulus	1
	Indeterminant conodonts	21
6902–6903	*Taphragnathus* 23360	5
	Cavusgnathus unicornis	2
	Apatognathus n. sp. a	2
	Spathognathodus penescitulus	1
	Indeterminant conodonts	12
6888–6889	*Taphragnathus* 23360	1
	Apatognathus n. sp. a	1
	Indeterminant conodonts	10
6878	Indeterminant conodonts	2
6825	Indeterminant conodonts	3
6815	*Apatognathus geminus*	3
	Apathognathus porcatus	1
	Cavusgnathus unicornis	1
	Taphragnathus 23360	2
	Spathognathodus penescitulus	1
	Indeterminant conodonts	26
6811.5–6812.5	Barren of conodonts	
6806.5–6807.5	*Taphrognathus* 23360	1
	Indeterminant conodonts	7
Top of the Hugoton Member of the St. Louis Limestone (6804 ft)		
6803–6804	*Apatognathus geminus*	3
	Cavusgnathus unicornis	4
	Cavusgnathus altus	3
	Spathognathodus scitulus	4
	Spathognathodus cristulus	2
	Indeterminant conodonts	14
6790–6791	*Spathognathodus scitulus*	4
	Apatognathus geminus	4
	Apathognathus porcatus	1
	Indeterminant conodonts	11
6783–6784.5	*Spathognathodus penescitulus*	1
	Taphrognathus 23360	1
	Cavusgnathus sp.	1
	Indeterminant conodonts	5
6772	Indeterminant conodonts	5
6761–6762.5	Barren of conodonts	
6752.5–6753.5	*Spathognathodus penescitulus*	2
	Indeterminant conodonts	7
6743.5–6744.5	Barren of conodonts	
6740–6741	*Cavusgnathus altus*	1
	Cavusgnathus sp.	1
	Spathognathodus cristulus	2
	Indeterminant conodonts	18
6737.0	Barren of conodonts	
6732–6733	*Magnilateralla robusta*	1
6729.0–6730	*Ligonodina levis*	1
6722.5–6723.5	*Spathognathodus scitulus*	1
	Gnathoduscommutatus commutatus	1
	Cavusgnathus altus	1
	Magnilateralla robusta	2
	Apathognathus porcatus	1
	Indeterminant conodonts	19
6713–6714	*Cavusgnathus altus*	2
	Indeterminant conodonts	6
6710–6711	*Cavusgnathus unicornis*	1
	Indeterminant conodonts	10
6699–6700	*Cavusgnathus unicornis*	1
	Indeterminant conodonts	3
6690	Barren of conodonts	
6686.0	Barren of conodonts	
6662.5–6663.5	*Cavusgnathus unicornis*	1
	Cavusgnathus offset	1
	Indeterminant conodonts	4
6661–6662	*Cavusgnathus unicornis*	2
	Cavusgnathus sp.	2
	Neopriontiodus sp.	1
	Ligonodina sp.	2
	Indeterminant conodonts	18
Top of the Stevens Member of the St. Louis Limestone (6660 ft)		
6649–6650	Barren of conodonts	
6643	Barren of conodonts	
6640–6641	Barren of conodonts	
6632–6633	Barren of conodonts	

(continued next column)

Biostratigraphy

Conodont biostratigraphy has been extensively used in conjunction with lithostratigraphic studies of Mississippian strata in Kansas (e.g., Thompson and Goebel, 1963, 1968). Definition of lithostratigraphic boundaries should be independent of biostratigraphic zones. Formations are rock-stratigraphic units defined by lithofacies. Conodont data, however, are useful in several ways. Comparison of conodont fauna from a correlative lithofacies on different parts of the shelf can indicate diachroneity, if resolution is sufficient. Conodont data are useful in comparison of lithofacies from different basins, for example to test whether St. Louis and Ste. Genevieve strata are roughly coeval in the Hugoton embayment and the Illinois basin. Thompson and Goebel (1968, p. 19) report that St. Louis and Ste. Genevieve strata in Kansas are "synchronous with the equivalent formations in the Mississippi River Valley" region based on conodonts. In addition, conodont biostratigraphy can help constrain lithostratigraphic correlations. Biostratigraphy combined with regional correlations indicates that the base of Mobil #1 Foster was not in the Salem Limestone as reported on the scout card (Abegg, 1991), but is instead the porous carbonate between the Hugoton Member E1 and E2 anhydrite.

The influence of environmental factors on conodont distribution is a concern in biostratigraphy. This concern is minimized in correlating between similar depositional settings. The general coincidence of Mississippian biostratigraphic and lithostratigraphic boundaries in Kansas (Thompson and Goebel, 1968) suggests that facies dependency is a strong possibility or that diachroneity is lacking.

Samples from the base of the Mobil #1 Foster core contain both *Taphrognathus* and *Cavusgnathus* (table 3). In the type area, the lower St. Louis Limestone corresponds to the upper part of the *Taphrognathus varians-Apatognathus*? (Warsaw Formation to lower St. Louis Limestone) zone (Collinson et al., 1971). The upper St. Louis Limestone corresponds to the *Apatognathus scalenus-Cavusgnathus* zone (Collinson et al., 1971). The boundary between these zones is distinguished by the earliest occurrence of common *Cavusgnathus* and *Apatognathus*, and the last occurrence of *Taphrognathus* (Collinson et al., 1971). The exact location of this biostratigraphic boundary in the Foster core is uncertain. Judging by more reliable first occurrences, the lower-upper St. Louis Limestone biostratigraphic boundary in the Mobil #1 Foster core is somewhere in the upper part of the Hugoton Member. In the type area, the St. Louis–Ste. Genevieve lithostratigraphic boundary corresponds to the base of the *Gnathodus bilineatus-Cavusgnathus charactus* zone (Ste. Genevieve Limestone to Cypress Sandstone) (Collinson et al., 1971). The lower boundary of this zone is marked by the last common occurrences of *Apatognathus* and *Spathognathodus scitulus* (Collinson et al., 1971). Above the quartzose grainstone at the base of the Stevens Member, these conodonts are absent, suggesting the quartzose grainstone (6,710 ft [2,013 m] core depth) approximates the base of the *Gnathodus bilineatus-Cavusgnathus charactus* zone. No conodonts were recovered from the Ste. Genevieve Limestone of the Foster core because most samples were taken from restricted shelf facies that are generally barren of fossils. Conodonts from Mobil #1 Foster indicate that lithostratigraphic boundaries in southwestern Kansas are roughly synchronous with equivalent formations in the Illinois basin.

Summary

1. Mobil #1 Foster (sec. 5, T. 34 S., R. 36 W.) contains six lithofacies representative of the St. Louis and Ste. Genevieve Limestones across much of the Hugoton embayment: 1) peloid grainstone/packstone, 2) anhydrite, 3) dolomite, 4) skeletal packstone/ wackestone, 5) oolitic grainstone/packstone, and 6) quartzose grainstone.

2. The uppermost Salem Limestone is characterized by dolomitic skeletal and oolitic limestones. The overlying St. Louis Limestone is commonly divisible into the Hugoton and Stevens Members. The Hugoton is the lower member, and the type section contains primarily peloidal limestone, dolomite, anhydrite. Breccia and algal boundstone are common facies elsewhere in southwestern Kansas. Strata of the Stevens Member are dominantly skeletal limestone. Additionally, uppermost St. Louis strata contain oolitic limestone. Ste. Genevieve Limestone strata are recognized by the lowest prominent quartz-rich limestone. The overlying Shore Airport Formation typically contains argillaceous limestone and intercalated calcareous shale.

3. Abundant peloids, evaporites, and paucity of stenohaline marine organisms in the Hugoton Member of the St. Louis indicate that the peloid grainstone/packstone, anhydrite, and dolomite facies were deposited in a restricted lagoon. Subadjacent oolitic facies in the uppermost Salem suggests that shoals created barriers to circulation in a backshoal lagoonal environment.

4. Periodic winnowing, intercalated oolites, and a diverse and abundant assemblage of echinoderms, brachiopods, and bryozoans indicate upper St. Louis skeletal packstone/wackestone in the Stevens Member of the St. Louis was deposited in a normal-marine shelf environment at or near fair-weather wave base. Stevens Member oolitic grainstone/packstone, the reservoir facies, accumulated in a

highly agitated, marine-shoal environment, probably at depths less than 15 ft (5 m).

5. A quartzose grainstone 3.8 ft (1.2 m) thick in the Stevens Member contains abundant rhizoliths and ubiquitous climbing translatent strata with dips less than 7°, indicating deposition by a vegetated eolian sand sheet.

6. A quartzose grainstone 9.4 ft (2.9 m) thick in the basal Ste. Genevieve lacks rhizoliths and consists of abundant climbing translatent, common grainfall, and minor grainflow stratification in crossbed sets up to 1.5 ft (0.5 m) thick with dips as high as 24°. This crossbedding and the apparent absence of vegetation indicate deposition by eolian dunes.

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Revision of Mississippian Stratigraphic Nomenclature in Kansas

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Abstract

The following changes to the Mississippian stratigraphic nomenclature of Kansas are suggested: 1) the Chattanooga Shale is almost entirely Devonian in age with, perhaps, only the uppermost part early Mississippian; 2) the term Misener Sandstone should be used for a Devonian sandstone at the base of the Chattanooga, not for Mississippian sandstones at the base of the Mississippian carbonates; 3) Hannibal Shale should be used in Kansas instead of Boice Shale; 4) Compton Limestone should be used throughout Kansas instead of the somewhat poorly defined term "Chouteau Limestone," which should be abandoned; 5) Sedalia Formation should be used throughout the state (instead of Sedalia Dolomite); 6) Northview Shale should be used as a formation-rank unit in Kansas, occurring above the Sedalia Formation; 7) the term "Fern Glen Limestone" should be abandoned; 8) St. Joe Limestone Member should be replaced with Pierson Limestone at a formation rank; 9) Reeds Spring Limestone should be elevated from member rank to formation rank; 10) Elsey Formation is recognized only in the extreme southeastern part of Kansas (southeastern Cherokee County) where it is laterally continuous in adjacent parts of Missouri and Oklahoma; 11) Burlington–Keokuk Limestone should be used in those areas where lithostratigraphic separation is not possible; 12) the base of the Meramecian Stage probably occurs within the Warsaw Formation, not at its base as previously placed; 13) the Ste. Genevieve Limestone is Chesterian; 14) Cowley Formation is recognized as a formation-level stratigraphic unit (equivalent to all or part of the St. Louis-upper Chattanooga interval) in the subsurface of south-central Kansas; 15) the St. Louis Limestone in the subsurface of southwestern Kansas is composed of the Hugoton Member below and the Stevens Member above; and 16) the Shore Airport Formation is recognized as the post-Ste. Genevieve Chesterian unit in the subsurface of southwestern Kansas.

Introduction

During work on a stratigraphic lexicon for the state of Kansas, it became apparent that Mississippian stratigraphic nomenclature needed to be updated to more closely parallel nomenclature in the type-Mississippian area and to reflect increased understanding of Mississippian surface-exposure stratigraphy in adjacent states. It is neither my intent to erect new names for Mississippian units in Kansas (even though some, such as the "unnamed unit(s) in the Chesterian," need them), nor to formalize loosely, and often indiscriminately, applied subsurface terms. Rather, I hope to bring Mississippian surface- and subsurface-stratigraphic nomenclature more closely into line with surface-stratigraphic nomenclature. Only those units affected by these changes and updates will be discussed briefly below, from oldest unit upward. A chart summarizing recommended nomenclatural changes is presented in fig. 1.

Because the majority of Mississippian units in Kansas are not exposed at the surface, most of the Mississippian stratigraphic names used in Kansas have been applied to subsurface units. Furthermore, almost all of these subsurface names have been extended from surface exposures in the type-Mississippian area. These subsurface Mississippian units have been important petroleum producers, therefore interest in them has been keen over the years and published works on their stratigraphy are numerous. Two works in particular (Lee, 1940; Goebel, 1968a) have been instrumental in shaping and defining the Mississippian nomenclature used in Kansas. Thompson (1986) updated, clearly defined, and gave nomenclatural histories for Mississippian stratigraphic units in Missouri, which includes a substantial amount of the type-Mississippian area.

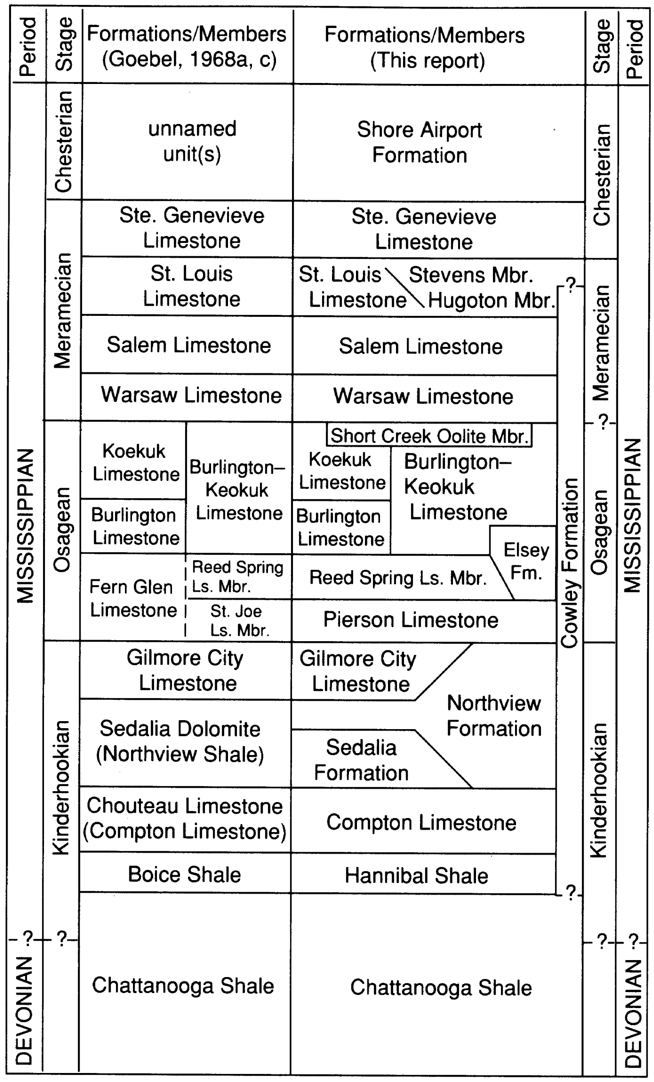

FIGURE 1—PROPOSED CHANGES IN MISSISSIPPIAN STRATIGRAPHIC NOMENCLATURE USED IN KANSAS. North to south distributional changes are represented schematically.

Chattanooga Shale

The Chattanooga Shale is a laterally extensive, easily recognizable black to gray-black shale present in the subsurface throughout most of Kansas (see Goebel, 1968b; Lambert 1992, this volume, for summary of Chattanooga Shale distribution and internal stratigraphy in Kansas). The Chattanooga in Kansas long has been regarded as undifferentiated Devonian and lower Mississippian. However, most of the Chattanooga Shale and equivalents in other states is Devonian in age (Carlson, 1963; McKnight and Fischer, 1970; Over and Barrick, 1990; Over, 1992). Nonetheless, Over and Barrick (1990) and Over (1992) noted that the three lowermost Kinderhookian conodont zones occur within the uppermost meter of the black Woodford Shale (=Chattanooga Shale) in Oklahoma. The majority of the Chattanooga Shale in Kansas is Devonian, as was suggested by Moore et al. (1951), but the uppermost part may be early Mississippian in age (see Lambert, 1992, this volume). Detailed conodont biostratigraphic studies are necessary in order to accurately assess the presence and position of the Devonian–Mississippian boundary in the Chattanooga Shale in Kansas. The subtle change in Kansas of moving the Mississippian–Devonian boundary to near the top of the Chattanooga Shale (fig. 1) reflects increased realization that most of the Chattanooga Shale in adjacent states is Devonian (see Carlson, 1963; Thompson, 1986; Over and Barrick, 1990; Over, 1992).

Related to the age question for the Chattanooga Shale, but not reflected in fig. 1, is the nomenclatural problem of "Misener Sandstone." The Misener Sandstone (without quotation marks) currently is used for the coarse, Devonian siliciclastic unit at the base of the Chattanooga Shale (see

Lambert, 1992, this volume). As such, it clearly cannot be younger than Devonian in age. However, "Misener Sandstone" (with quotation marks) has been used in the past for a coarse siliciclastic unit between Mississippian carbonates and either the Chattanooga Shale or older Paleozoic rocks where the Chattanooga Shale is absent (e.g., Goebel, 1968a; Moore, 1983). Whether in all cases this sandstone really is the Misener (Devonian) or some lower Mississippian sandstone (e.g., Bachelor or Bushberg) is equivocal. Clearly, where the Chattanooga Shale rests below this so-called "Misener Sandstone," the "Misener Sandstone" cannot be equivalent to the Misener Sandstone (restricted) that occurs below the Chattanooga Shale. Jewett (1954, p. 84) noted that the Misener Sandstone probably was the Sylamore Sandstone, a view currently shared by T. L. Thompson (written communication, 1990) of the Missouri Geological Survey. In contrast, the "Misener Sandstone" may be a Mississippian sandstone similar to the Bachelor or Bushberg sandstones. However, even if biostratigraphic equivalence with Bachelor or Bushberg sandstones could be demonstrated, I would be reticent to suggest use of either Bachelor or Bushberg in the absence of demonstrated lithostratigraphic continuity.

Hannibal Shale

When Reed (1946) erected the Boice Shale from the subsurface of Nebraska, he did so with the explicit understanding that the subsurface term "Boice" was preferable to the surface term "Hannibal" because no firm correlation from surface to subsurface could be made. Goebel (1968c) adopted Reed's terminology and applied it to the subsurface of Kansas. More recent information (Thompson, 1986, p. 20, 21, 64) has shown that the Hannibal Shale of Keyes (1892) does continue into the subsurface westward from its outcrop area in Missouri and is equivalent to the Boice Shale of Reed (1946). It is recommended that "Boice Shale" be abandoned in favor of the older, more established surface-stratigraphic term "Hannibal Shale" (fig. 1).

Compton Limestone

When Moore (1928, p. 120) erected the Compton Limestone, he noted that the upper beds of the Compton occur in facies relationship with the Northview formation. Goebel (1968c) noted that in southeastern Kansas the Chouteau is called the Compton Limestone. Nodine-Zeller (1987) depicted the Sedalia Dolomite overlying the Chouteau Limestone in Jackson County, Kansas. The term "Chouteau" has had so many different definitions over the years (see summary in Thompson, 1986, p. 34–64) that, as a lithostratigraphic unit, it probably has lost much of its meaning. It is suggested, therefore, that the term "Chouteau" be abandoned altogether (at least until a detailed stratigraphic study of what "Chouteau" really means) and replaced/constrained by "Compton Limestone," the term used in Missouri and southeastern Kansas.

Sedalia Formation

Sedalia Formation is recommended for use in Kansas rather than "Sedalia Dolomite." In addition, the Sedalia Formation occurs below (not above) or instead of (facies relationship with) the Northview Formation (see discussion below under "Northview Formation"). Otherwise, no changes in use of the term "Sedalia" are recommended.

Northview Formation

The Northview Formation was named by Weller (1901) for exposures near Northview, Webster County, Missouri. These exposures are near the northeastern limit of the Northview in Missouri, and occur near the axis of a depositional basin that extends toward the west-northwest into Kansas (see Beveridge and Clark, 1952, fig. 3). Wilson and Berendsen (1988) produced a net-shale map of the Northview Formation in Kansas and found that the shale was thickest (35 ft [10 m]) in the extreme southeastern corner of Coffey County, in east-central Kansas.

Some discrepancy regarding the relative position of the Northview Formation exists. Moore et al. (1951) and Goebel (1968c, p. 18) noted that "the lower part of the Sedalia Dolomite [=Sedalia Formation] thins southward, and in southeastern Kansas it is equivalent to the Northview Shale." Goebel (1968c, p. 18) also noted that "the upper part of the Sedalia Dolomite consists of noncherty or sparsely cherty, buff to gray dolomite, which extends from outcrops in Missouri westward in the Kansas subsurface to the northeastern flank of the Central Kansas uplift." Conversely, Thompson (1986, p. 58) noted that north of the Northview depositional basin, the Northview Formation "thins rapidly and interfingers with the uppermost beds of the *underlying* Sedalia Formation" [italics mine]. Thompson (1986, p. 59) also noted that "south of the 'Northview basin' the Northview thins rapidly to 4 to 6 ft of bluish dolomitic siltstone and silty dolomite." When originally proposed, "Sedalia" was used for rocks that were both late Kinderhookian and early Osagean (upper Compton Limestone and Pierson Limestone, as used herein). Beveridge and Clark (1952) restricted "Sedalia" to pre-Osagean dolomitic limestone, beneath the Northview, and the Osagean part of the "Sedalia" was called Pierson. Therefore, as currently understood, all Sedalia is pre-Northview (T. L. Thompson, written communication, 1990). For the purposes of this review and reclassification, the Sedalia Formation is considered to be in facies relationship with the Northview Formation. Where both formations occur, the Sedalia underlies the Northview.

Gilmore City Limestone

The Gilmore City Limestone is recognized only in the subsurface of northern Kansas (e.g., Lee, 1956; Lambert, 1988). Throughout most of the state, the Gilmore City is absent and the Pierson Limestone rests directly on the Northview Shale. Pinch-out of the Gilmore City Limestone from north to south is reflected diagrammatically in fig. 1.

Pierson Limestone

Standard stratigraphic practice in Kansas has been to recognize the Fern Glen Limestone with two members, the Reeds Spring above and the St. Joe below. The Fern Glen Limestone has not been recognized with certainty west of east-central Missouri (see Thompson, 1986, p. 70–74). Therefore, use of the term "Fern Glen" should be abandoned in Kansas because continuity with the type area cannot be demonstrated. The Pierson Limestone of Weller (1901) should be used as a formation-level unit instead of the St. Joe Limestone. Goebel (1968a, p. 1,754) noted the overall similarity of the St. Joe Limestone Member (=Pierson Limestone) in the subsurface of Kansas with outcrops in southwestern Missouri. However, Thompson and Fellows (1970) determined that the basal St. Joe was Kinderhookian and equivalent to the Compton Limestone and Northview Formation of southwestern Missouri, meaning that only upper St. Joe strata in the type area are Osagean. This type of detailed conodont biostratigraphic study is lacking in Kansas, so it is unclear whether or not the Pierson is entirely Osagean or is in part latest Kinderhookian in age.

Reeds Spring Limestone

The Reeds Spring Limestone is raised from member status within the Fern Glen Limestone to formational rank, otherwise, it remains essentially the same as outlined by Goebel (1968a, c), except for recognition of the Elsey Formation in extreme southeastern Kansas (see discussion below) and abandonment of the term "Fern Glen Limestone" (see discussion above).

Elsey Formation

The Elsey Formation was erected by Robertson (1967, p. 46) for the cherty limestone unit that Beveridge and Clark (1952) had called "Grand Falls." Seevers (1975, p. 2–3) noted that the upper part (about 45 ft [13.5 m] thick) of the Reeds Spring Limestone in Cherokee County, Kansas, has been called the Grand Falls Chert, and that the deposits of lead and zinc that were mined throughout the Tri-state district (Missouri–Kansas–Oklahoma) occur primarily in the Grand Falls Chert and overlying rocks of Mississippian age. Thompson (1986, p. 87–89) discussed history of use of the term "Grand Falls" and reasons for use of the better defined term "Elsey." Grand Falls Chert of Winslow (1894) is restricted to the immediate area of the type locality near the center of sec. 28, T. 27 N., R. 34 W., Newton County, Missouri (see Thompson, 1986, p. 88–89). The Elsey Formation is present only in southwestern Missouri, northwestern Arkansas, northeastern Oklahoma, and southeastern Kansas. The Elsey Formation is approximately 30 ft (9 m) thick, overlies the Pierson Limestone or Reeds Spring Formation, and underlies the Burlington–Keokuk Limestone. The Reeds Spring and Elsey Formations and lowermost part of the Burlington–Keokuk interval all occur in facies relationship with one another and are very difficult to distinguish west and north from the immediate area of southeastern Cherokee County, Kansas. Where Reeds Spring and Elsey cannot be separated, the term Reeds Spring should be used (instead of Reeds Spring–Elsey as used informally by Thompson, 1986, p. 5).

Burlington–Keokuk Limestone

Despite much work, recognition of a distinction between the Burlington and Keokuk limestones in Kansas is difficult in surface exposures and nearly impossible in the subsurface. In earlier works, the Burlington Limestone was assumed to be one of the most extensive Mississippian carbonate units in Kansas (Lee, 1940). More recent works (Goebel, 1968a, c) indicate that in western Kansas, much of what had been called Burlington is in fact Keokuk. Thus, the Keokuk is a much thicker and more widely extensive unit in both surface and subsurface areas than once thought, and certainly more so than the Burlington. The change in depiction of this Burlington–Keokuk relationship (fig. 1) reflects: 1) recognition that the Keokuk is thicker and more widely distributed than the Burlington; and 2) acknowledgment that this contact is not always discernible in the subsurface, thus necessitating a formal term "Burlington–Keokuk" (as opposed to Keokuk–Burlington) to be used in those cases. Where present, the top of the Short Creek Oolite Member marks the base of the Warsaw Limestone. Where absent, or where more than one oolite bed is present, the Warsaw and Burlington–Keokuk contact is difficult to distinguish, which may eventually result in reinstatement of a lithostratigraphic unit that encompasses this whole Warsaw and Burlington–Keokuk package (e.g., "Carthage Limestone" of Gallaher, 1898).

McKnight and Fischer (1970) used the terms "Boone Formation" and "Quapaw Limestone" for most of this sequence and the overlying Warsaw Limestone in the Wyandotte quadrangle, which includes an ~800-ft (240-m) strip of the southernmost part of Kansas. They subdivided the Boone into seven members: St. Joe Limestone Member, Reeds Spring Member, Grand Falls Chert Member, Short Creek Oolite Member, Baxter Springs Member, and Moccasin Bend Member, from bottom to top, respectively. Until detailed mapping in this part of Kansas is done, it probably is best to use the terms Keokuk and Warsaw for this sequence of members in the Boone Formation and overlying Quapaw Limestone.

Cowley Formation

When Lee (1940) erected the Cowley Formation, he did so based in large measure on the assumption that a major glauconitic zone represented a significant unconformity at the base of the Cowley Formation. Clair (1948, 1949) referred to this unit as "Cowley facies" instead because, using lithostratigraphic evidence, he judged Cowley to be a facies of other Mississippian units. Later, Thompson and Goebel (1968), using microfossil evidence, showed that the Cowley Formation of Lee (1940) was temporally equivalent with various Mississippian units from the lower part of the St. Louis Limestone to the Chattanooga Shale. However, none of the standard Mississippian units can be recognized within the "Cowley facies" of Goebel (1968a, c). Conformable relationship and biostratigraphic equivalence, if present, are not reasons to abandon a formation name. Lithologically, the Cowley is so distinctive relative to other Mississippian lithostratigraphic units in Kansas, that resurrection of Lee's (1940) name "Cowley Formation" is recommended (fig. 1). Clearly, additional work on lithostratigraphic definition and biostratigraphic interpretation of the Cowley Formation is warranted. Given the formation thickness (>500 ft [150 m] in places) and number of Mississippian stages the Cowley represents (Kinderhook–Meramec), detailed investigation may result in subdivision (e.g., Lambert, 1988) and increased understanding of the Cowley Formation.

Hugoton and Stevens Members of the St. Louis Limestone

Abegg (this volume, p. 39–66) has established criteria for recognition of two members in the St. Louis Limestone in the Hugoton embayment of southwestern Kansas. The underlying Hugoton Member is predominantly an evaporitic/dolomitic unit, whereas the overlying Stevens Member is predominantly a muddy fossiliferous limestone. The contact between the underlying Salem Limestone and overlying Hugoton Member of the St. Louis Limestone is marked by the last skeletal and oolitic limestones in the top of the Salem Limestone. The contact between the upper part of the Stevens Member of the St. Louis Limestone and the overlying Ste. Genevieve Limestone is marked by the appearance of quartz-rich limestones in the Ste. Genevieve Limestone. Detailed discussion of these members can be found in Abegg (this volume, p. 39–66).

Shore Airport Formation

Abegg (this volume, p. 21–38) has defined the Shore Airport Formation from cores in southwestern Kansas as Chesterian strata underlain by the Ste. Genevieve Limestone and overlain by the Kearny Formation (Pennsylvanian). The Shore Airport Formation is composed predominantly of maroon and gray mudstones and muddy limestones with features indicative of paleosol development throughout. The Shore Airport Formation is recognized as the appropriate name for that part of the Kansas Chesterian section previously referred to as "unnamed Chester." Detailed discussion of the Shore Airport Formation can be found in Abegg (this volume, p. 21–38).

Meramecian Stage

The upper and lower boundaries of the Meramecian Stage have been the subjects of much debate over the years (see summaries in Horowitz, 1984; Thompson, 1986; Maples and Waters, 1987; Kammer et al., 1989; Kammer et al., 1990). Stage boundaries, unlike the formational boundaries discussed previously, are defined biostratigraphically. I have chosen to use the term "Stage" for both the Meramecian and Chesterian (instead of "Series") because of the general restriction to intracontinental correlation of units referable to "Meramecian" and "Chesterian" (North American Commission on Stratigraphic Nomenclature, 1983, p. 868). The upper boundary of the Meramecian Stage (the Meramecian–Chesterian boundary) most recently has been proposed to coincide with biostratigraphic boundaries between conodonts and foraminiferal zones at approximately the St. Louis–Ste. Genevieve boundary (see Maples and Waters, 1987, 1988; Brenckle et al., 1988). Given the overwhelmingly related faunal similarity between the Ste. Genevieve and younger Chesterian units, the Ste. Genevieve Limestone was removed from the Meramecian Stage and placed in the overlying Chesterian Stage.

The Meramecian–Osagean boundary (the lower Meramecian boundary) has been in an equivalent state of flux to that of the Meramecian–Chesterian boundary (see discussions in Thompson, 1986; Kammer et al., 1990). This has led some state surveys to abandon the terms "Meramecian" and "Osagean" altogether in favor of the collective term "Valmeyeran," which was erected by Moore (1933) and formerly used in Kansas (Moore, 1935). Even though the Osagean–Meramecian boundary does not involve changes in a large number of taxa, I would not favor reintroduction of the "Valmeyeran stage" in Kansas for two reasons. First, as a term, Valmeyer is used by only two state geological surveys (Illinois and Indiana), neither of which border Kansas. Currently, all border and near-border states with Kansas (Oklahoma, Missouri, Nebraska, Colorado, Arkansas, Iowa, New Mexico, Texas) use Osage and Meramec rather than Valmeyer (Sutherland, 1979; Thompson, 1986; Burchett, 1979; Chronic, 1979; Glick, 1979; Avcin and Koch, 1979; Armstrong et al., 1979; Kier et al., 1979). Second, the Osagean–Meramecian contact is the only Mississippian boundary exposed at the surface in Kansas (southeastern Cherokee County). The current Osagean–Meramecian boundary has been judged to be approximately at the Warsaw–Keokuk contact. However, Kammer et al. (1990) have proposed that the Osagean–Meramecian contact be raised stratigraphically to within the Warsaw Formation in the Mississippian stratotype area, which equates roughly to the boundary between the Baxter Springs Member and Moccasin Bend Member of the Boone Formation (as used by McKnight and Fischer, 1970) in northeastern Oklahoma. Because the upper Keokuk and lower Warsaw formations are exposed in Kansas, the revised Osagean–Meramecian boundary probably is present at the surface, although its exact position has not yet been documented. Thus, even though the Osagean–Meramecian boundary may be only fortuitously recognized in the subsurface, the potential for its recognition at the surface is much greater. Figure 1 reflects the occurrence of the Osagean–Meramecian contact at some unknown position within the Warsaw Formation in Kansas, as is the case in the Mississippian stratotype area.

Remaining Questions

As noted above, the purpose of this paper is to update the Kansas Mississippian stratigraphic nomenclature. Clearly additional questions and problems that are beyond the scope of this work remain to be addressed. The nature of the facies relationship between the Cowley Formation and all other pre-Chesterian Mississippian units, although documented, is poorly understood. Facies relationships in the Northview–Sedalia interval and Chouteau–Compton interval are equally poorly investigated. Better biostratigraphic and lithostratigraphic subdivisions of the Chattanooga Shale are critical to understanding this important petroleum source rock. In addition, understanding the age and facies relationships of the sandstone (referred to by some authors as "Misener Sandstone," which it is not) present at the top of the Chattanooga Shale or between older Paleozoic rocks and the base of the Mississippian carbonates is crucial to understanding early Mississippian deposition in Kansas. Detailed biostratigraphic studies (such as Thompson and Goebel, 1968) and subsurface stratigraphic studies of the Mississippian rocks in Kansas are urgently needed. The entire Osagean sequence, in particular, is a very complicated package of facies relationships among no less than five different units that will require careful lithostratigraphic and biostratigraphic study to unravel. Clearly, much remains to be accomplished in the Mississippian of Kansas.

Conclusions

The following changes to the Mississippian stratigraphic terminologies of Kansas are suggested:

1. The Chattanooga Shale is almost entirely Devonian in age with, perhaps, only the uppermost part early Mississippian.
2. Misener Sandstone should not be used for a sandstone that occurs directly beneath the Mississippian carbonates.
3. Hannibal Shale should be used in Kansas instead of Boice Shale.
4. Compton Limestone should be used throughout Kansas. The term "Chouteau Limestone" should be abandoned.
5. Sedalia Formation should be used throughout the state (instead of Sedalia Dolomite).
6. The Northview Shale (as a newly recognized formation-rank unit in Kansas) occurs above the Sedalia Formation in both Missouri and Kansas.
7. Use of the term "Fern Glen Limestone" should be discontinued.
8. St. Joe Limestone Member should be replaced with Pierson Limestone at a formation rank.
9. The Reeds Spring Limestone should be elevated to formation rank from member rank.
10. The Elsey Formation is recognized only in the extreme southeastern part of Kansas (southeastern Cherokee County) where it is laterally continuous with Elsey Formation in adjacent parts of Missouri and Oklahoma.
11. Burlington–Keokuk Limestone should be used in those areas where lithostratigraphic separation is not possible. Where the two can be separated, usually most of the interval is Keokuk rather than Burlington.
12. The base of the Meramecian Stage probably occurs within the Warsaw Formation, not at its base as previously placed.
13. The Ste. Genevieve Limestone is Chesterian.
14. The Cowley Formation is reinstated as a formation-level stratigraphic unit (equivalent to all or part of the lower St. Louis–upper Chattanooga interval) in the subsurface of south-central Kansas.
15. Two Members of the St. Louis Limestone in the Hugoton embayment, southwestern Kansas, are recognized: the Hugoton Member in the lower part and the Stevens Member in the upper part.
16. The Shore Airport Formation is recognized as the post-Ste. Genevieve part of the Chesterian strata in the subsurface of southwestern Kansas.

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Revised Upper Devonian and Lower Mississippian Stratigraphic Nomenclature in Kansas

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Abstract

As revised here, the Chattanooga Shale of Kansas includes the basal Misener Sandstone Member overlain by informal lower, middle, and upper shale members. Present only in the subsurface, this formation underlies most of the eastern two-thirds of the state. Most of the Chattanooga Shale is Devonian in age, although the uppermost part may be Early Mississippian. The Misener Sandstone Member has an erratic distribution and is usually less than 1 m (3.3 ft) in thickness. The lower shale member is present only in south-central Kansas and is less than 15 m (49.5 ft) thick. The middle and upper shale members can be traced throughout much of the area of Chattanooga subcrop, and their combined thickness can be more than 76 m (250.8 ft). A lenticular limestone bed is present near the base of the upper shale member in central Kansas, and limestone and dolomite beds occur within the upper parts of both the middle and upper shale members in northeastern Kansas. Ferruginous oolites are present in the upper shale member in northeastern Kansas, near the contact with the overlying Mississippian carbonates. Sometimes called the Kinderhook Shale, the Chattanooga Shale of Kansas is equivalent to the Woodford Shale of Oklahoma, Texas, and New Mexico.

Introduction

The Chattanooga Shale and its equivalents are widely distributed in the eastern part of North America. With its type locality in Tennessee (Hayes, 1891), the Chattanooga Shale also is found in Alabama, Kentucky, Arkansas, and eastern Oklahoma (Cooper, 1931; Conant and Swanson, 1961). Many stratigraphically equivalent formations exist, such as the Woodford Shale of Taff (1902) in western and central Oklahoma, western Texas, and southeastern New Mexico (Cooper, 1931; Amsden, 1980; Ellison, 1950).

The Chattanooga Shale of north-central and northeastern Oklahoma has been traced into adjacent parts of Kansas (McClellan, 1930; Leatherock and Bass, 1936), and Hilpman (1967) commented on the similarity of lithology and fauna in the Woodford Shale of Oklahoma and the Chattanooga Shale of eastern Kansas. The Chattanooga Shale and Woodford Shale are obviously the same formation and will be called the Chattanooga Shale in this report. In Kansas, the Chattanooga Shale is present only in the subsurface and underlies the eastern two-thirds of the state (Goebel, 1968).

This predominantly shaly formation comprises the Upper Devonian and possibly part of the Lower Mississippian section in Kansas, but over the years a lack of precision has characterized the use of stratigraphic nomenclature applied to it. It is proposed here that outmoded names such as Kinderhook Shale be retired and that useful, informal new names such as the lower, middle, and upper shale members be introduced (fig. 1).

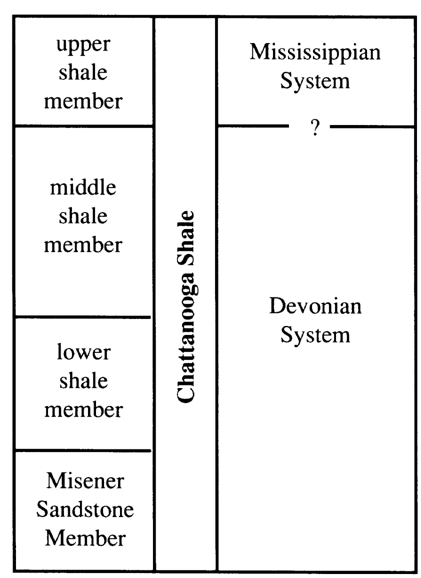

FIGURE 1—PROPOSED SUBDIVISIONS OF THE CHATTANOOGA SHALE.

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Age of the Chattanooga Shale

Early workers (White, 1929; Cooper, 1931; Moore, 1935) believed that the Chattanooga Shale of Kansas and Oklahoma was entirely Mississippian in age, based upon stratigraphic relationships and conodont biostratigraphy. Lee (1940, 1956) classified it as Devonian or Mississippian, because the Chattanooga was present below limestones of definite Mississippian age and above limestones and dolomites of definite Devonian age. More recently, a conodont study by Hass and Huddle (1965) suggested an age range from Late Devonian to Early Mississippian (Kinderhookian) for the formation in south-central Oklahoma. Over and Barrick (1990), working with conodonts from the formation in the same location as Hass and Huddle (1965), found that only the top 0.6 m (1.8 ft) was Mississippian (Kinderhookian), with the rest being Devonian. Carlson (1963) believed the Chattanooga Shale of Nebraska to be mainly Devonian on the basis of stratigraphic considerations. Therefore, most of the Chattanooga Shale of Kansas is probably Late Devonian in age, although the uppermost part may be earliest Mississippian.

The original misidentification of the entire formation as being earliest Mississippian in age caused some workers (Imbt and Harper, 1942; Ver Wiebe, 1946) to call it the Kinderhook Shale. Even today, driller's reports in Kansas frequently identify the formation by that name. It should instead be called the Chattanooga Shale.

Misener Sandstone Member

The Misener Sandstone Member was first described in Oklahoma by White and Greene (1924). Williams (1921) had previously suggested that an unnamed quartz sandstone at the base of the Chattanooga Shale in Kansas was equivalent to the Sylamore Sandstone of northeastern Oklahoma and northwestern Arkansas. White (1929) called this sandstone the Sylamore in surface exposures of eastern Oklahoma and Arkansas and the Misener in the subsurface of western Oklahoma, a practice adopted by Amsden and Klapper (1972). In Kansas, Moore (1935) and Moore and others (1951) called this unit the Misener Sandstone Member of the Chattanooga Shale, a practice used here because this name is widely accepted in Kansas and, unlike the name Kinderhook Shale, is not based upon erroneous assumptions as to stratigraphic position.

Amsden and Klapper (1972) used conodont biostratigraphy to date the Misener Sandstone of north-central Oklahoma as Middle to Late Devonian in age (Givetian to early Fammennian). The Misener Sandstone Member in Kansas, which is usually less than 1 m (3.3 ft) in thickness, may not be the same age as it is in Oklahoma because of the erratic distribution of the unit. It apparently developed where lower Paleozoic sandstones subcropped beneath the pre-Chattanooga erosional surface and were reworked in the early stages of Chattanooga deposition (Lee, 1956; Amsden and Klapper, 1972).

Lower, Middle, and Upper Shale Members

Ellison (1950) divided the Woodford Shale of Texas and New Mexico into lower, middle, and upper shale members on the basis of geophysical log response. Hester and others (1990) recognized the same members in the Woodford Shale of western Oklahoma and were able to correlate them in well logs northward across Oklahoma. Hester and others (1990) determined from calculations based on geophysical log readings that the middle shale member has a higher total organic carbon (T.O.C) content than either the lower or upper shale members.

The lower shale member is present only in south-central Kansas, where it has a thickness of less than 15 m (50 ft; Lambert, 1993). The middle and upper shale members are present throughout most of the Chattanooga subcrop, and have a maximum combined thickness of more than 76 m (251 ft).

In central Kansas a lenticular limestone bed as much as 12 m (40 ft) thick is present near the base of the upper shale member (Lambert, 1992), and may be the same limestone that Lee (1956) found within the Chattanooga Shale at this location. In northeastern Kansas, thin limestone and dolomite beds (usually less than 1 m [3.3 ft] thick) are found within the upper part of both the middle and upper shale members, and ferruginous oölites are present in the upper shale member just below the Chattanooga Shale–Mississippian carbonate contact.

Rock-cutting samples from wells drilled through the Chattanooga Shale in Kansas show that the middle shale member is commonly black while the upper shale member is often gray or green (Lambert, 1992). This is another indication that the middle shale member has a higher T.O.C. content than the upper shale member, because in general a shale unit becomes darker with increasing T.O.C. (McBride, 1974; Schmoker, 1980; Hosterman and Whitlow, 1981). Geochemical core analysis confirms these vertical differences and also indicates that the over-all T.O.C. of the formation decreases to the north across Kansas, although in any given locality the middle shale member is the most organic-rich part of the formation (Lambert, 1993).

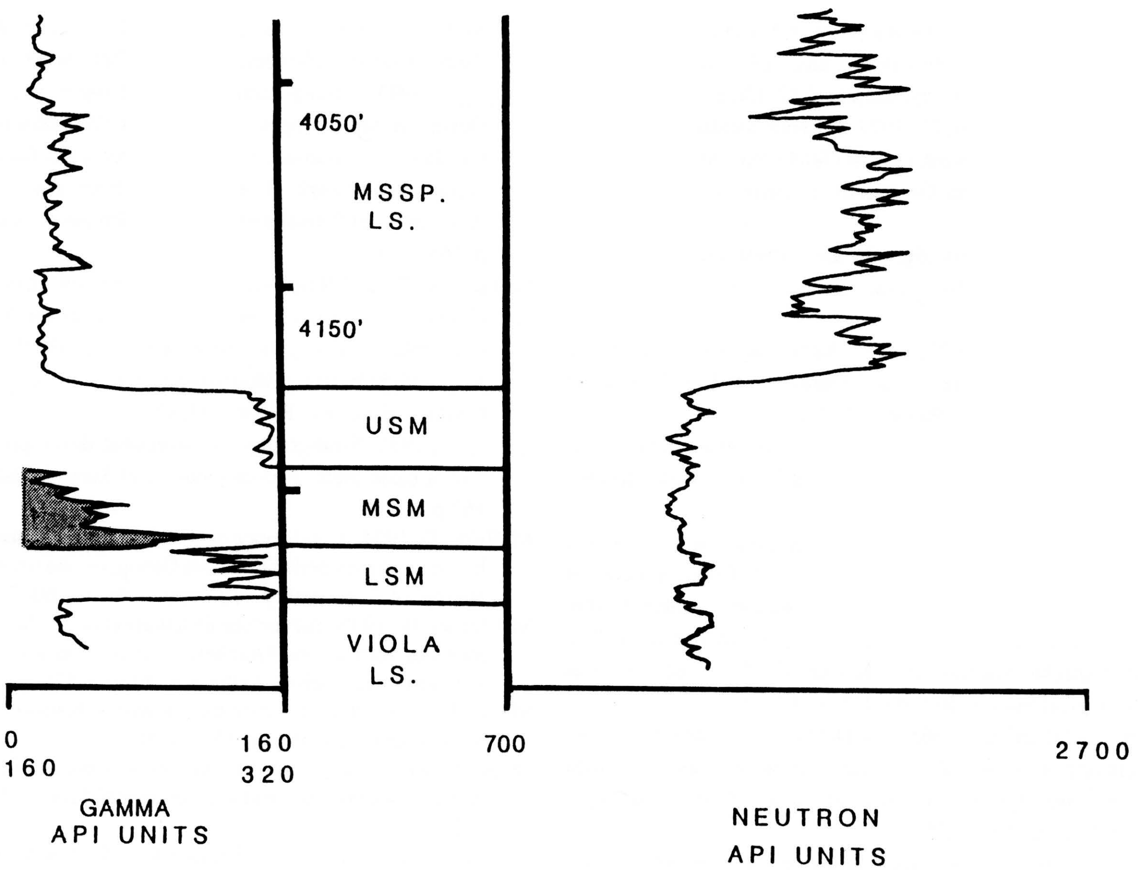

FIGURE 2—Geophysical log for the Phoenix #1 Orme well, located in Kingman County, south-central Kansas (sec. 4, T. 28 S., R. 6 W.). Depth below surface (feet) is shown in central column. All three shale members of the Chattanooga Shale are present. LSM = lower shale member, MSM = middle shale member, and USM = upper shale member.

Conclusions

The Chattanooga Shale in Kansas consists of the Misener Sandstone Member, overlain by informally defined lower, middle, and upper shale members. Restricted to the subsurface of the eastern two-thirds of the state, the formation is the equivalent of the Woodford Shale in western and central Oklahoma, western Texas, and southeastern New Mexico. It is probably almost entirely Devonian in age, although the uppermost part may be earliest Mississippian. The basal Misener Sandstone Member is equivalent to the Misener Sandstone of western Oklahoma and the Sylamore Sandstone of eastern Oklahoma. The informal shale members can be distinguished in well-cutting samples and on geophysical logs and appear to indicate vertical differences in the total organic carbon (T.O.C.) content of the shales. T.O.C. content of the entire formation decreases to the north in Kansas, although at any given location the middle shale member will be more organic-rich than either the lower or upper shale members.

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