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PETROLOGY OF MIDDLE PENNSYLVANIAN (DESMOINESIAN) "UPPER BLUEJACKET" SANDSTONE (CHEROKEE GROUP) OF BOURBON, CRAWFORD, AND CHEROKEE COUNTIES, KANSAS

by

Ralph E. Worthington

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Thesis supervisor: Assistant Professor Robert L. Brenner

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Ralph E. Worthington

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Geology at the July, 1982 graduation.

Thesis committee: Robert R Brenner
Thesis supervisor

Keene Swett
Member

Philip H Heckel
Member

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ABSTRACT

Stratigraphic correlation of the Bluejacket Sandstone interval in the subsurface was accomplished by using laterally continuous radioactive black shales, which are recognizable on geophysical well-logs, as key marker beds. The discontinuous and lenticular nature of the Bluejacket sandstones had previously hindered correlation on a regional scale. Several log cross-sections illustrate the correlation of the Bluejacket sandstone interval using these easily recognized marker beds. Approximately 125 control points in southeastern Kansas were used to determine sandstone distribution in the Cherokee Basin. Three sandstone trends were recognized, which suggest that the Bluejacket Sandstone was deposited in a dominantly north-south trend concentrated near the center of the basin. A smaller sandstone separates from the main sandstone body in the northwestern part of the basin, then curves toward the deeper basin farther to the south. A third sandstone occurs along the eastern margin of the basin, trending southwestward. Environmental interpretation of geophysical well-logs and the sandstone distribution suggest that the

Bluejacket was deposited by a fluvial-deltaic system that prograded into and over the nearby shallow sea.

The "upper Bluejacket" Sandstone occurs in the subsurface in southeastern Kansas, and crops out in the Tri-State area of Kansas, Missouri, and Oklahoma. Cores from Bourbon, Crawford, and Cherokee Counties in Kansas, which were described and sampled for petrographic analysis, show the "upper Bluejacket" to consist primarily of interbedded sandstones and shales. Sandstones contain a diverse mineralogy, with quartz occurring as the most abundant detrital grain, along with subequal, although variable, amounts of feldspars and lithic fragments. The framework grains are set in a predominantly clay matrix, which constitutes about twenty percent of the sandstone.

Three stages of diagenesis have severely altered the original mineralogy of the "upper Bluejacket". Stage One: during, or immediately following deposition, pyrite formed as a replacement of organic matter and Spherulitic siderite concretions formed within the finer grained interlaminations. Stage Two: the formation of clay coats on detrital grains is recognized as the earliest cement that occurred throughout the sandstone. This was followed by the precipitation of silica cement in the form of quartz overgrowths, which are developed extensively throughout the sandstone. Conversion of smectite clay minerals to illite

occurred throughout the diagenetic history and is interpreted to have supplied the necessary ions to form many of the authigenic cements. Stage Three: dissolution of feldspars provided the Si and Al ions and pore space necessary to allow delicate vermicular booklets of kaolinite to form. Associated with the late-stage conversion of smectite to illite, localized supersaturation of ions formed scattered patches of iron-rich carbonate cements. Fe-dolomite is the most abundant, with siderite and calcite present in lesser amounts. Carbonate cements, conversion of mica to chlorite, and sericitization of feldspars are interpreted to be late diagenetic alterations.

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INTRODUCTION

Geologic History

The geologic history of eastern Kansas has been discussed by many authors, summarized by Merriam (1963), and more recently, Moore (1979) focused on the Pennsylvanian tectonic and depositional features of the southern Mid-Continent. During Morrowan and Atokan time, all or most of eastern Kansas was exposed as a low-lying land area of Mississippian and older Paleozoic units. By the beginning of Atokan time, the major Pennsylvanian tectonic features of the Mid-Continent (Fig. 1) had formed, which influenced sedimentation in the Arkoma and Anadarko Basins in Oklahoma (Moore, 1979).

Eastern Kansas is separated from central Kansas by the Nemaha Uplift, which extends from present Nemaha County south through Sumner County. This pre-Desominesian, post-Mississippian element divided the Salina and Sedgwick Basins to the west from the Forest City and Cherokee Basins to the east. The Forest City and Cherokee Basins are separated by the Bourbon Arch, a low, broad feature that trends southeastward from Lyon, through Coffey, Anderson, and

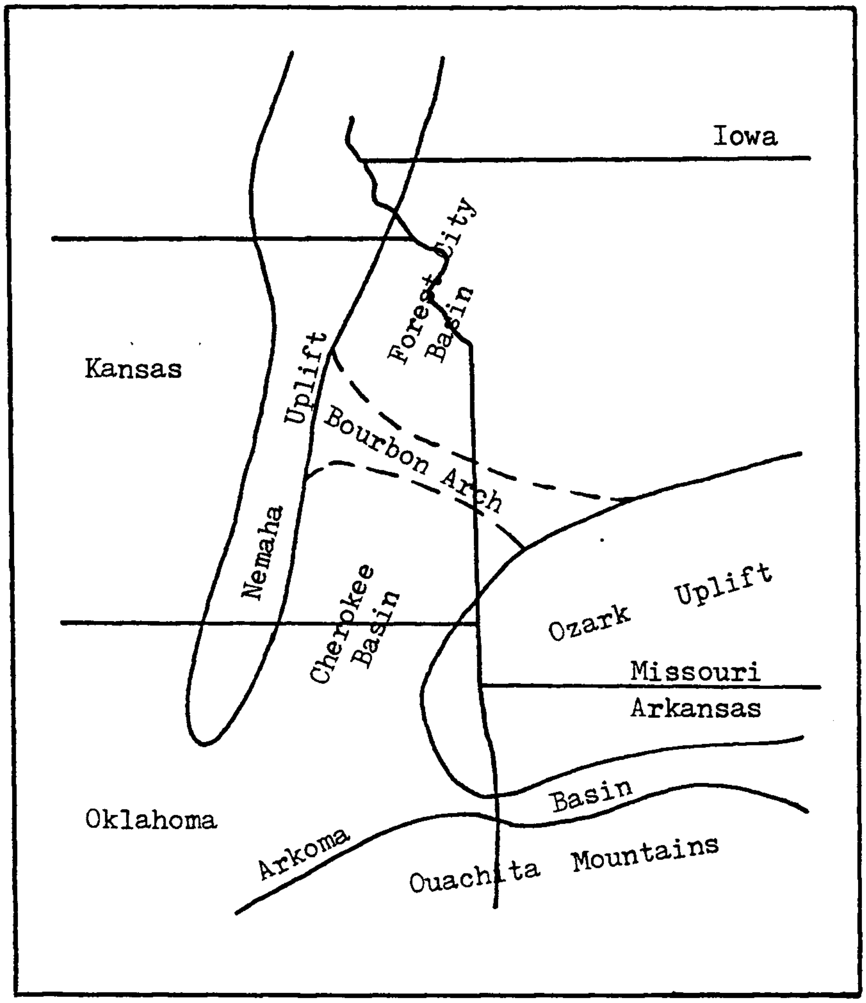

Figure 1. Generalized Middle Pennsylvanian structural features of eastern Kansas and surrounding area. (Modified from Hulse, 1979).

Bourbon Counties, and continues eastward into Missouri. The Cherokee Basin is an extension of the Arkoma Basin of Oklahoma and represents a shallow shelf or platform, which developed on the older Chautauqua Arch (Merriam, 1963).

During early Desmoinesian time, much of the Mid-Continent was intermittently inundated such that marine conditions alternated with widespread deltaic advances. These deltaic deposits prograded southward across the Cherokee platform into the basins farther south. By late Demoinesian time, deltaic deposition from the north became subdued by longer periods of marine advance, and the southern Mid-Continent area periodically became a broad carbonate shelf (Moore, 1979).

Cherokee Group

In eastern Kansas, the Cherokee Group is the lowest major division of the Desmoinesian Stage and consists of all Pennsylvanian beds between the base of the Fort Scott Limestone and top of the Mississippian (Merriam, 1963; Zeller, 1968). Lithologically, the group is composed mostly of shale, sandy shale, some sandstone and coal beds, along with rare, thin, limestone beds. Thickness of the Cherokee Group in southeastern Kansas is variable, but commonly ranges from about 107 meters (350 feet) to about 122 meters (400 feet) (Jewett, 1954).

Zeller (1968) summarized the present nomenclature of the Cherokee Group in Kansas (Fig. 2). The Cherokee Group is separated into two formations, the Krebs and Cabaniss, which are not easily divisible in the subsurface. From surface exposures in southeastern Kansas, Howe (1956) made this separation at the top of the Seville(?) Limestone. Howe also stated, that for practical purposes because the Seville(?) Limestone is absent in most places, the top of the Bluejacket Sandstone member may be regarded as the upper boundry of the Krebs Formation (Zeller, 1968). Ebanks and others (1977) further subdivided the Cherokee Group in southeastern Kansas into sandstone-bearing horizons on the basis of key marker-beds (Fig. 2) that are tracable into the subsurface and identifiable on geophysical well-logs.

Bluejacket-Bartlesville Sandstone

Problems with correlating the discontinuous sandstones of the Cherokee Group have resulted in cases where two or more names have been applied to the same or equivalent formations (Jewett, 1954). The Bluejacket-Bartlesville Sandstone is an example. Weirich (1968) related the discovery and development of the "Bartlesville Sand" to a well drilled in Wilson County, Kansas in 1892. In 1897, two wells were completed in or near Bartlesville, Oklahoma that produced from a sandstone "in about the same stratigraphic

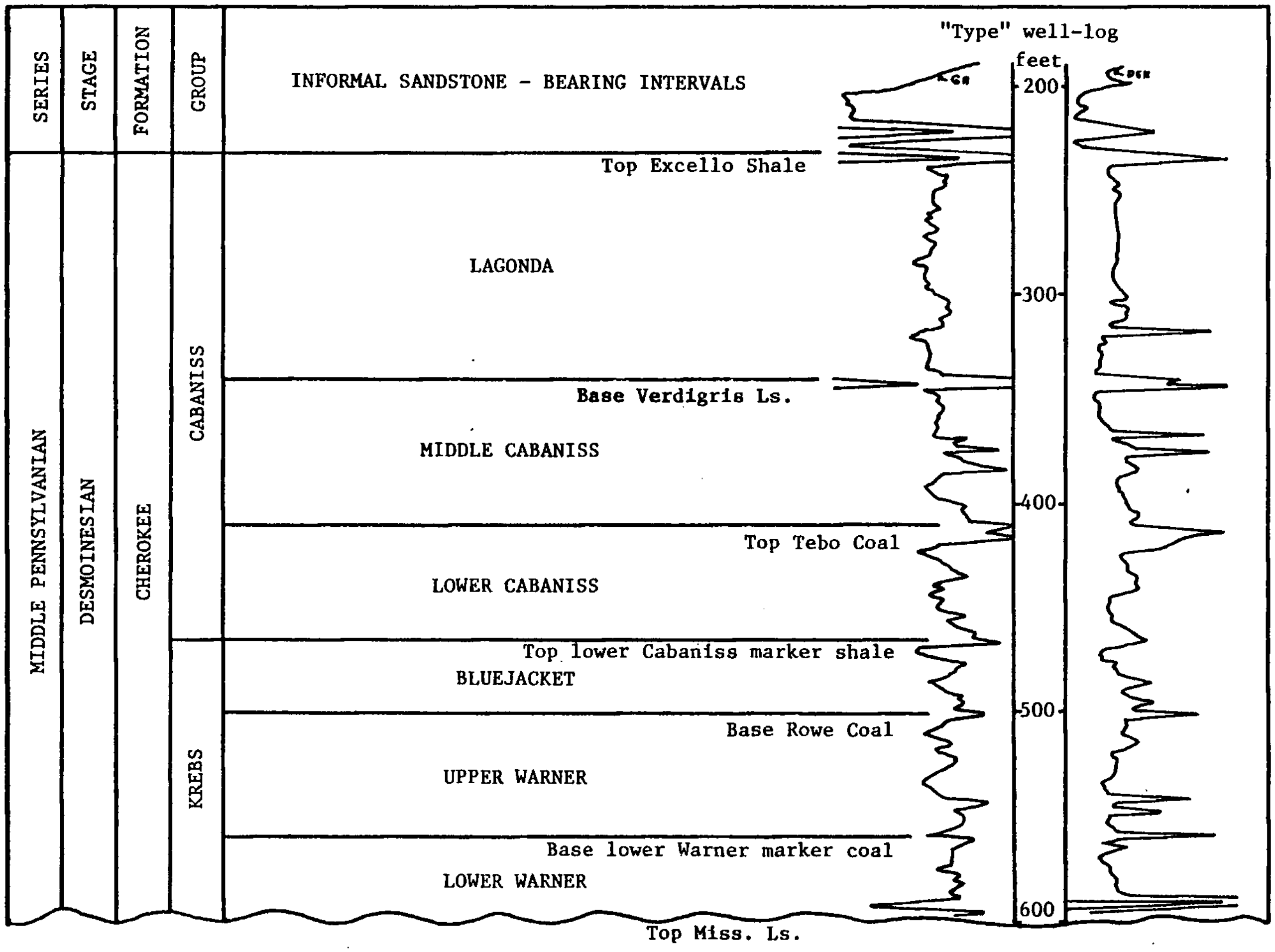

Figure 2. Subdivisions of the Cherokee Group in Kansas and stratigraphic intervals identified on "type" gamma-ray-density well-log. Cherokee Group subdivisions from Zeller (1968), "sandstone-bearing" intervals and well-log from Ebanks and others (1977).

horizon". Weirich (1968) also stated that the name "Bartlesville Sand" first appeared in the literature in Bulletin IX, Oklahoma Geological Survey in 1913. In eastern Kansas, the name "Bartlesville Sand" is a common name applied to any of several sandstone bodies that occur in the Cherokee section below the Verdigris Limestone (Jewett, 1954).

The Bluejacket Sandstone was originally described by D. W. Ohern in 1914, (Howe, 1956) and later redefined by Howe (1951) from exposures west of Bluejacket, Oklahoma. Howe correlated the "type Bluejacket" to exposures in southeastern Kansas and suggested that the persistent sandstone of the subsurface in southeast Kansas, commonly called "Bartlesville", was apparently the Bluejacket. Ebanks and others (1977) and Ebanks (1979b) recognized the existence of two horizons of Bluejacket Sandstone and introduced the informal terms "upper" and "lower" Bluejacket. The "upper Bluejacket" is distributed in a southwesterly trend across Bourbon, Crawford, and Cherokee Counties, Kansas (Fig. 3). The thickness varies from 0 to 6.5 meters (20 feet) and generally is thickest toward the southwest. Incomplete exposures near the Kansas-Oklahoma border have made correlations difficult, although Ebanks (1979b) has shown the the "upper Bluejacket" is more continuous with the "type Bluejacket" of Oklahoma, whereas

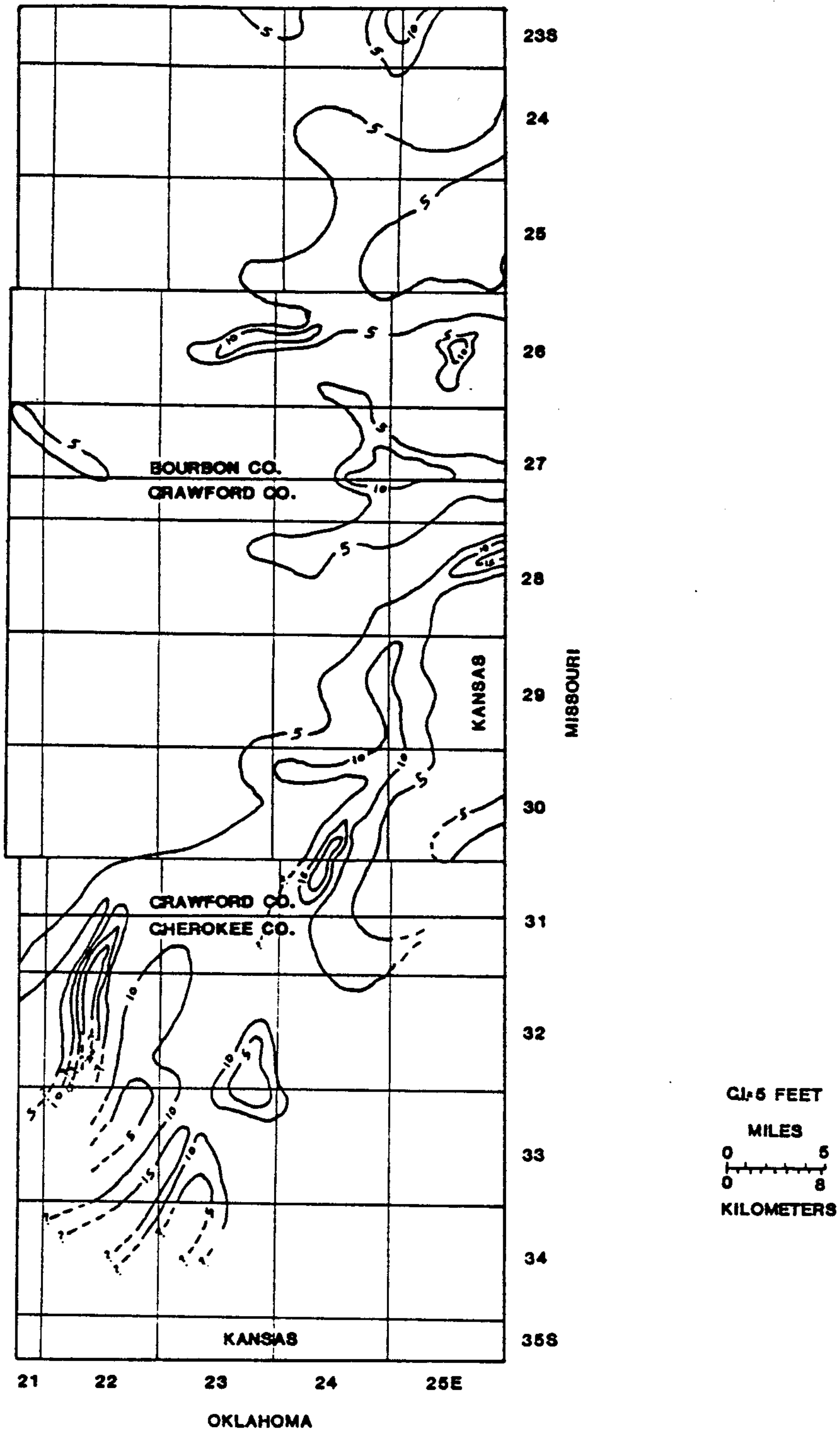

Figure 3. Subsurface distribution of "upper Bluejacket" Sandstone in southeastern Kansas. (From Ebanks and others, 1977).

the "lower Bluejacket" is best developed in eastern Bourbon and Crawford Counties in Kansas, and is continuous with exposures in Missouri.

Purpose

The Cherokee Basin in southeastern Kansas has been of economic interest since oil was discovered there in 1873 (Oros, 1979), and continues to be explored due to recent price incentives for oil and gas (Ebanks and others, 1977). A heavy-oil study in Bourbon, Crawford, and Cherokee Counties, Kansas (Ebanks and others, 1977) encountered "upper Bluejacket" sandstone in several wells. Five of these sandstone-rich intervals were cored and sampled by the Kansas Geological Survey for geochemical analyses of the interstitial fluids. Porosity, permeability, and fluid saturations were also measured in that study. The primary objectives of the present study are to describe the petrographic characteristics and interpret the diagenetic history of the "upper Bluejacket" Sandstone of southeast Kansas.

Ebanks and others (1977) provided a good understanding of Cherokee stratigraphy in southeastern Kansas using key marker-beds to correlate units in the subsurface. A third objective of this investigation is to determine the distribution and stratigraphy of the Bluejacket Sandstone in the subsurface, between the Cherokee outcrop belt and the Nemaha Uplift, using the marker-defined unit. Combining the data from this study with published data made possible an interpretation of both the depositional environment of the Bluejacket and the probable source of siliciclastic materials.

Location

The principal area of interest for this study is within Bourbon, Crawford, and Cherokee Counties in southeastern Kansas. To determine the distribution of the Bluejacket Sandstone in the subsurface, the study area was extended westward to Range 1E. and restricted to the counties in eastern Kansas south of Township 23S. Figure 4 is an index map of the study area that shows the location of cores used for petrologic study of the "upper Bluejacket" Sandstone and the well-log control used to correlate the Bluejacket in the subsurface and determine sandstone distribution in the Cherokee Basin.

Previous Investigations

The depositional environments of the Bluejacket Sandstone in Oklahoma have been studied in detail by Visher and others (1968, 1971), who were able to delineate several subenvironments within a greater deltaic complex. Hayes (1963) studied the petrology and depositional environments

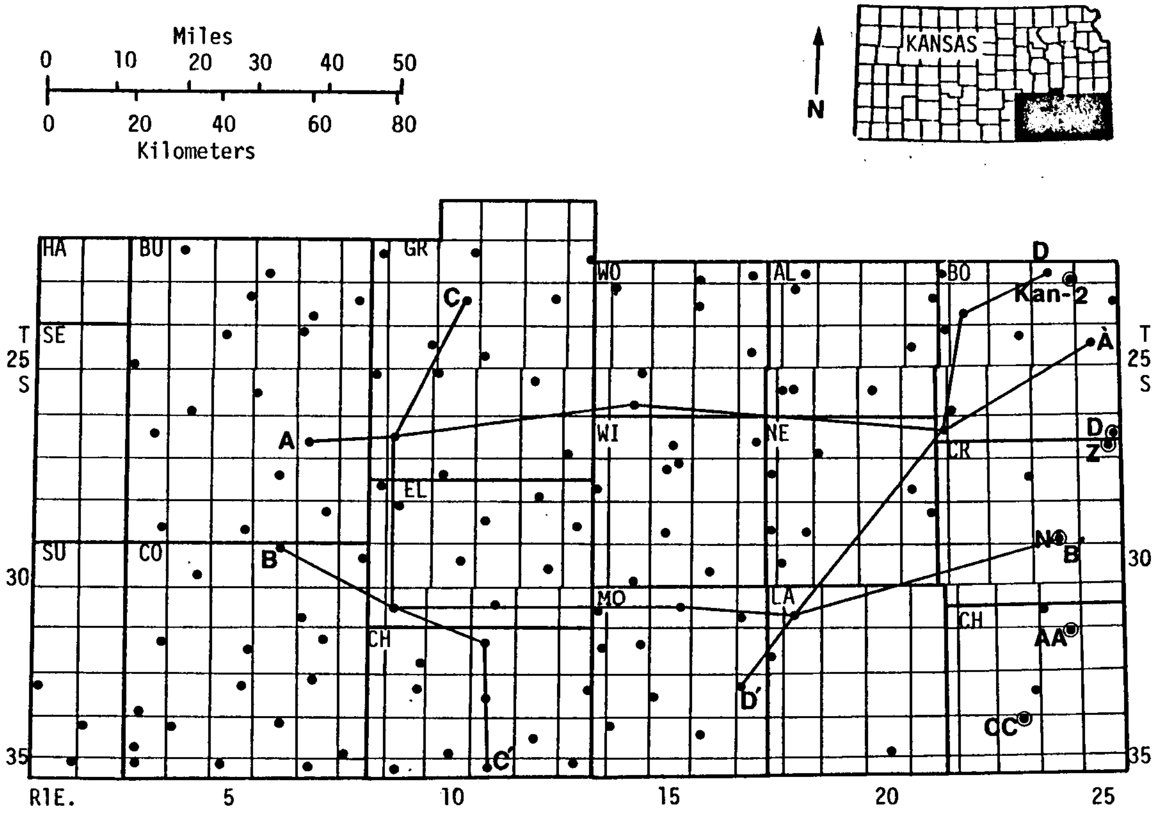

Figure 4. Location map of study area. Cores used in this study are Kansas Geological Survey test holes (K.G.S.) D, N, Z, AA, CC, and Shell corehole Kan-2, indicated by ◉. Geophysical well-log control used to correlate the Bluejacket interval and determine sandstone distribution in the subsurface is indicated by ●. Lines A-A', B-B', C-C', and D-D' show positions of cross-sections in Figures 8, 9, 10, and 11.

of sandstones of the Krebs Group in Missouri, and concluded that those sandstones were largely of tidal-flat origin. Bartlesville shoestring sandstones in Greenwood and Butler Counties, Kansas have been interpreted as barrier-bars (Bass, 1936), and alluvial channel-fills (Hulse, 1979). Jewett (1954) discussed the use of the term "Bartlesville Sand" and its stratigraphic position in eastern Kansas. Weirich (1953) and Bennison (1979) related the principles of shelf sedimentation to the sandstones of Oklahoma and Kansas.

Ebanks and others (1977) provided the basis for this study as they investigated the occurrences of heavy-oil in lower Cherokee sandstones in Bourbon, Crawford, and Cherokee Counties, Kansas. Ebanks (1979b) correlated lower Cherokee sandstones in the Tri-State area of Kansas, Missouri, and Oklahoma, which had previously been miscorrelated because of incomplete exposures and irregular distribution over the area. Woody (1982) examined selected Cherokee sandstones in southeast Kansas and found diagenetic alterations similar to those in Pennsylvanian sandstones in north-central Texas and Tertiary sandstones of the Gulf Coast.

Methods of Study

Field studies were conducted over a five month period beginning in May, 1981 to observe the distribution and occurrence of the "upper Bluejacket" Sandstone at outcrops in the study area. During that time, cores from six wells were studied and described in detail (Appendix) for identification of sedimentary structures and for sampling for thin-section analyses. Outcrop and core descriptions were used for interpreting lithologies and for correlating geophysical well-logs. Gamma-ray--density logs are available for all of the cores, except Kan-2. Tracing the Bluejacket interval in the subsurface was accomplished using approximately 125 gamma-ray and electric well-logs (located on Fig. 4) supplied by the Kansas Geological Survey. An interpretation of the depositional environment of the Bluejacket Sandstone was made by studying the sandstone geometry and distribution, which were determined by constructing cross-sections and a sandstone isolith map (Shelton, 1973).

Samples for thin-section studies were collected from cores at one-foot intervals, and also where distinct changes in lithology or structure occurred. From the 11.3 meters (37 feet) of core studied and sampled, 57 thin-sections were prepared for petrologic analysis. Chips cut from cores that were heavily stained with oil were cleaned using a soxhlet extractor and a heavy-oil solvent, tetrahydro-naphthalene, at the Tertiary Oil Recovery Project at the University of Kansas. This allowed for removal of oil and easier identification of grains. Cleaning was not complete, however, and may have led to erroneous or anomalous identification of clay matrix, cements, and organics. Sandstone chips were then impregnated with blue-dyed epoxy to aid in recognition of interconnected pore space and dissolved grains. Selected thin-sections were stained with Alizarin Red-S and Potassium Ferricyanide to identify carbonate cements.

Modal analyses of 24 thin-sections were carried out using 200 grid points per thin-section on a mechanical stage. The diagenetic history of the "upper Bluejacket" Sandstone was determined by observing grain-to-grain, grain-to-cement, and cement-to-cement relations in the thin-sections. The petrographic microscope served as the primary tool in this investigation. X-ray diffraction analysis, the Scanning Electron Microscope (SEM), and the cathodoluminoscope were used to support the petrographic observations.

STRATIGRAPHIC AND DEPOSITIONAL FRAMEWORK

Lower Cherokee sandstones in southeastern Kansas have been interpreted to have been deposited by the repeated extension and shifting of thin, alluvial-deltaic complexes across the shelf (Ebanks and others, 1977; Heckel and others, 1979; Ebanks, 1979a and 1979b). Each extension resulted in lobes or belts of sandy deposits prograding into and over earlier floodplain or delta-fringe environments, which resulted in repetitive, or "cyclic", lithologies being deposited. In southeast Kansas, this idealized "cyclic" sequence of genetically related lithologies of the lower Cherokee Group has been suggested: (in upward sequence) dark marine shale with rare limestone -- gray sideritic shale -- gray silty shale with sandstone interbeds -- rare cross-bedded sandstone -- thin bedded sandstone, siltstone and shale, underclay (Heckel and others, 1979). In Oklahoma, the deltaic environments of the Bluejacket-Bartlesville (Figs. 5 and 6) are thought to represent three episodes of progradation (Visher and others, 1971; Shelton, 1973; Bennison, 1979). Considering this type of depositional environment, models of alluvial and deltaic environments

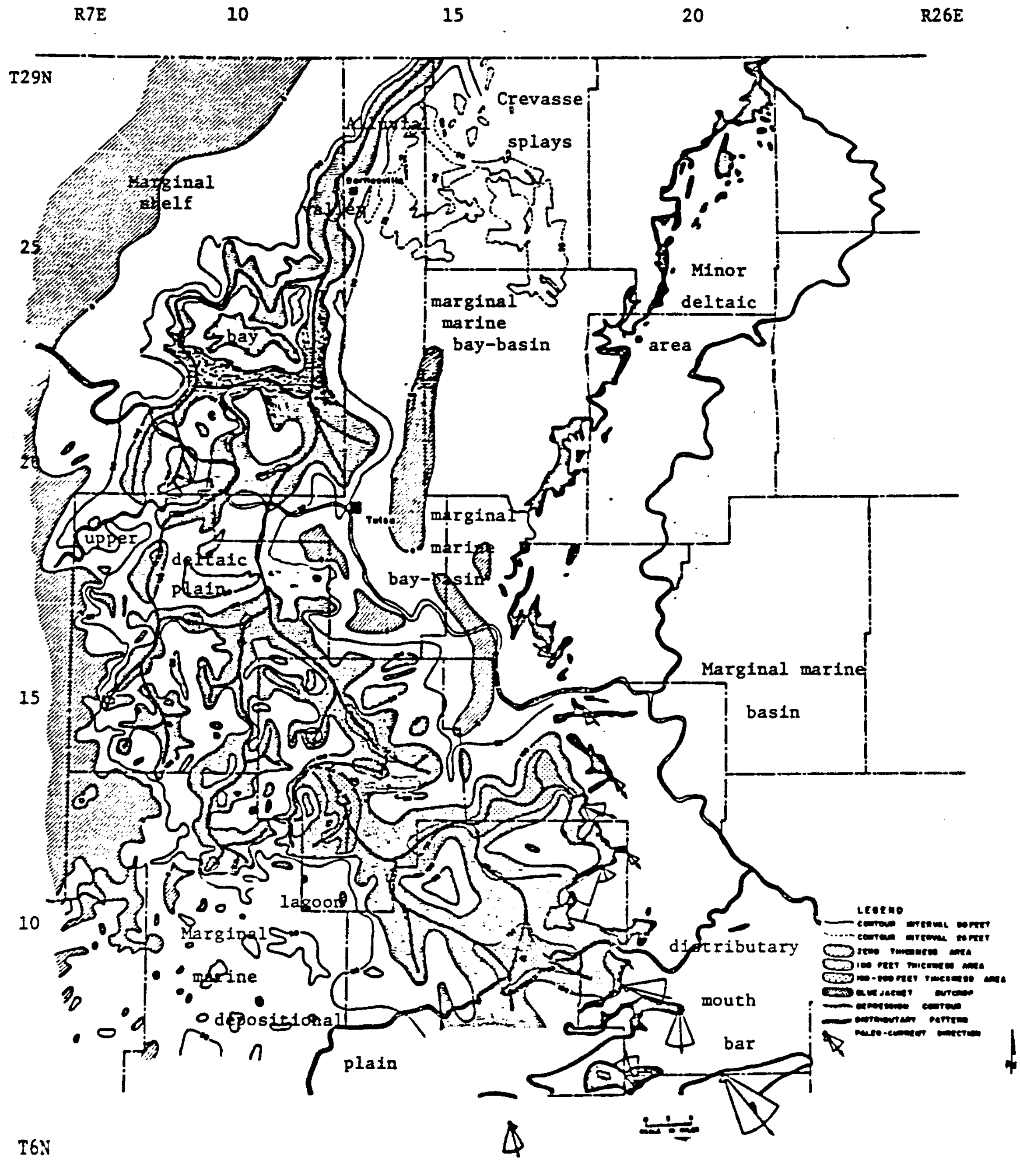

Figure 5. Sandstone distribution of Bartlesville Sandstone in Oklahoma. Map shows environmental reconstruction of deltaic elements based on sandstone geometry, vertical sequences, sedimentary structures, textures, clay mineralogy, and E-log patterns. (Modified from Visher and others, 1971).

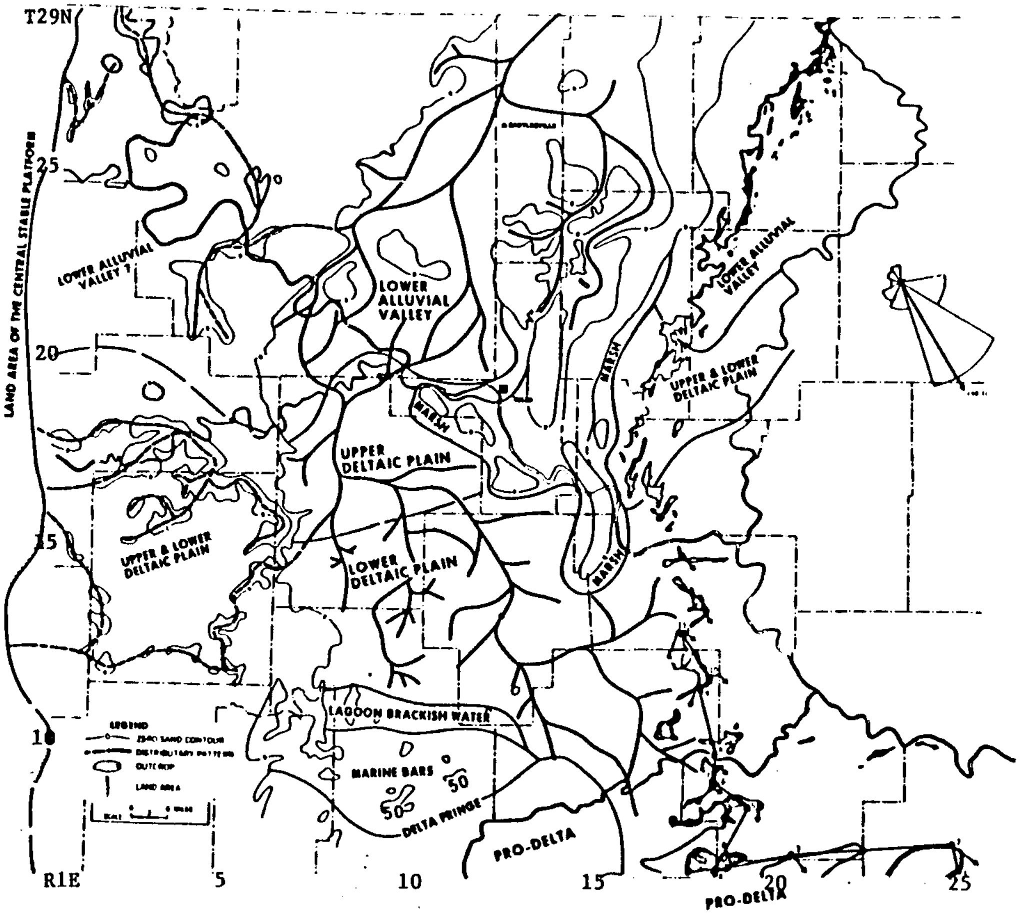

Figure 6. Paleogeographic reconstruction of the Bluejacket-Bartlesville fluvial-deltaic system in northeastern Oklahoma. (From Visher, 1968).

will be briefly examined, with emphasis on vertical and lateral lithologic associations that can be recognized on well-logs. Lithology is interpreted in a gross sense (i.e., sand, shale) because detailed lithologies such as silty sand, sandy silt, clayey silt, silty clay, clay, etc., cannot be recognized from well-logs.

Depositional Models

The major features of an alluvial plain are its stream patterns, point bars, natural levees, and floodplain deposits. The migrating channel of a meandering river deposits point-bars that are characterized by a fining-upward sequence of sediments with an abrupt basal contact. Natural levees are composed of overlapping splay deposits formed during floods and show a vertical sequence of poorly sorted silts and sands. On low-lying areas of the floodplain, fine muds containing silty or sandy laminae deposited during floods may be interbedded with peat or coal and may pass up to coarser-grained splay or levee deposits. Crevassing may occur during floods and form lobate delta-like appendages to the main body (Pettijohn and others, 1973; Blatt and others, 1972). Table 1 summarizes many of the characteristics of alluvial sand bodies. The vertical sequence that is most common to alluvial sands is medium-to-thick-bedded, coarse-grained sands, overlain by thin-bedded

Table 1. Characteristics of alluvial sands. (From Pettijohn and others, 1973; originally from Potter, 1967).

PETROLOGY

Detrital. Abundant shale pebbles and shale-pebble conglomerates. Generally carbonaceous debris. Petrographically immature to moderately mature. Pebbles and cobbles, if present, may be both local and distal. Detrital plus chemical cements. Faunal content low to absent.

TEXTURE

Poor to moderate sorting and moderate to low grain-matrix ratio. Abundant silt in fine-end tail. Tendency to poor rounding. High variability.

SEDIMENTARY STRUCTURES

Asymmetrical ripple marks and abundant well-oriented crossbedding, commonly unimodal. Parting lineation and deformational structures are common minor accessories. Beds tend to be lenticular with erosional scour. Some tracks and trails.

INTERNAL ORGANIZATION

Strong asymmetry. Upward decrease in grain size and bed thickness, possibly with conglomerate near base. Larger channel-fill sandstone bodies tend to be coarser-grained than smaller ones.

SIZE, SHAPE, AND ORIENTATION

Commonly very elongate. Width ranges from a few tens of feet to composites of 30 miles. Dendritic as well as anastomosing and bifurcating patterns. Elongate downdip. Excellent correlation of internal directional structures and elongation.

ASSOCIATED LITHOLOGIC TYPES

Vertical: overlying silty shales, commonly of alluvial origin. Possible peat and coal. Basal contact commonly sharply disconformable. Multistory sandstone bodies. Marine units in mixed sections.
Lateral: silty shale and siltstone commonly with abundant carbonaceous material as well as roots, leaves, and stems. Multilateral sandstone bodies. Correlation generally difficult.

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and finer-grained sands and silts. Gamma-ray well-log signatures reflect this sequence by showing a sharp basal deflection of low gamma-radiation with an increase in radiation upward (Fig. 7A), which corresponds to an increase in shaley sediments. Floodplain deposits of silty or sandy mud show a high gamma-radiation, interrupted by thin, sharp, deflections of low gamma counts (Fig. 7B) that may indicate sand deposited by crevasse splays, or thin limestones deposited in bays or inland lakes.

Deltaic deposits are very similar to alluvial deposits, but deltas are complex systems, and several subdivisions of the delta model are needed to represent it adequately. Scott and Fisher (1969), for example, identified 20 distinct depositional environments and resulting facies in the Mississippi delta system. Scott and Fisher (1969) stated that progradation and bifurcation of distributary channels are among the most important and characteristic processes in the formation of deltas. Crevasse splays commonly form new distributary channels by avulsion and account for the extensive growth of the subaerial deltaic plain. Elongate bar-finger sands that form the framework of the delta display a coarsening-upward sequence overlying delta-front or prodelta muds (Pettijohn and others, 1973). On a gamma-ray log, this is indicated by a transitional, serrated lower boundary with decreasing radiation upwards (Fig. 7C),

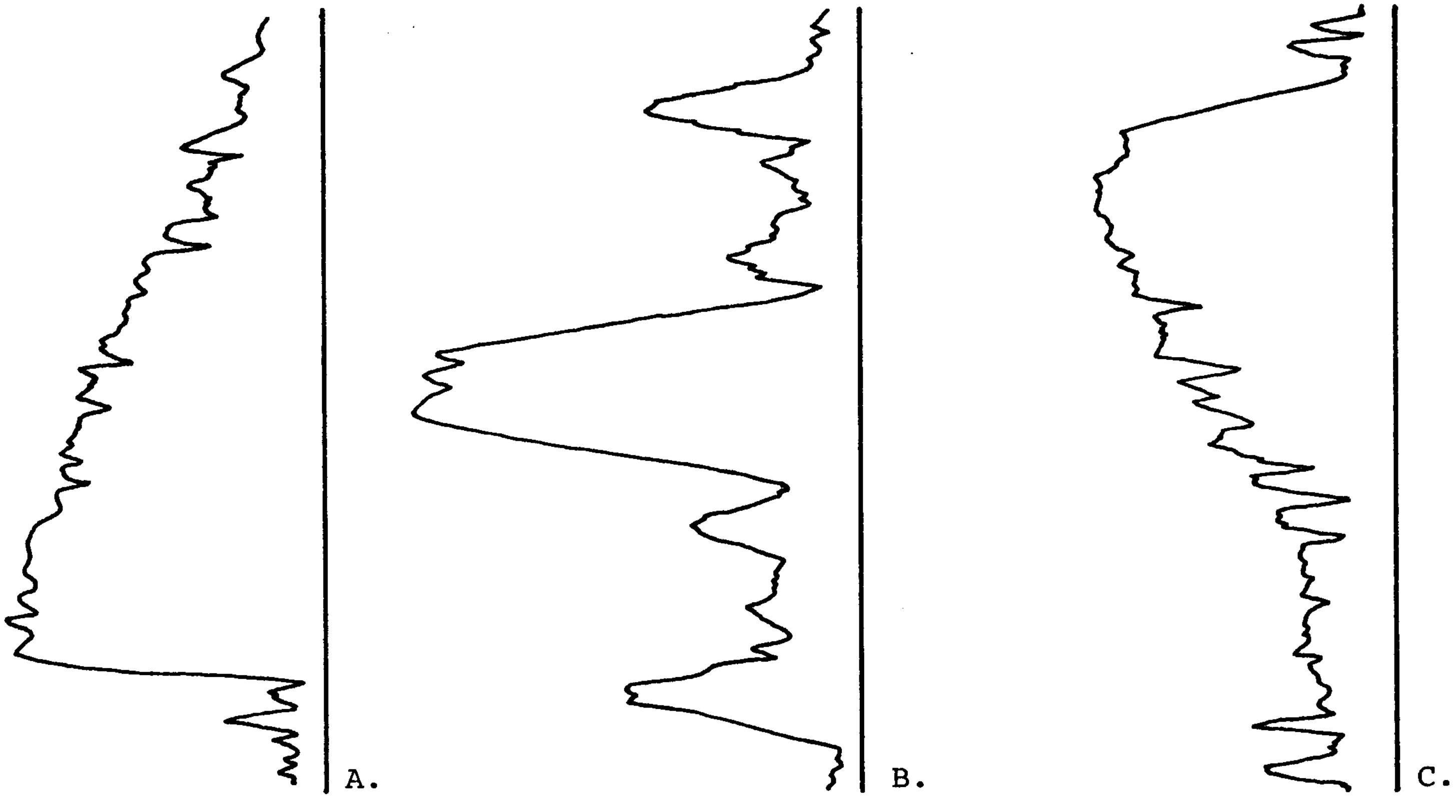

Figure 7. Lithologic interpretation of gamma-ray logs. A. An increase in gamma radiation upward indicates an increase in shaley sediments. Sharp basal deflection and fining-upward sequence suggest point-bar sandstone. B. A serrated log pattern indicating thin, interbedded shaley sediments. Low gamma counts could indicate thin limestones, sandstones, or coal. C. An upward decrease in gamma radiation indicates transition from shaley sediments up to coarser, thicker-bedded sandstone. Gradational basal contact and abrupt upper contact with shaley sediments suggest near-shore marine (barrier-bar, bar-finger, etc.) or delta-front sandstone. These interpretations are more definitive if additional data (associated lithologies, paleontology, sedimentary structures, etc.) are available.

showing the transition from mud to coarser, less shaley, sands. The upper boundary is usually sharp, and thin coals and limestones may overlie the sand body. Delta-plain deposits are similar to alluvial floodplain deposits and usually contain abundant swamp deposits of coal and thin limestones that were deposited in inland bays and low-lying land areas transgressed by the nearby sea. Due to progradation and delta switching, fluvial and marine-shelf sand bodies are usually interbedded with deltaic deposits (Pettijohn and others, 1973).

Stratigraphic Correlation

Well-to-well log-correlation studies permit accurate subsurface mapping of formations present in the wells and for correlation to outcrops. Standard lithology logs such as the spontaneous potential, or SP, which correlates on differences between permeable beds vs. shale beds, and gamma-ray, which correlates on radioactivity associated with shaliness, are used for correlation. For best correlation, the log should respond to some property of the stratum that does not vary much from well-to-well. Black shales within the Cherokee Group have a natural high radioactivity caused by high concentrations of uranium. The typical gamma-ray response to these radioactive black shales is to show maximum deflection to the right (high gamma-ray count) of the log, commonly going off-scale at least once, and sometimes twice, depending on the calibration of the recording tool. These black shales make excellent markers for correlation as they are tracable laterally throughout the Cherokee Basin. Ebanks and others (1977) and Ebanks (1979b) selected black shales as marker-beds to correlate sandstone-bearing intervals within the Cherokee Group over Bourbon, Crawford, and Cherokee Counties, Kansas. The discontinuous nature of the sandstones in the Cherokee section hinders correlation of individual sandstone units over distances of more than a few square miles. Laterally persistent limestones that occur in the Cherokee Group are difficult to use as marker-beds because they are commonly below well-log resolution (less than about two feet thick).

The Bluejacket sandstone interval is of primary interest in this study,although sandstones occurring within this interval in the subsurface of southeast Kansas are known as "Bartlesville" sandstones. The discontinuous nature of the "Bartlesville" sandstones has confused stratigraphers for years and has resulted in miscorrelation of individual sandstone bodies that occur throughout the Cherokee Basin. Jewett (1954) for example, stated "as used now the name 'Bartlesville' may mean any of several sandstone bodies that occur in the Kansas Cherokee section below the Verdigris Limestone". Therefore the use of widely tracable marker-beds identifiable on well-logs (black shales) provide a more reliable correlation marker than do individual sandstones. The marker-beds used by Ebanks and others (1977) to define the Bluejacket interval are (for the upper boundary) "approximately the dividing point between the Cabaniss and Krebs Formations, actually the top of a radioactive black shale which is probably within the upper Cherokee, or Cabaniss, section and which is called the lower Cabaniss marker . . . and (for the lower boundary) the base of the Rowe Coal". This interval is shown on the well-log in Figure 2. Ebanks and others (1977) suggested that the marker-beds may not be tracable outside of their study area and that other marker-beds may need to be defined. It was found that a persistent shale underlying the Bluejacket Sandstone was more easily recognized than was the Rowe Coal.

To correlate the Bluejacket sandstone interval, it was first necessary to correlate the entire Cherokee group by comparing well-logs to one another and matching for similarity, and for characteristic log responses to lithologic markers. The Excello shale, which marks the upper boundary of the Cherokee Group, and the Little Osage shale member of the overlying Fort Scott Limestone Formation, provide easily recognized responses on gamma-ray logs (Fig. 2). The lower boundary is easily recognized by the thick Mississippian limestone section contrasting with the predominantly shales and interbedded thin sandstones of the Cherokee Group, and is recognized as an erosional surface. The logs used by Ebanks and others (1977) provided the starting point for correlation. Working westward across the basin, other logs were correlated to the logs used in that heavy-oil study. Several log cross-sections were constructed to illustrate the correlation of the radioactive black shale marker-beds and sandstone-bearing intervals of the Cherokee Group in general, and the Bluejacket sandstone interval in particular. Well-logs for these cross-sections were selected to give a representative view of the Bluejacket sandstone interval throughout the Cherokee Basin. Where possible, logs used by Ebanks and others (1977) were included in the cross-sections to assure accuracy when correlating the sandstone-bearing intervals. The stratigraphic horizon used as a datum is the top of the Excello Shale.

Cross-Section A-A'

Cross-section A-A' (Fig. 8) consists of six wells that represent an east-west cross-section of the Cherokee Basin, extending eastward from Range 7W. to Range 25W. (Fig. 4). All of the well-logs illustrate the easily correlated radioactive black shale marker-beds, which are continuous across the basin. The basin geometry shown in cross-section

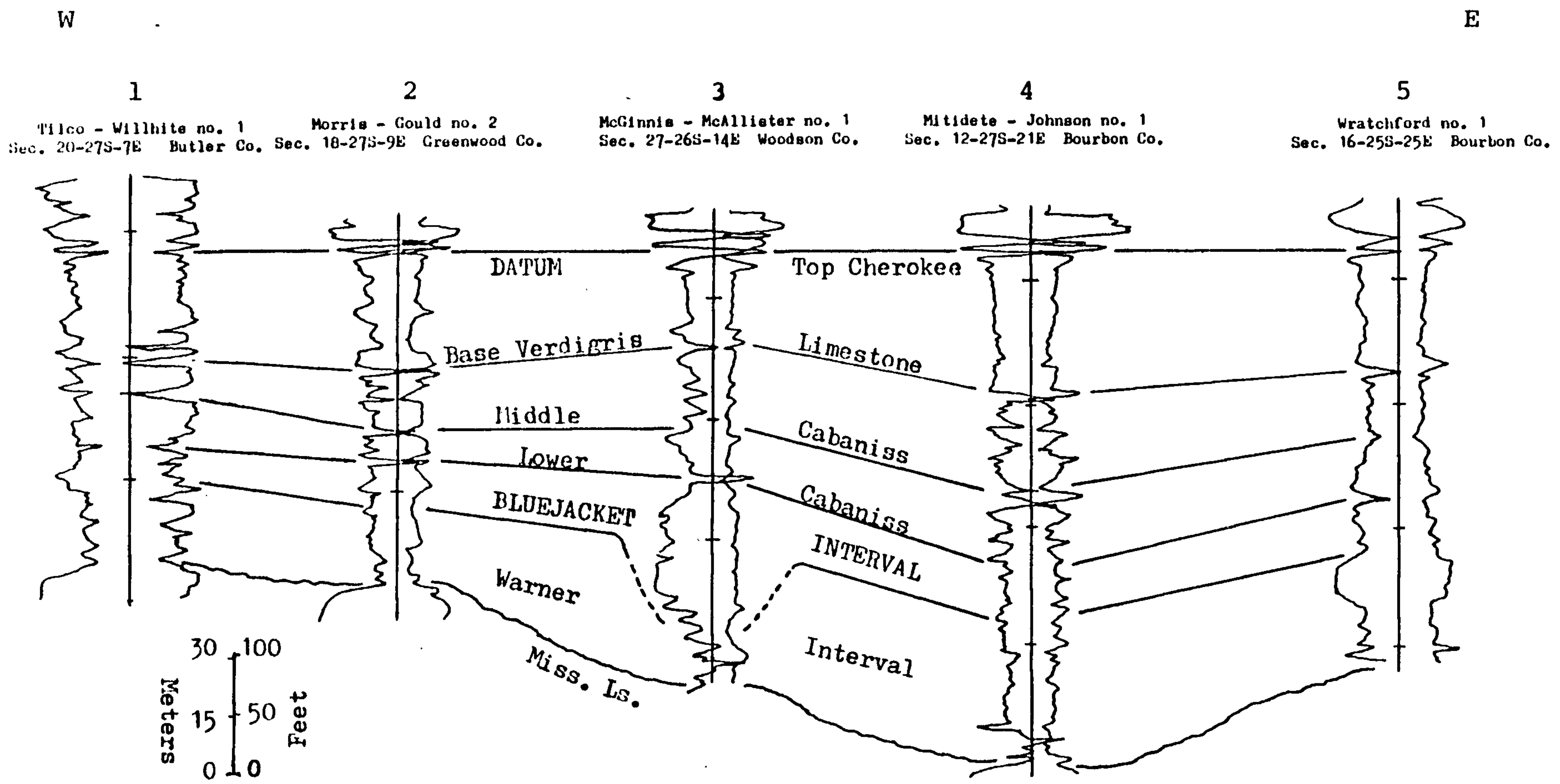

Figure 8. Cross-section A-A'. Consult Figure 4 for location, orientation and horizontal scale.

A-A' reflects pre-existing structural features. The Cherokee Group thins westward (toward wells numbered 1 and 2), which coincides with the Nemaha Uplift (Fig. 1) and the smaller Beaumont Anticline (Merriam, 1963, p. 184). Located in the extreme western part of the study area, the Nemaha Uplift was a positive area during Cherokee sedimentation, upon which apparently few, if any, sediments accumulated and where the Cherokee section thins to practically nothing. This cross-section shows the Cherokee section thickest in the eastern part of the basin, near the southwest corner of Bourbon County (well no. 4). The thinner section in northeastern Bourbon County (well no. 5) probably reflects the presence of the Bourbon arch (Fig. 2), which appears to have had little effect on the Bluejacket interval or intervals stratigraphically higher.

The Bluejacket interval does not vary much in thickness, but all of the stratigraphic intervals generally thicken where sandstone is present and thin where there is no sandstone in the interval, perhaps due to compaction of shales. Well-log signatures indicate that thin sandstones are present in each well, with the thickest sandstone occurring in well no. 3. Individual sandstones are usually less than about 10 feet thick, and are discontinuous over distances of more than a few square miles. Sandstones within the Bluejacket interval are generally higher in the interval in the eastern part of the basin, and stratigraphicly lower towards the west. Sandstones are multi-story and occur in roughly three stratigraphic positions within the Bluejacket interval, which supports the interpretation by Bennison (1979) and others that three episodes of progradation occurred during Bluejacket sedimentation.

Cross-Section B-B'

Cross-section B-B' (Fig. 9) is an east-west cross-section across the southern part of the Cherokee Basin (Fig. 4) and shows characteristics similar to those in cross-section A-A' (Fig. 8). The Cherokee section is thinnest in the western part of the basin, but thickens dramatically between wells 7 and 8. Thin Cherokee sections in wells 6 and 7 reflect pre-existing structures, as well no. 6 coincides with the Beaumont Anticline and well no. 7 is located on the Dexter-Otto Anticline (Merriam, 1963, p. 184), which appear to have affected Warner sedimentation more than the other stratigraphic intervals.

The Bluejacket interval is essentially the same thickness across the entire cross-section, except for well no. 8. Sandstones in the Bluejacket interval are multi-story and multi-lateral, as in cross-section A-A', with the thickest sandstones occurring in well no. 8. The thick

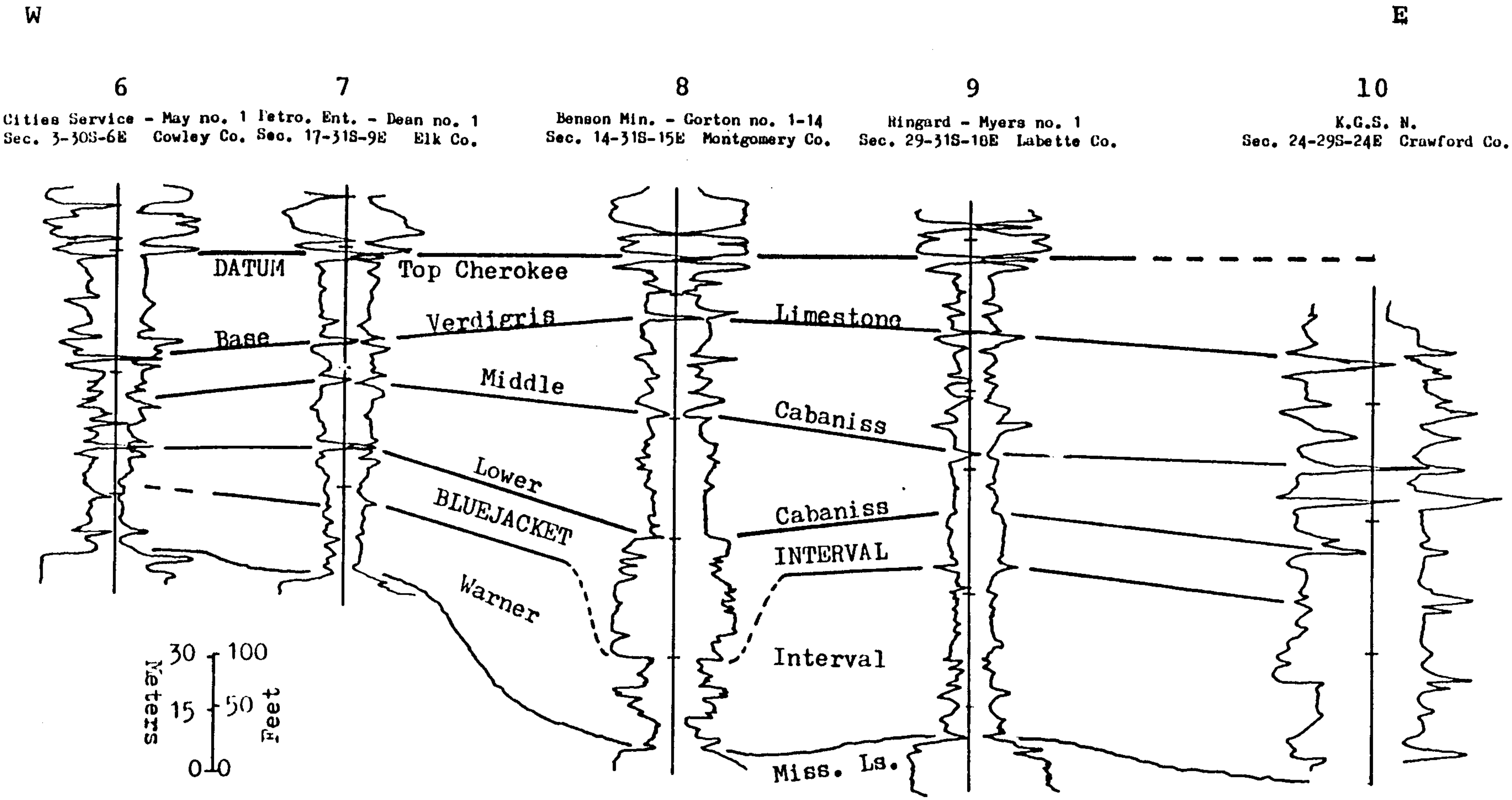

Figure 9. Cross-section B-B'. Consult Figure 4 for location, orientation and horizontal scale.

Cherokee section in well no. 10 (compared to well no. 5 in Fig. 8), located in central Crawford County, illustrates the thickening of the Cherokee section toward the south, as noted by Ebanks and others (1977, p. 7).

Cross-Section C-C'

Cross-section C-C' (Fig. 10) is a north-south cross-section of the western part of the basin, extending from Township 24S. south to Township 35S. (Fig. 4). Wells 2 and 7 appeared in cross-sections A-A' and B-B', respectively. Wells 7, 12, and 13 show the gradual thickening of the Cherokee section toward the south, which is contrasted with the abrupt thickening toward the east near the center of the basin as illustrated in cross-sections A-A' and B-B'. This is due in part to the cross-section following the axes of two minor anticlines (shown in wells 2 and 7) mentioned previously. The northward thickening of the section in well no. 11 suggests that these structures may be absent in the northeast part of the basin.

In the Bluejacket interval, sandstones are thin, multi-story, and multi-lateral. Sandstones are generally present in the upper two-thirds of the interval, which is still essentially the same thickness across the western part of the basin. Thick sandstone, as seen in wells 3 and 8, is absent in this cross-section. This suggests that the

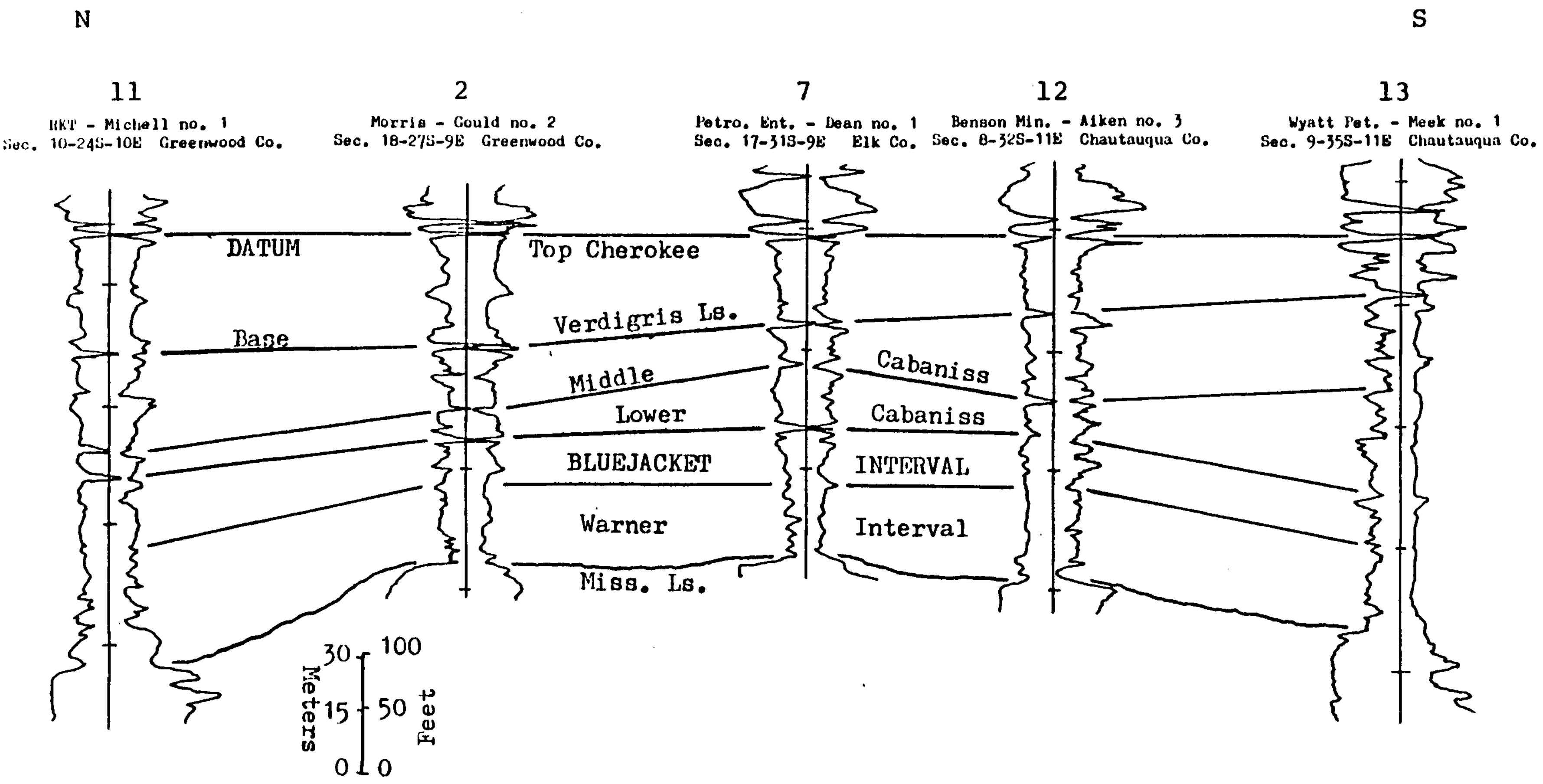

Figure 10. Cross-section C-C'. Consult Figure 4 for location, orientation and horizontal scale.

deepest part of the basin, located to the east of this cross-section, contains the thickest sandstone, possibly representing the more fluvial aspect of the prograding sediments that filled in topographic lows in the pre-existing surface.

Cross-Section D-D'

Cross-section D-D' (Fig. 11) is a northeast-southwest cross-section across the eastern part of the basin (Fig. 4), extending from Township 23S.-Range 24E. to Township 33S.-Range 17E. Wells 4 and 9 appeared in cross-sections A-A' and B-B', respectively. Wells 14 and 15 illustrate the thinner Cherokee section in the presence of the Bourbon Arch, as seen in well no. 5. The Cherokee section thickens toward the south, as noted earlier, indicated by well no. 16. As in cross-section C-C', there are usually only two sandstones in the Bluejacket interval, best illustrated in wells 14, 15, and 16. The sandstones within the Bluejacket interval are thin, multi-story, and multi-lateral across the eastern part of the basin.

Stratigraphic Summary

Some of the characteristics illustrated by the previous cross-sections are; 1) thinner Cherokee sections occur over minor structures in the western and northeastern parts of the basin; 2) lowermost Cherokee sediments appear to have

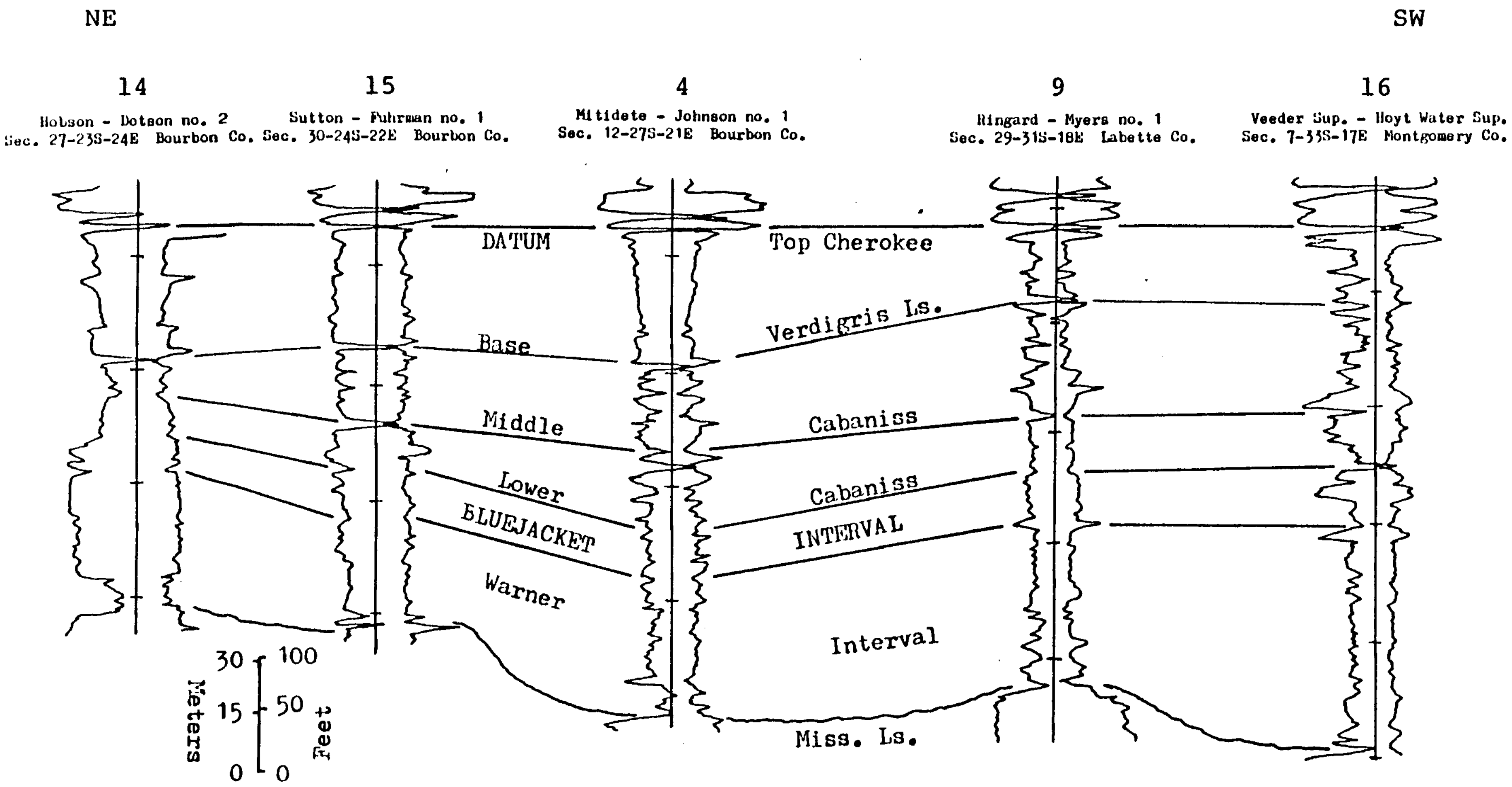

Figure 11. Cross-section D-D'. Consult Figure 4 for location, orientation and horizontal scale.

filled in most of the irregularities of the pre-existing surface during initial deposition. This left only slight irregularities which allowed middle and upper Bluejacket sandstones to be deposited over a more extensive area. 3) the thickness of the Bluejacket sandstone interval does not vary significantly across the basin, except for wells 3 and 8, which indicates that this unit was deposited upon almost a flat surface; 4) the Bluejacket sandstones are usually thin, multi-story and multi-lateral, with one or two sandstones most commonly seen on well-logs; and 5) the thickest sandstone is present near the center of the study area, which coincides with a thicker Cherokee section.

Sandstone Distribution

The gross sandstone isolith map (Fig. 12) is used to interpret the trend (that element of sand body geometry that defines sand length in geographic terms) and distribution of the Bluejacket Sandstone across the Cherokee Basin. The sandstone isolith represents more than ten feet of sandstone present within the Bluejacket interval, indicated by the SP curve of the electric logs and the gamma-ray curve of the gamma-ray logs. A distance greater than one-half of the way out from the shale line was chosen as representing mostly sand. The sandstone isolith also combines published data from Weirich (1953), and Jewett (1954) (which is assumed to

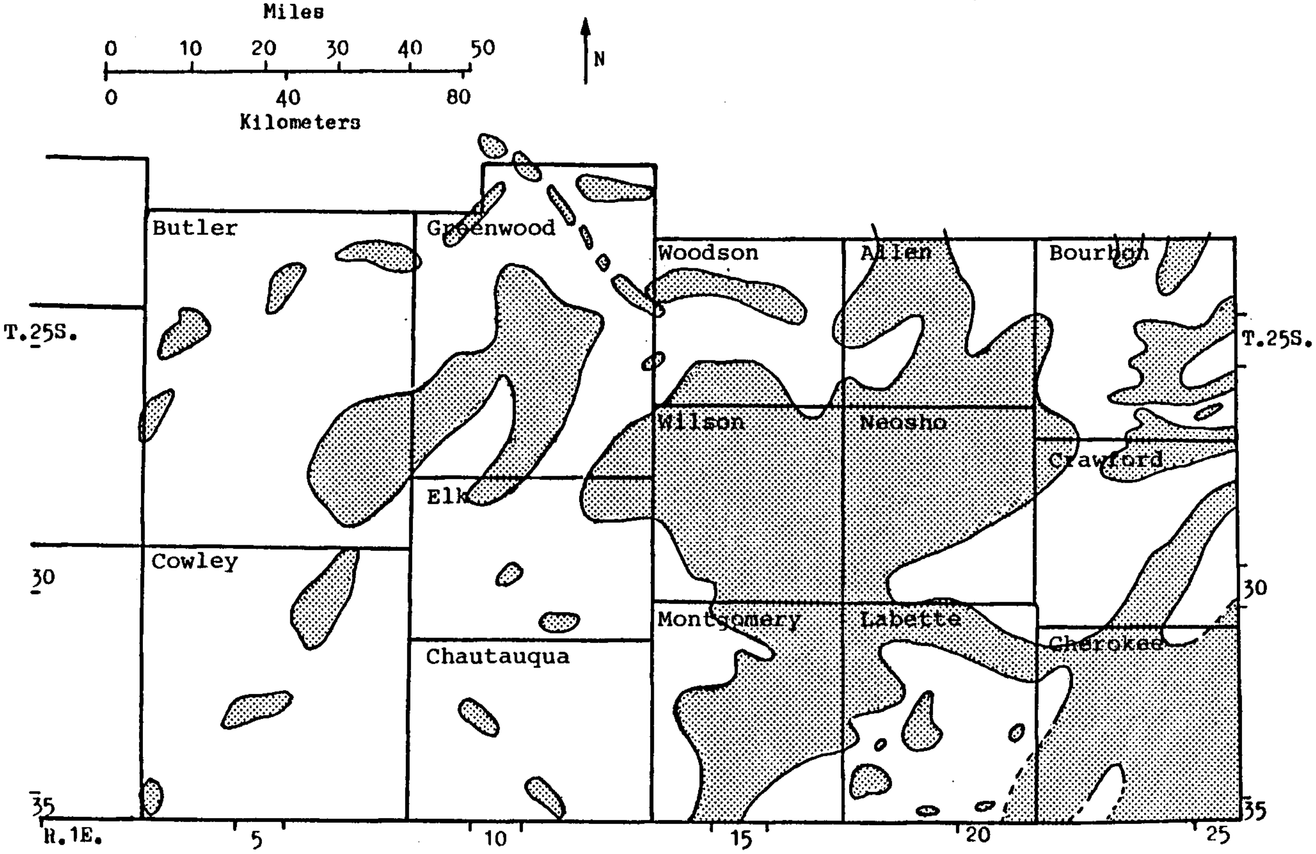

Figure 12. Distribution of Bluejacket Sandstone in the Cherokee Basin. Shaded area represents more than 10 ft. of sandstone within the Bluejacket interval, determined from well-logs and published data from Weirich (1953), Jewett (1954), and Ebanks and others (1977).

occur within the same stratigraphic interval used in this study), and Ebanks and others (1977).

Considering the sparse well-control used for constructing this isolith map, some restrictions must be placed on any interpretations drawn from examining the sandstone distribution. The multi-story and multi-lateral occurrence of Bluejacket sandstones in the subsurface has already been established. Therefore, when looking at the isolith map, consider the shaded part to represent areas where sand depostion was concentrated and not as a sandstone of equal thickness occurring across the entire shaded area. It was beyond the scope of this investigation and beyond the well-log control used in this study (average approximately one well per 94 square miles) to accurately delineate or determine the morphologies of each of the individual sandstone bodies that occur within this interval.

There are three general Bluejacket Sandstone trends in the Cherokee Basin, each representing a part of a large fluvial system that is correlated with the main Bluejacket delta (Figs. 5 and 6), delineated by Visher and others (1968, 1971) in Oklahoma. Sandstone in Missouri enters the extreme eastern and southeastern part of the study area, and extends southwestward into Oklahoma. The lower Cherokee sandstones in this tri-state area have been the subject of recent studies by Ebanks and others (1977), Wells (1979), Heckel and others (1979), Harrison and others (1979),and Ebanks (1979a, 1979b). The Bluejacket interval in this part of the study area contains two horizons of sandstone and are informally referred to as "upper Bluejacket" and "lower Bluejacket" (Ebanks and others, 1977). In Bourbon and northeastern Crawford Conties, elongate, lobate, thin and discontinuous sand bodies are present. Cores D, Z, and Kan-2 (located on Fig. 4 and described in the Appendix) represent the "upper Bluejacket" sandstone in this area and consist of laminated siltstone and very-fine to fine sandstone, with abrupt basal contacts, overlying shale. Gamma-ray logs indicate abrupt upper and lower contacts (Fig. 13) for these multi-story sandstones, which probably represent crevasse splay deposits. A thicker, more continuous, elongate sandstone trending from east-central Crawford through southwest Cherokee Counties and into Oklahoma probably represents the "updip extension" of the deltaic sandstone shown by Visher and others (1971, p.1224) to be a "minor deltaic area" (Fig. 5) east of the main Bartlesville delta (Ebanks, 1979b).

Sandstone in the east-central part of the study area trends roughly north-south from Allen County south through Montgomery County and is correlated with the main Bluejacket-Bartlesville delta in Oklahoma (Figs. 5 and 6). Well-logs (well no. 8, Fig. 9) show thick sandstones with

K.G.S.-Z
Sec. 26 T.27S. R.25E.
Crawford Co.

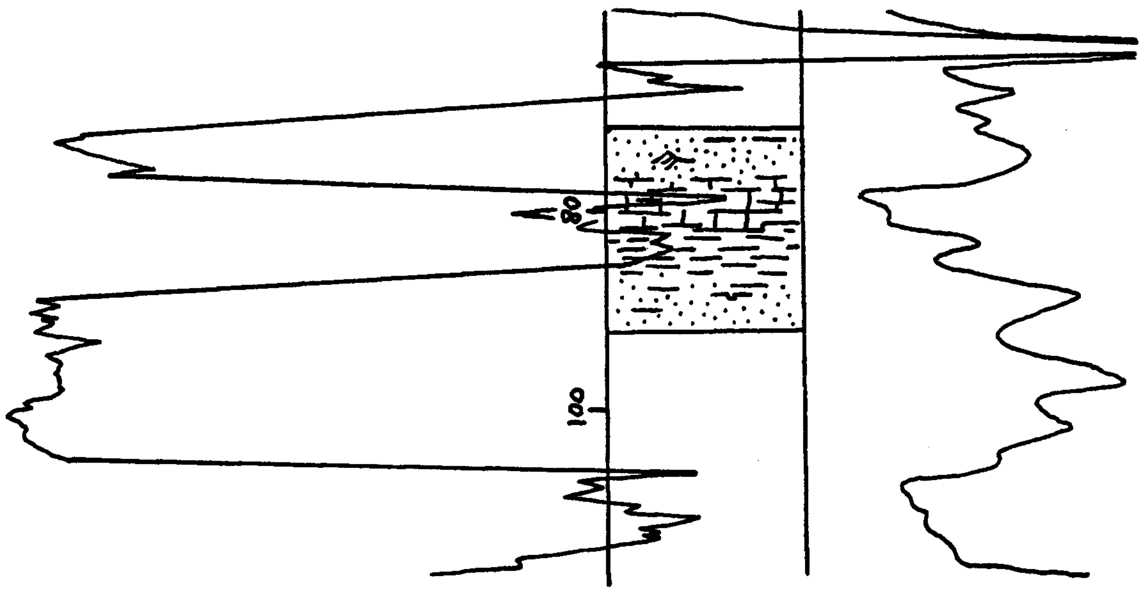

Figure 13. Gamma-ray log showing thin, multistory sandstones. Sandstones overlie thin coal bed and are interbedded with shale and a thin limestone, suggesting alluvial or delta plain sequence. Sharp basal and upper contacts shown on the log suggest erosion or rapid, episodic deposition, perhaps by crevasse splays. (From Ebanks and others, 1977).

abrupt basal contacts and transitional serrated upper contacts (fining-upward sequence with some interbedded shales and siltstone in the upper part) characteristic of meandering river point-bar deposits. Well-log no. 3 (Fig. 8), in southwestern Woodson County, shows transitional serrated upper and lower boundries that may reflect, as suggested by Ebanks (1979a, 1979b), distributary-mouth deposits that were cut into by their own prograding channel-fill deposits. These well-log signatures and sandstone trend, because it is correlative with the alluvial valley sandstone in northeastern Oklahoma (Figs. 5 and 6), strongly suggest that this sandstone represents the main Bluejacket-Bartlesville fluvial system.

A bifurcating pattern in Allen County shows sandstone trending east-west toward the western part of the study area, where smaller, discontinuous, elongate sandstone bodies are distributed across the basin. Hulse (1979) interpreted Bartlesville shoestring sandstones in southwest Greenwood County to have been deposited in a fine-grained, meandering, alluvial river. The straight-line pattern of sandstone trends was accounted for by the fluvial system following pre-existing faults and topographic lows. According to Hulse (1979), the Bartlesville in southwest Greenwood County is a multi-storied sandstone body with a sharp erosional base and fining-upward in grain size and in the scale of sedimentary structures. Sandstone consists of a conglomeratic base fining upward to siltstone. Clay chips, iron and calcareous nodules, wood fragments and organic matter are present as well. Well-logs from this area show an abrupt basal contact and fining-upward sequence, indicated by an increase in gamma-radiation upward (Fig. 14), characteristic of a point-bar deposit. The northeast-southwest trend of these sandstone bodies suggests correlation with "channel-like sand bodies" in northern Oklahoma (Fig. 6; Visher, 1968, p.38 and 42), but further studies are needed in this area to better define and delineate the Bluejacket-Bartlesville sandstones.

Depositional Environment

Alluvial and deltaic environments have several subenvironments that are similar, which makes interpretation of an individual sandstone body within the Bluejacket interval difficult. Some characteristics common to these two environments are: 1) a decrease upward in grain size and sedimentary structures; 2) narrow, elongate, multi-story sandstone bodies; 3) meandering stream channels; 4) natural levees; 5) crevasse splay deposits; 6) abundant organic matter; and 7) associated lithologies of swamp, peat, coal, limestone, and multi-lateral sandstone bodies. Many of these lithologies and environments are recognized in the Bluejacket interval.

Merchant-Hamilton Demoss No. 1
C E½ NE SW Sec. 10-T29S-R7E
Butler Co.

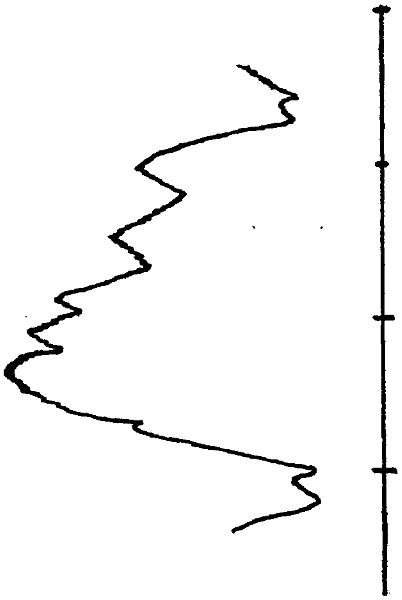

Figure 14. Gamma-ray log showing an increase in radiation upward, corresponding to an increase in shaliness. Fining-upward sequence is characteristic of point-bar deposits. Sandstones in this part of the study area have been interpreted as point-bar deposits by Hulse (1979).

The depositional environment suggested for the Bluejacket interval in southeast Kansas, based on 1) sandstone distribution, 2) environmental interpretations of well-logs, 3) associated lithologies recognized on well-logs, and 4) sandstone trends that correlate with Bluejacket-Bartlesville Sandstone trends in Oklahoma, is that the Bluejacket sandstones on the Cherokee platform were probably deposited by a fluvial-deltaic system that periodically prograded into and over the nearby shallow sea. Thicker sandstones in the east-central part of the study area possibly represent a major channel that formed during the early stages of progradation (Visher and others, 1971). The following environmental reconstruction is suggested.

The Cherokee shelf existed as a shallow-water extension of the Arkoma Basin in Oklahoma. Fluvial systems prograded rapidly in shallow water building thin shale wedges ahead of them. Swamps developed in low-lying areas of the floodplain which allowed numerous thin coals to form. Meandering streams following topographic lows developed on the lower floodplain, and, during flood, crevasse splays deposited lobate sand bodies on the natural levees and floodplain. Abandoned channels were later reoccupied, resulting in multi-storied and multi-lateral sand bodies. Point-bars developed in the meandering streams and distributary channels resulting in discontinuous, narrow, elongate sandstone bodies. Lateral shifting of these streams resulted in more widespread sand deposits. During the process of stream abandonment, or when progradation stalled, siliciclastic sedimentation ceased and the nearby sea encroached these low-lying areas and deposited thin limestones. Repeated extension of these fluvial systems resulted in a cyclic sequence of sediments that characterize the Cherokee Group.

MINERALOGY - PETROGRAPHY

The mineralogy of the "upper Bluejacket" Sandstone is diverse (Table 2), with quartz the dominant grain type, followed by subequal, although variable, amounts of feldspars and rock fragments. The sandstone consists of very-fine to medium sand-size grains that are generally well-sorted, subrounded to subangular, and dispersed throughout a matrix of clay and silt-sized particles, which contains abundant organic matter. Several authigenic cements were identified, including clay, silica, and carbonates. The general description of graywacke (Pettijohn and others, 1973, p. 198-201) encompasses the mineralogic variability of the sandstone.

Using various classification schemes, the "upper Bluejacket" has been described as a lithic arenite to lithic graywacke (Ebanks and others, 1977) and as a litharenite to lithic arkose, sublitharenite to feldspathic litharenite (Worthington, 1982). The average composition of the framework (sand-size) grains from Table 2 indicates that the "average" Bluejacket is a lithic arkose (Folk, 1974 classification), feldspathic graywacke (Pettijohn and

Table 2. Modal analyses of 24 selected thin sections. 200 point counts per thin section were made following a rectangular grid covering the entire slide. Data were normalized and are expressed as a percentage of the total sandstone composition.

	K. G. S. - D		K. G. S. - N				Avg. this page
	74.1	74.5	228.5	230.0	234.0	234.5	
QUARTZ							
Monocrystalline	40.0	33.5	38.0	42.5	47.5	35.5	39.5
Polycrystalline	2.5	0.5	3.0	2.0	2.0	0.5	1.8
FELDSPAR							
K-Feldspar	9.5	18.0	1.0	1.5	7.5	3.0	6.8
Plagioclase	1.0	1.0	4.0	T	0.5	1.0	1.3
LITHIC FRAGMENTS							
Argillaceous	1.0	1.0	0.5	0.5	0.5	---	0.6
Chert	3.5	2.0	4.5	3.5	3.0	0.5	2.8
Metamorphic	4.5	3.0	T	2.5	2.0	3.0	2.4
CEMENTS							
Silica	13.5	18.0	9.0	8.5	12.5	8.5	11.7
Siderite	9.5	5.5	---	---	---	0.5	2.6
Fe-dolomite/Calcite	3.0	0.5	0.5	0.5	2.5	2.0	1.5
CLAY							
Kaolinite	0.5	3.5	1.5	T	3.0	1.5	1.7
Chlorite	---	---	---	T	---	---	T
Mica	2.5	3.0	---	T	1.0	2.5	1.5
Illite-Smectite/Matrix	6.5	7.5	26.5	24.5	17.5	41.5	20.7
HEAVY MINERALS	T	T	T	T	T	T	T
PYRITE	2.5	1.0	0.5	---	---	---	0.7
ORGANIC MATTER	T	T	T	---	---	---	T
POROSITY	---	2.0	12.0	14.0	0.5	T	4.8

Table 2 (cont'd.).

	K. G. S. - Z						Avg. this page
	72.0	72.5	73.0	73.5	74.0	76.0	
QUARTZ							
Monocrystalline	30.0	31.0	37.5	32.0	30.0	23.7	30.7
Polycrystalline	---	2.7	6.0	4.4	7.5	3.6	4.8
FELDSPAR							
K-Feldspar	14.5	9.3	10.0	5.2	8.5	7.9	9.2
Plagioclase	2.0	0.4	2.5	1.2	1.0	0.8	1.3
LITHIC FRAGMENTS							
Argillaceous	2.5	---	4.5	---	3.5	---	1.8
Chert	3.0	2.2	0.5	2.8	2.0	2.8	2.1
Metamorphic	4.5	6.2	5.0	4.0	8.5	5.9	5.7
CEMENT							
Silica	8.5	17.8	10.5	21.6	18.0	22.5	16.5
Siderite	10.5	4.0	2.5	2.0	0.5	---	3.3
Fe-dolomite/Calcite	6.5	3.6	3.5	4.0	4.0	2.0	3.9
CLAY							
Kaolinite	6.0	---	9.5	---	7.0	---	3.8
Chlorite	---	---	1.0	---	1.5	---	0.4
Mica	2.5	---	0.5	0.8	0.5	0.8	0.9
Illite-Smectite/Matrix	7.5	10.7	4.5	12.8	0.5	24.5	10.1
HEAVY MINERALS	---	---	T	---	---	---	T
PYRITE	---	---	---	2.0	---	0.8	0.5
ORGANIC MATTER	T	T	0.5	T	0.5	T	0.2
POROSITY	5.5	12.0	1.5	7.2	6.5	5.1	6.3

Table 2 (cont'd.).

	K. G. S. - AA						Avg. this page
	31.2	32.0	33.2	34.5	36.7	37.5	
QUARTZ							
Monocrystalline	25.5	36.5	36.5	40.5	28.0	29.5	32.8
Polycrystalline	2.0	2.5	2.0	1.5	4.0	3.5	2.6
FELDSPAR							
K-Feldspar	8.5	7.0	9.0	8.0	2.5	6.0	6.8
Plagioclase	1.0	1.0	1.0	2.0	1.5	0.5	1.2
LITHIC FRAGMENTS							
Argillaceous	0.5	2.0	2.5	6.5	1.0	---	2.1
Chert	---	---	---	0.5	1.5	---	0.3
Metamorphic	3.5	4.0	3.0	2.5	9.0	2.0	4.0
CEMENT							
Silica	16.5	14.5	18.0	16.5	9.5	0.5	12.6
Siderite	6.0	2.5	4.0	4.0	4.5	15.0	6.0
Fe-dolomite/Calcite	17.0	5.5	4.5	0.5	11.0	18.0	9.4
CLAY							
Kaolinite	2.0	7.0	5.0	3.5	0.5	1.5	3.3
Chlorite	3.0	2.0	3.0	1.0	1.5	1.5	2.0
Mica	1.0	0.5	1.0	T	0.5	---	0.5
Illite-Smectite/Matrix	5.0	8.5	10.0	8.5	5.0	1.0	6.3
HEAVY MINERALS	---	---	---	---	---	---	---
PYRITE	0.5	1.0	0.5	0.5	T	T	0.5
ORGANIC MATTER	2.5	2.0	T	2.5	19.5	21.0	7.9
POROSITY	5.0	3.5	0.5	2.0	0.5	---	1.9

Table 2 (cont'd.).

	K. G. S. - CC			Kan-2			Avg. this page
	42.0	42.8	43.5	275.0	276.0	277.0	
QUARTZ							
Monocrystalline	41.0	42.5	40.0	37.0	41.0	41.5	40.6
Polycrystalline	1.0	1.0	0.5	3.0	2.5	1.5	1.6
FELDSPAR							
K-Feldspar	4.5	4.0	7.0	8.0	8.5	7.5	6.6
Plagioclase	0.5	1.0	0.5	1.5	2.0	1.0	1.1
LITHIC FRAGMENTS							
Argillaceous	---	---	---	---	---	0.5	0.1
Chert	1.0	---	2.0	1.5	1.5	1.0	1.2
Metamorphic	2.0	1.5	3.0	6.5	7.5	4.5	4.2
CEMENT							
Silica	3.0	11.0	5.0	5.0	8.0	7.0	6.5
Siderite	3.0	T	T	9.0	4.5	4.5	3.5
Fe-dolomite/Calcite	3.0	3.5	0.5	4.5	1.0	2.0	2.4
CLAY							
Kaolinite	1.0	---	---	1.0	0.5	0.5	0.5
Chlorite	T	T	T	---	---	---	T
Mica	0.5	1.0	2.5	1.5	1.5	0.5	1.3
Illite-Smectite/Matrix	37.5	33.0	39.0	20.0	18.5	25.0	28.8
HEAVY MINERALS	T	T	T	---	---	---	T
PYRITE	---	---	---	---	---	---	---
ORGANIC MATTER	T	T	T	T	T	T	T
POROSITY	2.5	1.0	T	1.5	3.0	3.0	1.9

others, 1973 classification), or a lithic subarkose (McBride, 1963 classification). Figure 15 illustrates the variability of composition of the sandstone.

Detrital Grains

Quartz

Quartz is the most abundant detrital mineral in the "upper Bluejacket" Sandstone, making up 23 to 50 percent of the total composition and 50 to 85 percent of the detrital grains (Table 2). Monocrystalline quartz is the most common type of quartz, and grains are slightly undulose, although a few display strongly undulose extinction (greater than 10 degrees). Quartz grains are very-fine to medium sand-size, subrounded to subangular, and were observed containing both randomly oriented and aligned liquid and gas-filled inclusions (Fig. 16). Rare mineral inclusions of apatite, zircon, and mica were also observed. Many of the quartz grains possess overgrowths that give the grain a subhedral to euhedral shape.

Semi-composite or composite quartz grains (Folk, 1974, p. 74) with less than ten subcrystals have been classified as polycrystalline quartz. Those grains with more than ten subcrystals have been classified as quartzite rock fragments, based on empirical relationships (Folk, 1974; Scholle, 1979). Polycrystalline quartz is usually less than

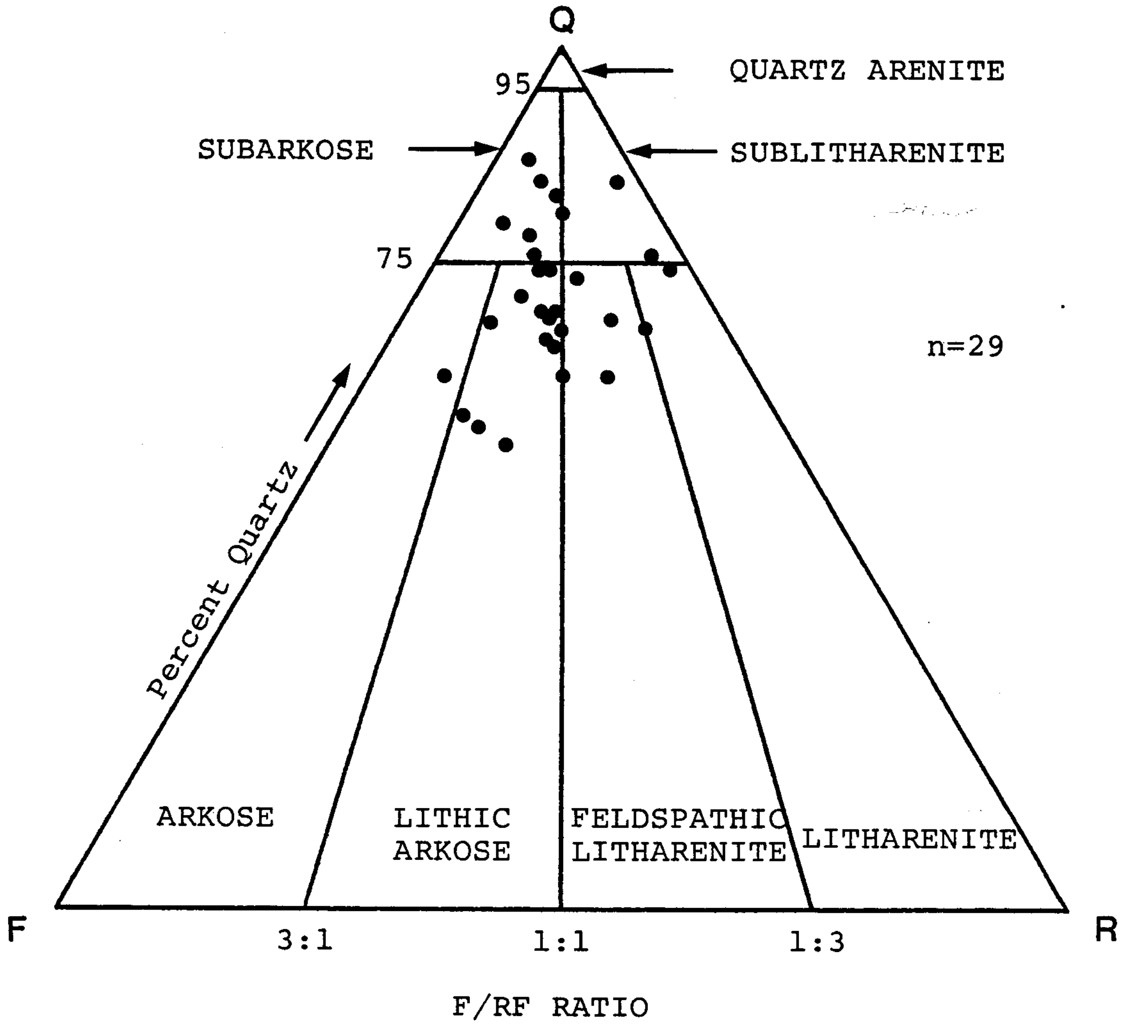

Figure 15. Triangular diagram plot of detrital sand-sized grains. Q=monocrystalline and polycrystalline quartz; F=feldspars; R=metamorphic and sedimentary rock fragments, and chert. Triangle subdivisions are from Folk (1974). Rock classification is discussed in the text. Data from Table 2, with an additional five points from unpublished data of Ebanks and others (1977).

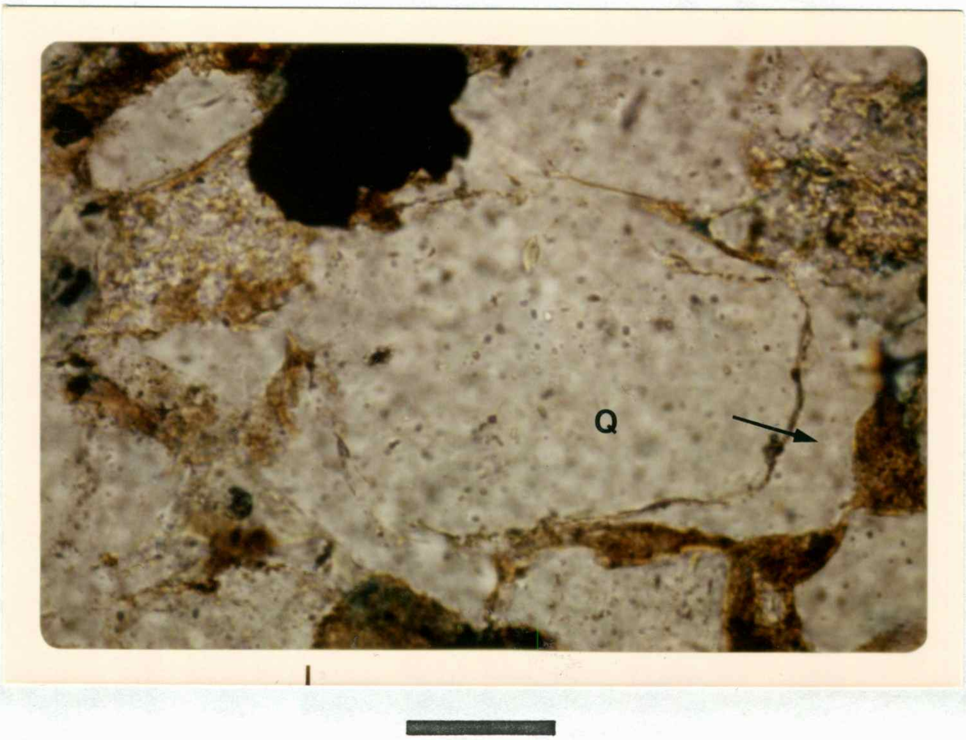

Figure 16. Photomicrograph of quartz grain containing numerous inclusions and well-defined overgrowth. Q=quartz, arrow indicates overgrowth separated from grain by clay rim. Bar scale is 0.05mm. (K.G.S.-D - 74.1).

five percent of the total quartz present. It is commonly observed without alterations or overgrowths but occasionally is cemented to other grains with silica cement. Polycrystalline quartz grains are generally smaller and more rounded than monocrystalline quartz.

Feldspar

Plagioclase and potassium feldspar make up about 5 to 30 percent of the detrital grains but are usually less than ten percent of the total composition (Table 2) of the "upper Bluejacket" Sandstone. Recognition of feldspars was made by the presence of cleavage, twinning, parallel or aligned sericite alterations (Fig. 17), and remnant grain shapes.

Feldspar grains are generally smaller than quartz grains, mostly very-fine to fine sand-size, and are angular to subrounded and subequant. Plagioclase feldspar commonly displays albite twinning, and rare periclase twins were observed. Rare examples of altered plagioclase grains with unaltered overgrowths or twins also were observed.

Lithic Fragments

Sedimentary Rock Fragments

Both argillaceous rock fragments and chert were recognized in the "upper Bluejacket" Sandstone. Together they constitute about five percent of the detrital grains and are most abundant in cores Z and AA (Table 2).

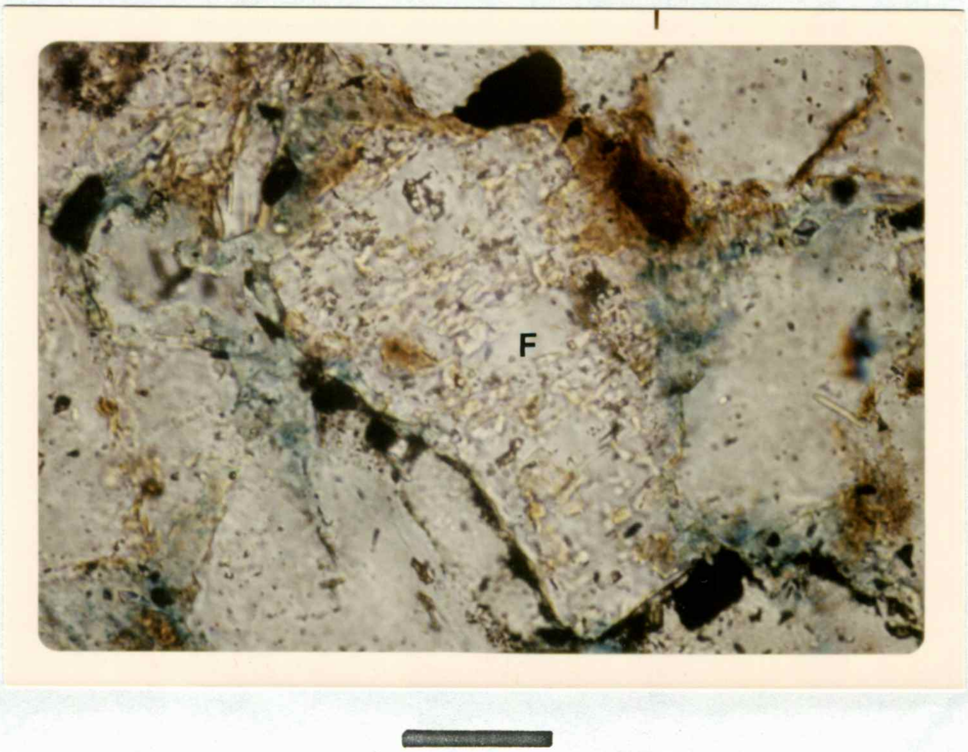

Figure 17. Photomicrograph showing feldspar grain containing numerous aligned sericite inclusions. Bar scale is 0.05 mm. (K.G.S.-AA - 33.2).

Argillaceous rock fragments are present as fine sand-sized siltstone and shale fragments that are abundant locally, but are not present in all samples. Argillaceous rock fragments are light-gray to brownish-red in plane-polarized light, and many are oil-stained. Shale clasts are commonly deformed, probably during compaction, and are recognized as larger-than-normal "pore-filling" (Fig. 18), and/or a patchy distribution of clays. Many of these argillaceous grains have been partially or wholly replaced by siderite, and are distinguished from carbonate rock fragments by their compactional effects (i.e., squeezed between grains).

Detrital grains of chert make up about two percent of the sandstone, and are present in most or all of the samples. The amount of chert in each sample does not vary as much as does the amount of argillaceous rock fragments. Chert grains are subrounded to rarely subangular and are commonly very-fine to fine sand-size. They usually are not altered except where adjacent to carbonate cements, which etches and replaces the chert.

Metamorphic Rock Fragments

Metamorphic rock fragments in the "upper Bluejacket" usually constitute only one or two percent of the sandstone (Table 2). Quartzite fragments are the most common metamorphic rock fragments and are made up of numerous silt-

Figure 18. Photomicrograph showing compactional effects on argillaceous rock fragments. Shale clasts are commonly squeezed between grains and occur as a "patchy distribution of clays". Arrow points to one argillaceous rock fragment. Notice the blue-dyed epoxy, which suggests secondary porosity. Oversized pore space and remnant grain shapes (SP) indicate that grains (or cements) have been dissolved. Bar scale is 0.5 mm. (K.G.S.-Z - 73.5).

size quartz grains. Quartzite fragments are subrounded to subangular, subequant, and very-fine to fine sand-size. They rarely contain inclusions and generally are not altered except for etching by carbonate cements.

Foliated quartz-mica gneiss fragments are present in minor amounts. These grains are composed mainly of quartz interlayered with mica, biotite, and chlorite, and are very-fine to fine sand-size. The foliated quartz-mica gneiss fragments are commonly etched and partially replaced by carbonate cements, and chlorite is observed replacing the mica.

Accessory Minerals

Micas and Clays

Muscovite, biotite, and chlorite are present as detrital grains and vary in size up to about 0.5 mm. Muscovite is generally larger and more abundant than biotite or chlorite. Mica grains are commonly aligned with stratification, and broken or bent due to compaction and cementation.

Illite-smectite clays are present as matrix, which averages about 20 percent of the total composition of the "upper Bluejacket" Sandstone (Table 2). X-ray diffraction analysis indicated that highly crystalline illite is more abundant than smectite. The minute size of the clays and the oil-stain restrict petrographic observations, and in most cases, determining whether the clay is detrital or authigenic is difficult. Argillaceous rock fragments that have been compressed between and around grains may have been inadvertently identified as clay matrix.

Pyrite

Pyrite is present in trace amounts and is most common in samples with high organic contents. Pyrite usually replaces the organic matter and occurs in small groups of crystals, but sample 74.7 in core D contained a pyrite zone or veinlet two centimeters long and two millimeters wide.

Heavy Minerals

Zircon and tourmaline were recognized in trace amounts. Heavy minerals are usually coarse silt-size or finer, rounded to subangular, and are present in most samples.

Organic Matter

Although not a mineral, organic matter occurs throughout the "upper Bluejacket". Organic matter is dark reddish-brown to black, and is present in small patches or along clay laminations. Samples that were not cleaned contain abundant trapped, or "dead" oil, which partially fills pore space (Fig. 19).

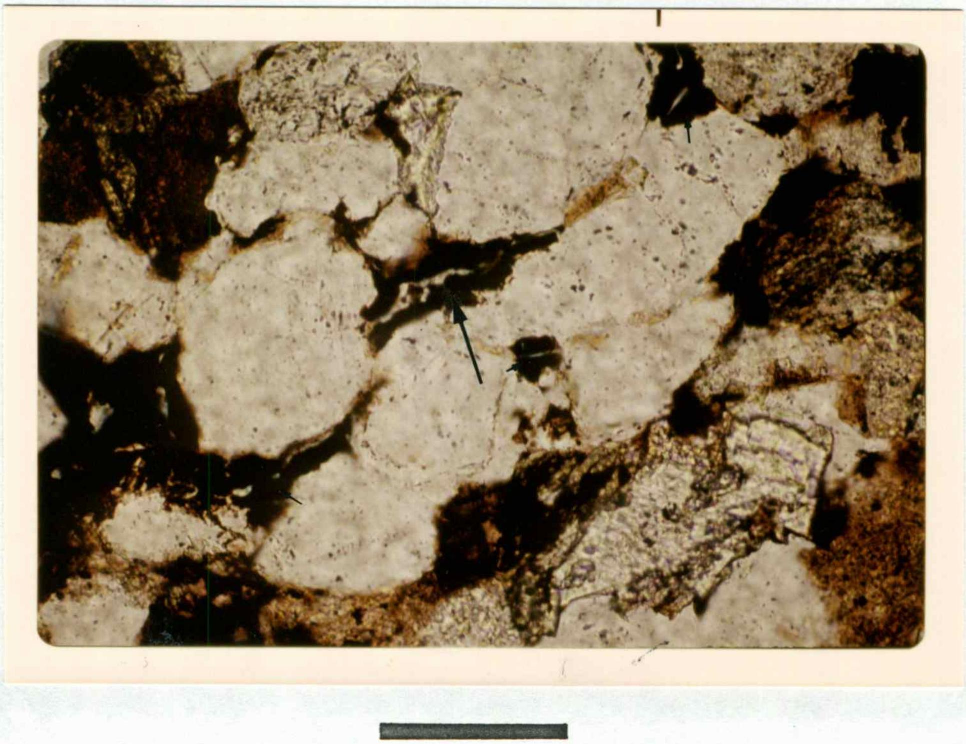

Figure 19. Photomicrograph illustrating abundant trapped, or dead oil partially filling pore space. Arrow points to dead oil. Bar scale is 0.1mm. (K.G.S.-AA - 36.5).

Cements

Authigenic cements make up about 20 percent of the total composition of the sandstone. Although there are many different cements, they have been grouped into the following categories, according to their decreasing abundance: 1) silica; 2) carbonates, including siderite, ferroan dolomite or ankerite, and calcite; and 3) clays, including kaolinite and chlorite.

Silica

Silica overgrowths on quartz grains are the most common and widespread cement and are present on most quartz grains. These optically continuous overgrowths are easily recognized by the presence of clay rims, or coats, which separate the overgrowth from the host grain. Silica overgrowths commonly form subhedral to euhedral crystal faces in pore space but when adjoining grains have extensive overgrowths, the common result is interlocking crystals (Fig. 20), which cause the boundaries to be irregular. A mosaic may form if enough grains are involved and precipitation of overgrowths is not hampered by pore-filling clays and organic matter. Overgrowths usually contain inclusions, and are sometimes etched by carbonate cements.

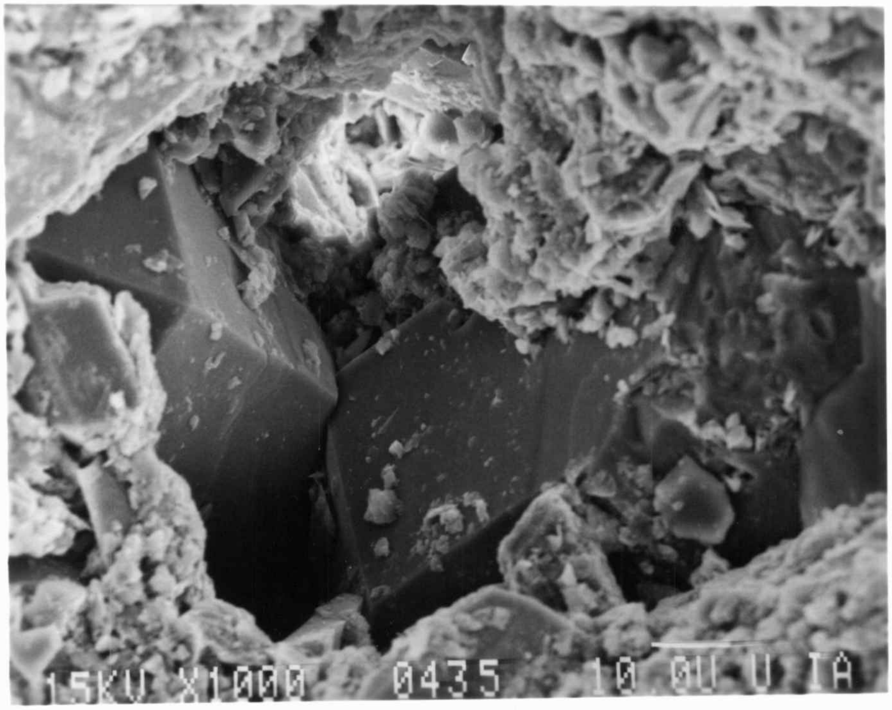

Figure 20. Scanning electron micrograph showing extensive quartz overgrowths forming interlocking crystals. Complete pore filling by overgrowths such as these has eliminated effective porosity. Scale and magnification is at the bottom of the figure. (K.G.S.-CC - 43.5).

Carbonates

There are at least three different carbonate cements in the "upper Bluejacket" Sandstone, which were identified using petrography, staining, x-ray, and cathodoluminescence. Siderite is the most abundant, followed by ferroan dolomite, and calcite. Siderite is easily distinguished from the other carbonate cements by its size, color, and mode of occurrence. Ferroan dolomite and calcite are best distinguished from each other using cathodoluminescence, where Fe-dolomite is a dull red color and calcite appears orange. Using petrography, distinguishing between these two optically similar carbonates is difficult, even after staining for iron. They seldom, if ever, occur together and are irregularly distributed in small patches throughout the sandstone. Examination under cathodoluminescent light enabled estimates of their relative modal percentage to be made, which indicated that ferroan dolomite is about ten times more abundant than calcite. Together, these two carbonate cements constitute only about four percent of the total rock volume (Table 2).

Siderite

Siderite is the second most abundant cement in the "upper Bluejacket", making up about five percent of the total composition of the sandstone (Table 2). Siderite is present in almost all of the samples studied and occurs in two crystallographic forms. Spherical, concretionary siderite occurs primarily in the shaley and finer-grained sandstone and siltstone as nodules that are up to about 0.25 mm. in diameter. Where extensive, these spherulites give slabbed core surfaces a reddish-brown appearance (Fig. 21), and commonly occur in zones or laminations (Fig. 22). Siderite spherulites are dark brown in plane-polarized light and are typically observed with dark bands near the edges of the concretions (Fig. 23). Siderite concretions are occasionally observed in a septarian form of growth.

Siderite also occurs as a cement (Fig. 24), usually in conjunction with replacive siderite and organic matter. These fine, crystalline rhombs are dark brown and have very high relief. Additionally, siderite is observed as a replacement of argillaceous rock fragments, or "psuedo-matrix" (Schmidt and McDonald, 1979). Replacive siderite is generally in the form of fine-grained rhombs, which are obscured in the presence of clays and organic matter.

Ferroan Dolomite

Ferroan dolomite is present in almost all samples, making up about three percent of the total composition of the sandstone. X-ray diffraction analysis indicated variable amounts of iron present in the dolomite, but d-

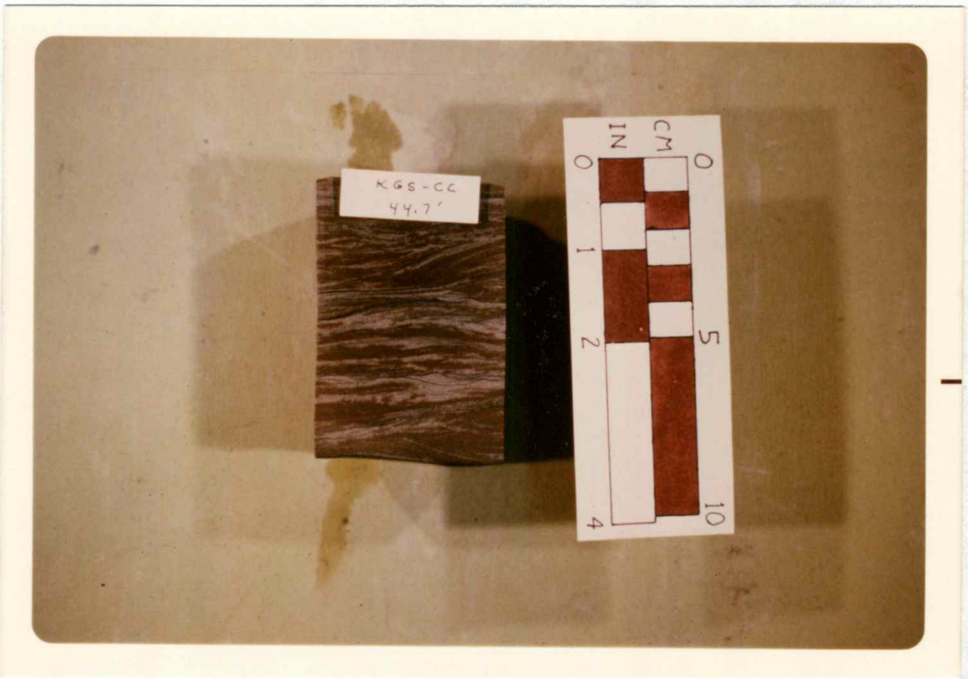

Figure 21. Siderite spherulites are concentrated along shaley interlaminations and give cores a reddish-brown color. (Photograph of slabbed core K.G.S.-CC at 44.7 ft. (13.53m)).

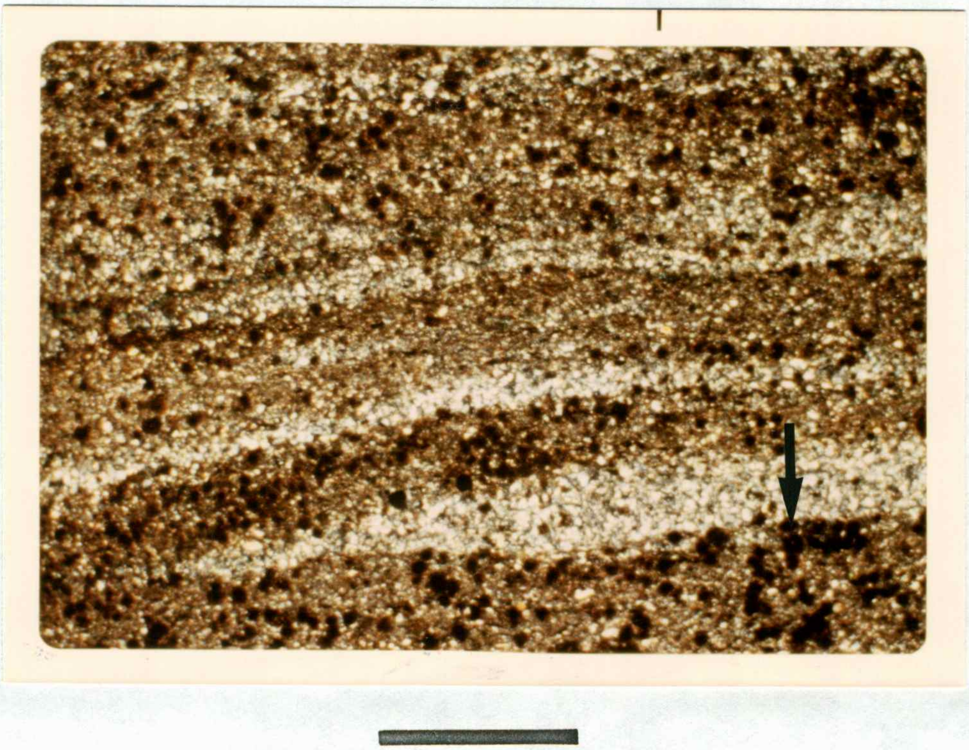

Figure 22. Photomicrograph illustrating siderite spherulites occurring within the finer-grained interlaminations. Arrow points to one spherulite, which are as large as 0.25 mm in diameter, and occasionally are observed in a septarian form of growth. Bar scale is 3.0 mm. (K.G.S.-D - 75.5).

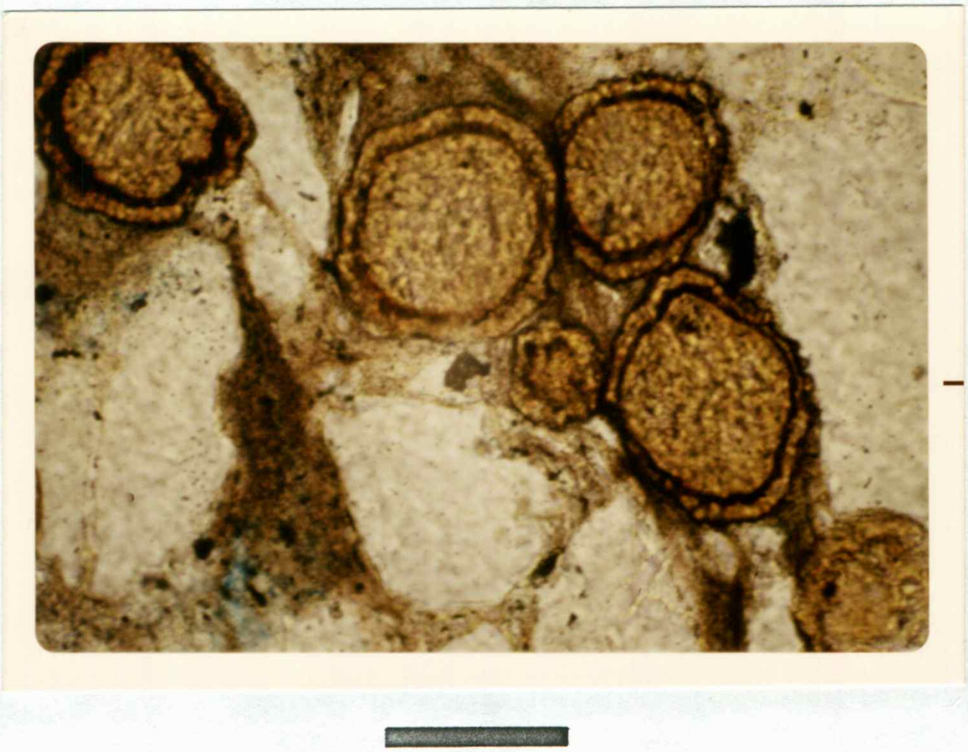

Figure 23. Photomicrograph of spherical, concretionary siderite with typical dark band of iron oxide near outer rim. Bar scale is 0.1 mm. (K.G.S.-N - 232.0).

Figure 24. Photomicrograph of siderite cement. Note the remnant grain shape (arrow) and pore-filling kaolinite, suggesting kaolinite has filled in secondary porosity created by leaching of feldspar. Bar scale is 0.5 mm. (K.G.S.-Z - 72.0).

spacings (unit-cell dimensions) of ankerite (Howie and Broadhurst, 1958) were not observed. In plane polarized light, Fe-dolomite appears as light-gray, coarse crystals that occur as a patchy, irregularly distributed, pore-filling spar cement (Fig. 25) in the cleaner sandstones. It is also commonly observed etching and replacing quartz and feldspar grains (Fig. 26).

Calcite

Calcite occurs only as a minor cement in the "upper Bluejacket" Sandstone. Estimates from point-counts indicate that calcite is only about 6.0 percent of the total carbonate cement in the sandstone. Where recognized, it is observed as a patchy, spar cement, rarely surrounding grains.

Clays

Kaolinite

Kaolinite constitutes about two percent of the total composition of the "upper Bluejacket" Sandstone. In thin-section, it is observed as a low-birefringent, irregularly distributed pore-filling of clusters of granules (Fig. 27). SEM investigations revealed large vermicular booklets of kaolinite within the pore spaces (Fig. 28). Pore-filling kaolinite commonly occurs in association with dissolved feldspar grains.

Figure 25. Photomicrograph of patchy, randomly distributed ferroan dolomite cement. Arrows point to the cement. Bar scale is 0.5 mm. (K.G.S.-Z - 73.5).

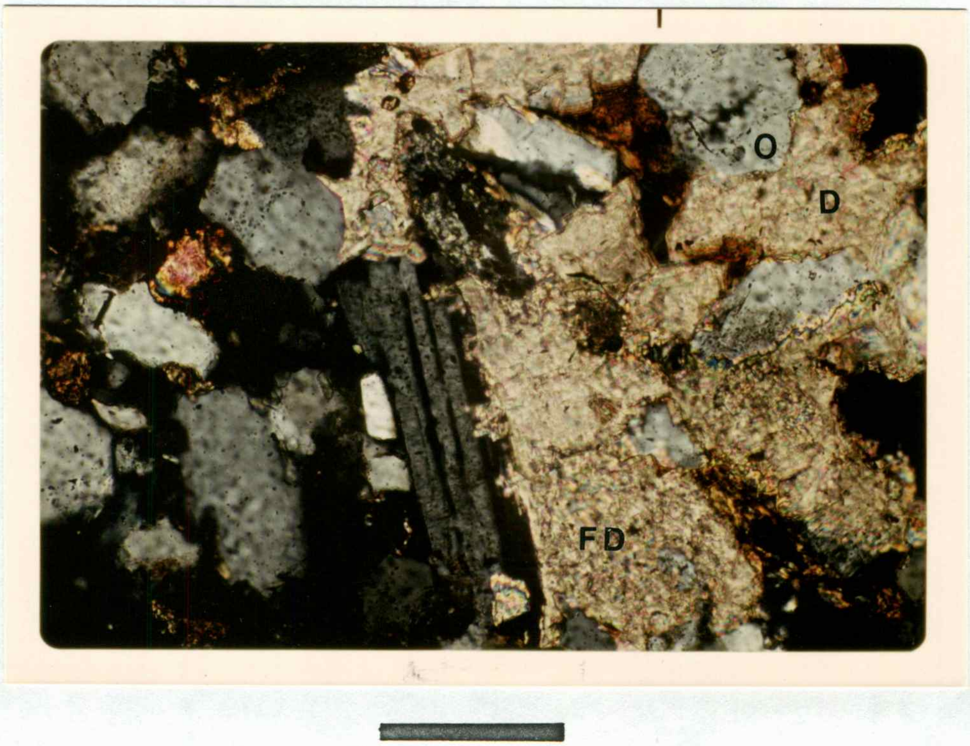

Figure 26. Photomicrograph of ferroan dolomite cement etching and replacing detrital grains. Large crystal (FD) at the bottom of the figure appears to have almost completely replaced a grain, possibly feldspar. Relative timing of this cement and quartz overgrowths is illustrated in upper right corner of figure, where ferroan dolomite (D) post-dates quartz overgrowth (O). Bar scale is 0.1 mm. (K.G.S.-AA - 31.2).

Figure 27. Photomicrograph of irregularly distributed pore-filling kaolinite cement. Blue-dyed epoxy indicates secondary micro-porosity. Note "ghost" rim (arrow) where a grain, probably feldspar, has been leached. Bar scale is 0.1 mm. (K.G.S.-Z - 73.5).

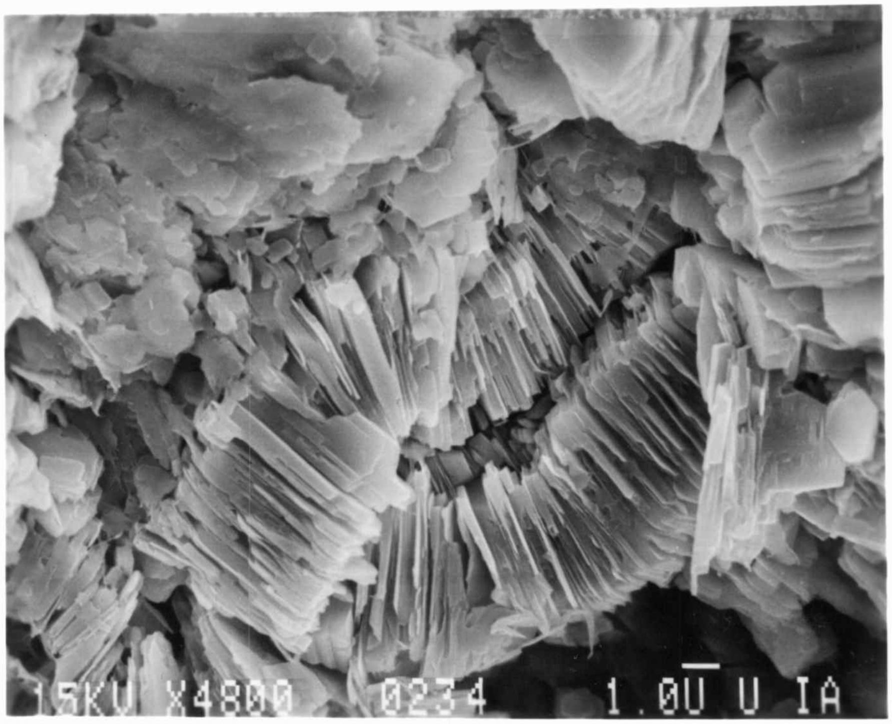

Figure 28. Scanning electron micrograph showing vermicular booklets of kaolinite. An authigenic origin for this kaolinite is indicated by its delicate "worm-like" morphology that would not have survived transport. Scale and magnification is at bottom of figure. (K.G.S.-N - 234.0).

Chlorite

Chlorite is present as a authigenic cement, which is not volumetrically significant. Authigenic chlorite is recognized by its low birefringence, low relief, and pale yellow-green color. The most common occurrence is as a clay coating around grains (Fig. 16), separating the grain nucleus from overgrowths. Chlorite also occurs as a pore-filling and replacement of mica.

Provenance

Weirich (1953), Visher and others (1968, 1971), and Hayes (1963) have suggested that a northern source area, the Canadian Shield, supplied most of the Bluejacket sediments. Hulse (1979) suggested a more local source for the Bluejacket in the western part of the basin. Sandstone distribution and petrographic observations from this study, suggest that that most of the sediments were derived from the north, probably the Canadian Shield, with local source areas contributing sediments as well. Mississippian and older Paleozoic carbonates from the Nemaha Uplift, a positive area to the west of the study area, and the Ozark Dome to the east, probably contributed the detrital chert that is present in the sandstone, although whether or not the Ozark Dome was a positive area when the Bluejacket was deposited is unclear. Argillaceous rock fragments were probably added locally as the Bluejacket fluvial system eroded pre-existing sediments.

DIAGENESIS

Diagenetic processes that have altered the original mineralogy of the "upper Bluejacket" Sandstone include cementation, dissolution, and replacement. Diagenetic alterations are discussed in the following order: 1) pyrite and spherulitic siderite; 2) authigenic silica; 3) feldspar alterations; 4) clay minerals; and 5) carbonate cements.

Pyrite and Spherulitic Siderite

In the "upper Bluejacket", pyrite and spherulitic siderite occur locally as a replacement of organic matter and concretionary spherulites, respectively. Fine-grained siderite nodules and pyrite form a common diagenetic association in shales and shaley sandstones associated with coal measures (Tripplehorn, 1970; Blatt and others, 1972). Hulse (1979) and Woody (1982) described pyrite and siderite nodules in Cherokee sandstones in southeastern Kansas, and as a modern analog, Ho and Coleman (1969, in Blatt and others, 1972) described siderite nodules and pyrite in sediments below the swamps of the Atchafalaya Basin of the Mississippi Delta. Larson and Chilingar (1979) discussed features of Recent sediments that explain the early occurrence of siderite nodules and pyrite. The upper 10 meters of Recent sediments are characterized by the reduction of sulfates and oxides of iron, manganese, etc., after organisms have consumed the free oxygen. The eventual saturation of interstitial waters with some components (Fe++, Mn++, SiO_2, etc.) leads to the precipitation of diagenetic minerals such as sulfides of iron and siderite. The variation in Eh, pH, and concentrations of various ions in different areas of the sediment results in subsequent redistribution (concretions) of authigenic minerals.

Precipitation of siderite or pyrite is favored in a moderately to strongly reducing environment (Fig. 29), and occurs with decomposition of organic matter in the sediments. Berner (1981) has shown that rocks containing both siderite and pyrite have been subjected to a highly reducing, methanic, anoxic, nonsulfidic, chemical environment where the sulfur was tied up early by precipitation of iron sulfides, allowing siderite to form under low dissolved sulfur conditions. Siderite and pyrite form under negative Eh and moderate to high pH conditions, as indicated by Figure 29, and will remain stable as long as reducing conditions predominate. Once oxygenated by groundwater or exposed to the surface, siderite alters to magnetite and iron oxide, which gives surface exposures a rusty, brownish-orange color. The dark bands that are

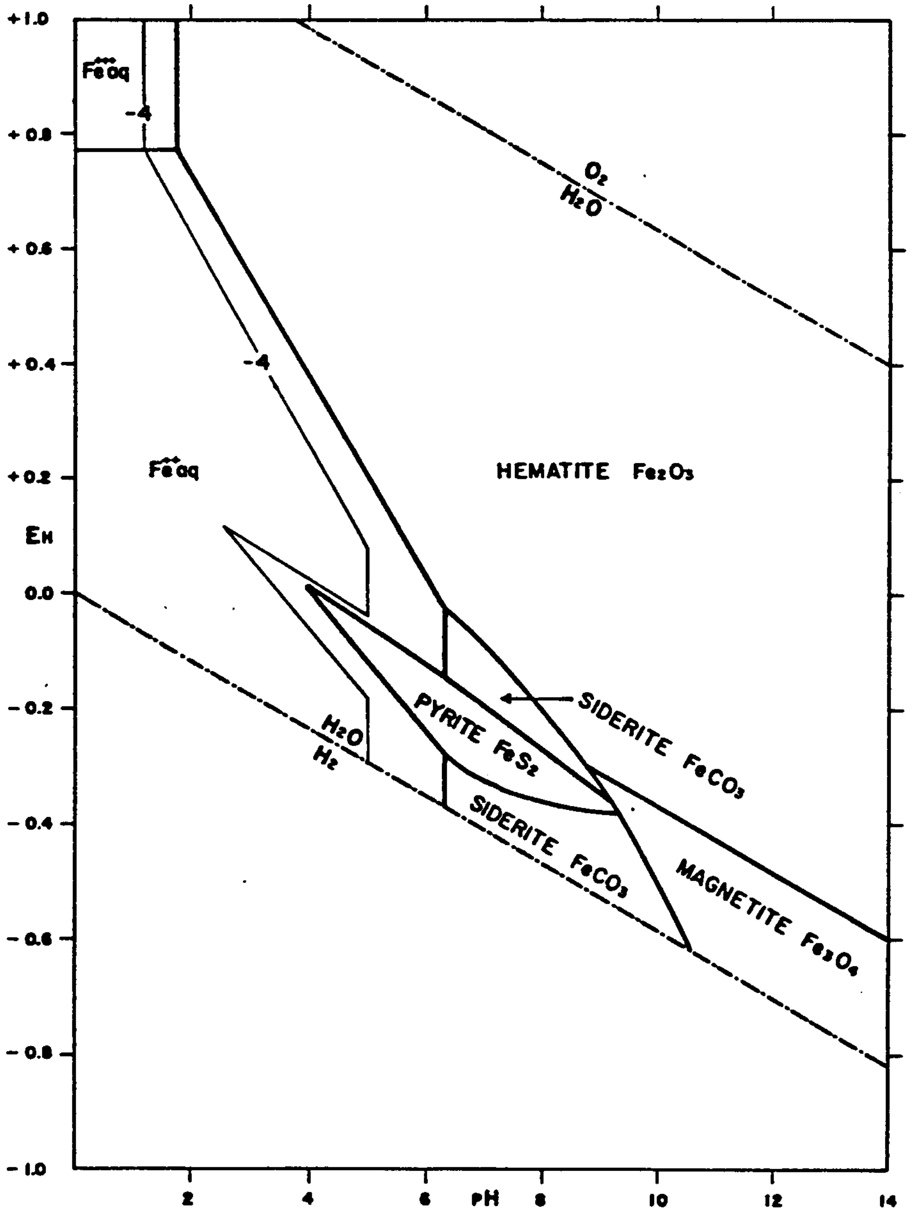

Figure 29. Stability relations of iron oxides, sulfides, and carbonate in water at 25°C and 1 atm. pressure. Total dissolved sulfur = 10^{-6}. Total dissolved carbonate = 10^{0}. Note the elimination of FeS field by $FeCO_3$ under strongly reducing conditions. (From Garrels, 1960).

typically observed on the siderite spherulites (Fig. 23) may be iron oxide, which probably precipitated when the sediments were exposed to more oxygenated waters.

Authigenic Silica

Authigenic silica is the most abundant cement in the "upper Bluejacket" and occurs throughout the sandstone. The most common form of silica cementation is by syntaxial overgrowths, which are recognized by their optical continuity with the host grain across a clay rim. Sources of silica cement in sandstone have been suggested by many authors (e.g., Dapples, 1959; Siever, 1959). Blatt (1979) suggested that pore waters enriched in dissolved silica, supplemented by pressure solution and clay mineral diagenesis, are the primary source of silica. In addition, hydrolysis of feldspars may be locally important as a silica source. In the Bluejacket, there is little evidence of pressure solution (e.g., sutured grain boundaries and interpenetrating grains with subsequent overgrowths) to suggest that it was a major source of silica. It is more likely that in the interlaminated sandstones and shales of the lower Cherokee Group, the low-temperature illitization of smectite clay minerals may have provided most or all of the silica, as suggested by Bucke and Mankin (1971), Boles and Franks (1979), and Lahann (1980). The expulsion of pore water from the shales during compaction would provide a continuous replenishment of silica as it was gradually withdrawn by precipitation as quartz overgrowths.

There is abundant literature (e.g., Bucke and Mankin, 1971; Land and Dutton, 1978; Blatt, 1979; and Woody, 1982) that suggests the formation of quartz overgrowths is an early diagenetic event. Dapples (1959) felt that authigenic silica began precipitating as quartz overgrowths during deposition and continued through early burial. Quartz overgrowths appear to have formed early in the diagenetic history of this sandstone. Uncompacted grains, extensive development throughout the sandstone, and euhedral crystal faces (Fig. 30) indicate that overgrowths were not restricted much by adjacent grains and therefore probably formed prior to compaction.

Feldspar Alterations

Dissolution of feldspar grains is a relatively common diagenetic alteration in this sandstone, and is recognized as partially dissolved (honeycombed) grains (Fig. 30) or as clay rims around oversized pore spaces that suggest a remnant grain shape (Figs. 18, 24, and 30) (Hayes, 1979). Pittman (1979) stated that feldspar dissolution is common in sandstones of all ages. Heald and Larese (1973), Pittman (1979), and Schmidt and McDonald (1979), discussed the

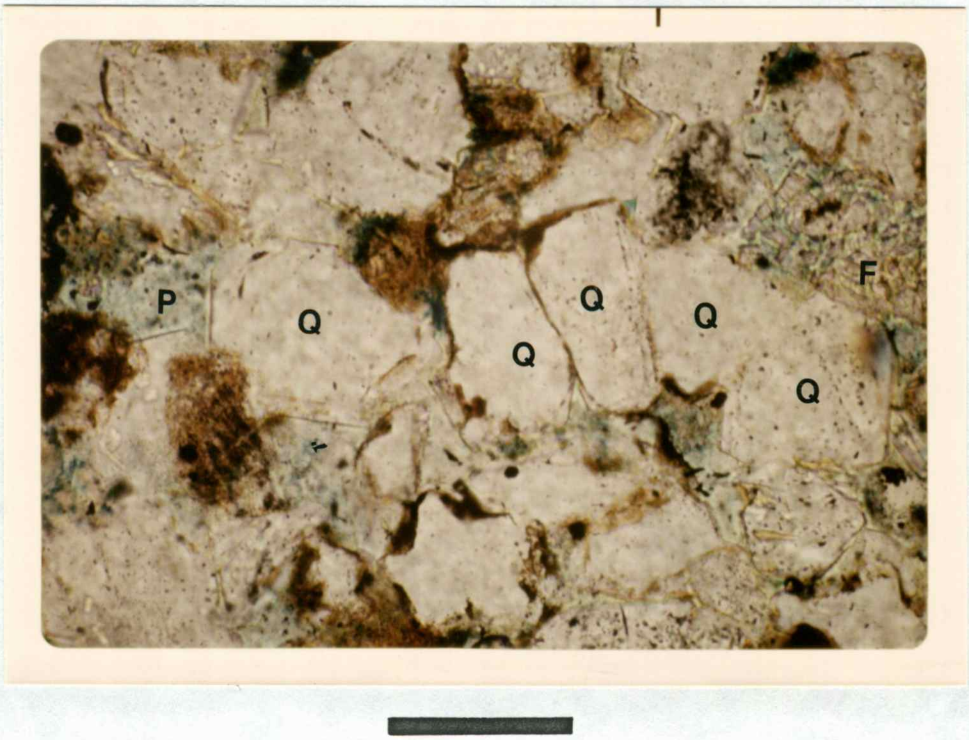

Figure 30. Photomicrograph of quartz grains with well-developed overgrowths having euhedral crystal faces. Kaolinite cement (white) partially fills secondary pore space, indicated by blue-dyed epoxy. Notice partially dissolved (honeycombed) feldspar grain (F) in upper right corner. Bar scale is 0.1 mm. (K.G.S.-AA - 34.5).

dissolution of feldspar and its contribution to the formation of secondary (solution) porosity in sandstones. Leaching of feldspar, or any detrital or authigenic mineral, creates secondary porosity after the original or primary, porosity has been partially or completely destroyed by compaction or cementation (Hayes, 1979). Impregnating the sandstone chip with blue-dyed epoxy prior to thin-section grinding allows distinction between secondary porosity (space filled with blue epoxy) and plucking of grains (space filled with colorless mounting epoxy). Using this method, it is apparent that there is abundant secondary porosity in the Bluejacket (Figs. 18 and 24), which probably contributes to its importance as a hydrocarbon reservoir in the subsurface in the Cherokee Basin. Leaching of feldspars usually occurs early in the burial history and continues through deep burial (Milliken and others, 1981).

In addition to creating secondary porosity, dissolution of feldspar releases Si and Al ions into a micro-environment that allows kaolinite to precipitate as a pore filling (Keller, 1970; Bucke and Mankin, 1971). Blatt (1979) suggested that the dissolution of feldspar may be locally important as a source of silica, which may contribute to the formation of quartz overgrowths. In the "upper Bluejacket", feldspar dissolution may have contributed some silica for quartz overgrowths, but petrographic evidence (Figs. 27 and

29) suggests that it primarily resulted in kaolinite formation, which is discussed in 'Clay Minerals'. Kaolinization of feldspar is a near-surface alteration that occurs when the sediment is exposed to relatively fresh meteoric water. This usually occurs early in the burial history of the sediment, or late, after the rock has been uplifted to within tens of meters of the surface (Pettijohn and others, 1973; Fuchtbauer, 1974).

Sericitization of feldspar grains (Fig. 17) is another common diagenetic alteration recognized in this sandstone. Replacement by mica usually takes place preferentially along cleavage planes, and has altered the feldspars to varying degrees. Fuchtbauer (1974) and Boles and Franks (1979) consider this alteration to take place late in diagenesis. Another replacement process observed in this sandstone is ferroan dolomite replacing feldspars, among other grains, and replacement has progressed to various stages (Figs. 26 and 31). This stage of diagenesis usually occurs late in the burial history of the rock, at least in fluvial-deltaic sediments (Bucke and Mankin, 1971; Loucks and others, 1977; Boles and Franks, 1979; Milliken and others, 1981; and Woody, 1982), and is promoted by an increase in the pH of the pore solution (Fuchtbauer, 1974).

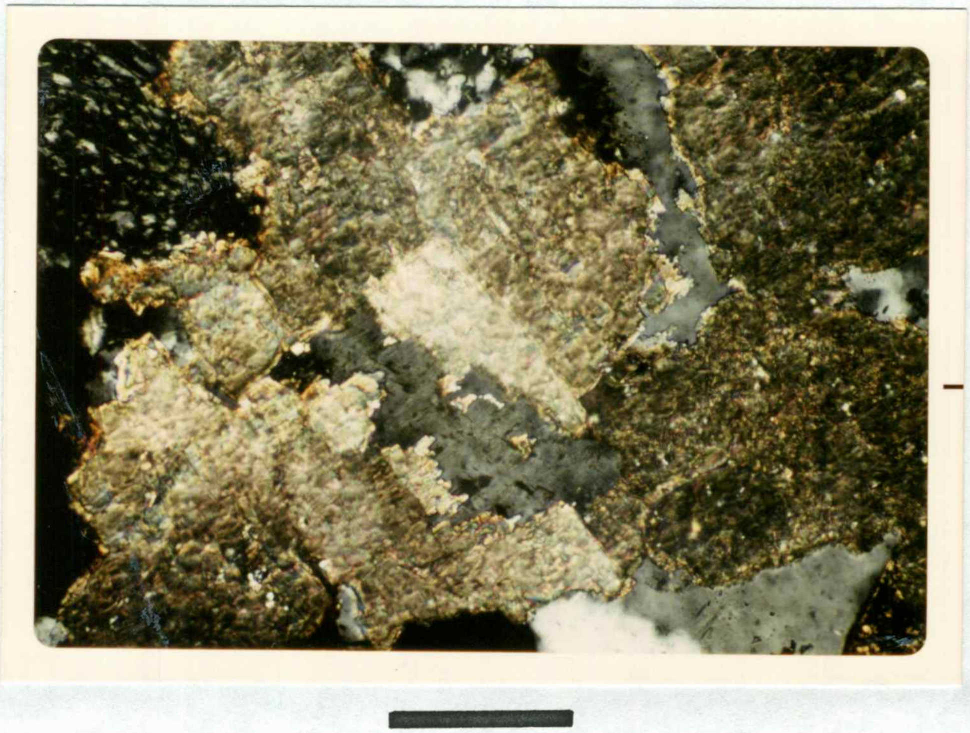

Figure 31. Photomicrograph of ferroan dolomite (yellowish) replacing feldspar grain (gray). A micro-environmental origin for ferroan dolomite is supported by the different stages of extinction of these crystals. Bar scale is 0.1 mm. (Shell Corehole Kan-2 277.0).

Clay Minerals

X-ray analysis indicated highly crystalline illite and lesser amounts of mixed-layer illite/smectite clay minerals in the sandstone, but distinguishing between detrital and authigenic illite is difficult. In x-ray diffraction analysis, high illite crystallinity is consistant with an authigenic origin, and Woody (1982) identified delicate authigenic illite clays in other Cherokee sandstones in southeastern Kansas. Smectite (expandable layered) clay minerals are converted to illitic (non-expandable layers) clay minerals by dewatering (removal of interlayer water) during compaction, which occurs throughout the burial history of the rock (Burst, 1969). Fixation of the interlayer position occurs when K+, probably released during feldspar dissolution, "kicks out" other interlayer cations, resulting in an illite structure for the clay minerals (Grim, 1968).

Bucke and Mankin (1971), Boles and Franks (1979), and Lahann (1980), have suggested that illitization of smectite clay minerals provides the ions necessary to form many different authigenic minerals throughout diagenesis. The conversion of smectite to illite is capable of releasing large amounts of Fe, Mg, Ca, Na, and Si. Silica released early in this conversion is the source of Si that precipitates as quartz overgrowths, as mentioned earlier.

Additionally, Ca can be released to form early carbonate cements. Fe and Mg are usually released at greater depths and temperatures, and form late-stage iron- and magnesium-rich carbonate cements and chlorite. Dapples (1979) stated that authigenic chlorite suggests a reducing environment during formation, which is consistant with the early formation of siderite nodules and pyrite. In the Bluejacket, chlorite is present as clay rims on detrital grains, which apparently formed early in the diagenetic history of the sand.

Wilson and Pittman (1977) stated that the most useful criteria for recognizing authigenic clays in sandstones is the delicacy of the clay morphology, which could not have survived transport. Delicate "worm-like" booklets of kaolinite, observed under the SEM (Fig. 28), support an authigenic origin for this kaolinite. As mentioned earlier, kaolinite occurs in association with dissolved feldspar grains and probably formed as a result of feldspar dissolution. Keller (1970) used his concept of a micro-environment to explain that while conditions for kaolinite formation may not exist throughout the rock, locally the Al:Si and [K+]/[H+] ratios may be favorable to form kaolinite whereas a few millimeters distant, an entirely different product may form. This explanation accounts for the patchy distribution of the kaolinite in the sandstone.

Bucke and Mankin (1971) listed four major factors that allow kaolinite to form: 1) porosity and permeability, allowing migration of interstitial water and growth space; 2) presence of K-feldspar as a source of Al and Si; 3) presence of partially degraded illite as a K+ acceptor; and 4) presence of organic matter to maintain a low pH. As mentioned earlier, kaolinite that forms as a result of feldspar dissolution is considered to be a near-surface alteration that occurs when the rock is invaded by meteoric water.

Carbonate Cements

Carbonate cements are a relatively common diagenetic product in sandstones, and usually consist of calcite, dolomite, ferroan dolomite (ankerite), and siderite (Pettijohn and others, 1973). These carbonate minerals can coexist (Fig. 32) but there is no well established sequence of preciptiation (Pettijohn and others, 1973), although calcite is probably the most common in ancient rocks (Blatt and others, 1972). In fluvial-deltaic sediments of the Gulf Coast (Loucks and others, 1977; Boles and Franks, 1979; Milliken and others, 1981; and Lahann, 1980) and the Mid-Continent (Bucke and Mankin, 1971; Woody, 1982), iron- and magnesium-rich carbonate cements are a late-stage diagenetic alteration that occurs when Fe and Mg are released from

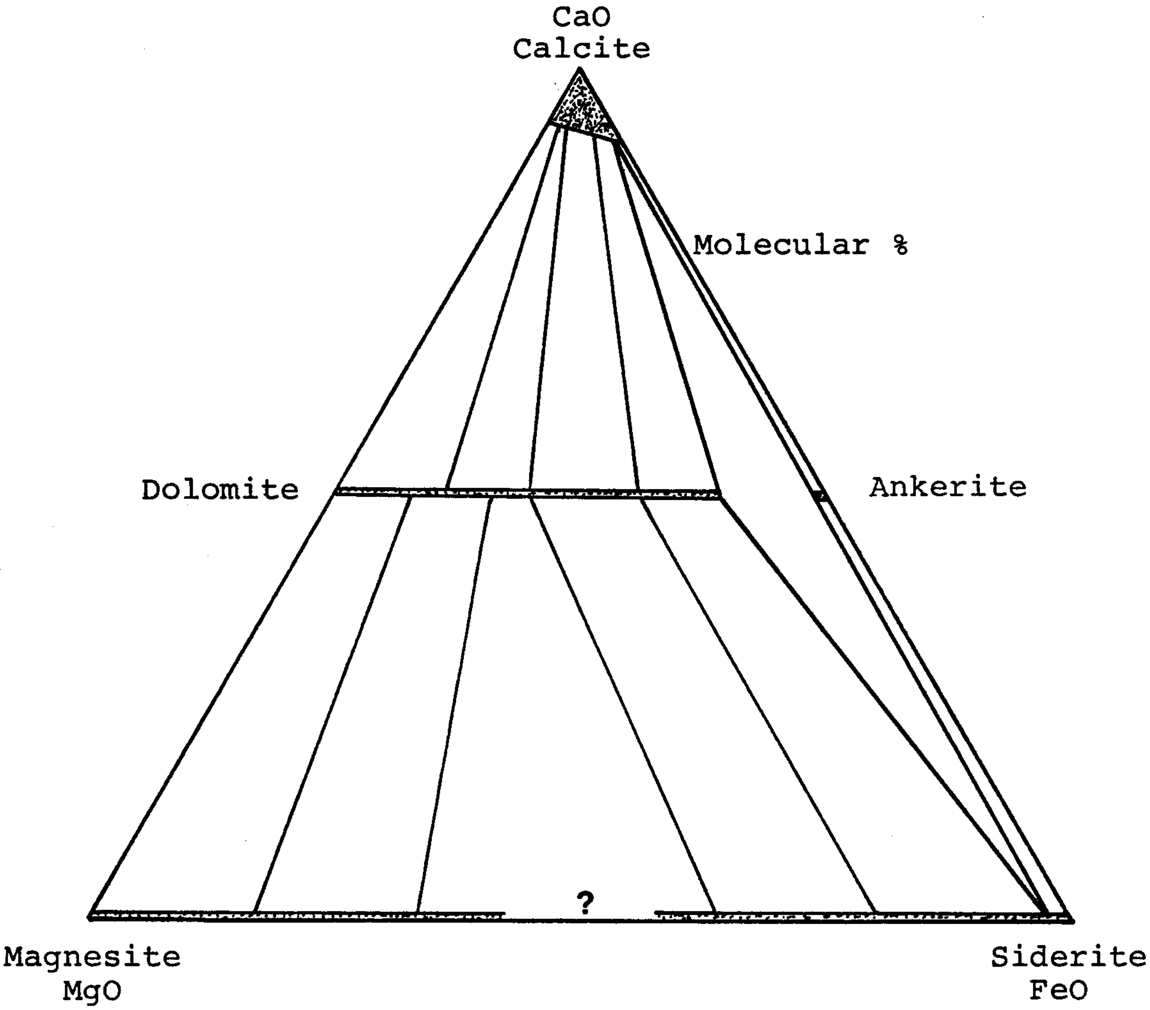

Figure 32. Compositions of carbonates in the system $CaO-MgO-FeO-MnO-CO_2$. The CO_2 component is not considered in this diagram. A complete solid solution series exists between dolomite and ankerite. A complete series may also exist between magnesite and siderite, but such a series is not well established. Tielines connect possible coexisting carbonate members. The three-mineral triangle portrays the coexistence of calcite-ankerite-siderite. (From Hurlbut and Klein, 1977).

interlayer positions within clay minerals during illitization. These workers have concluded that late-stage carbonate cements form in associaton with organic matter in the subsurface. Boles and Franks (1979) and Loucks and others (1977) found that carbonate cements at shallow depths were calcite, whereas the carbonate cements at greater depths were ankerites. They concluded that late-stage illitization of shales released Fe and Mg which reacted locally (in a micro-environment) with the calcite to form ankerite, and dolomite formed where smectites are iron-poor or where iron was taken up by other phases.

Iron- and magnesium-rich carbonates in the Bluejacket commonly occur as a patchy, randomly distributed cement which usually occurs both as a passive pore filling and partial replacement of matrix and detrital grains. This occurrance and distribution is compatible with the micro-environment envisioned for the formation of these cements, and is consistant with the findings of Boles and Franks (1979) and Woody (1982), because ferroan dolomite and siderite are apparently late-stage cements. The minor amount of calcite may be remnant of earlier calcite that has been replaced by ferroan dolomite, although petrographic evidence to support this was not observed. Ferroan dolomite in this sandstone probably formed instead of ankerite because some of the iron was being tied up by the formation of siderite cement.

Paragenesis and Diagenetic History

The course of sandstone diagenesis is programmed by the preburial, prediagenetic factors of provenance, depositional environments and tectonic setting. These interrelated factors influence sand composition and texture, which in turn govern mineral reactions and fluid-flow rates (Hayes, 1979). The diagenetic history of the "upper Bluejacket" began with deposition and burial in a fluvial-deltaic environment on a stable shelf. Compaction of the sediments was not excessive, as they were probably never buried by more than 3500 ft (1067 m) of younger sediments (Ebanks and James, 1974).

Timing of diagenetic alterations in the "upper Bluejacket" Sandstone appears relatively straightforward, although relationships between many of the later alterations are not clearly established. Interpretations are based on grain-to-grain, grain-to-cement, and cement-to-cement relations, and speculation that some cements may have been derived from other diagenetic alterations and earlier cements. The suggested sequence of alterations in the sandstone is: 1) formation of siderite spherulites and pyrite, and chloritic clay coatings on detrital grains; 2) quartz overgrowths; 3) feldspar dissolution; 4) kaolinite formation; 5) precipitation of iron- and magnesium-rich carbonate cements; and 6) sericitization of feldspar and alteration of micas to chlorite. The migration of hydrocarbons followed all of these diagenetic changes. Some processes probably occurred throughout the diagenetic history, such as illitization of smectite clay minerals, and several of the changes were not single events, but overlap in time and occurrence.

The diagenetic history of the "upper Bluejacket" is presented in three stages (Fig. 33), which correspond to the suggested timing and scale of each diagenetic event. Stage One diagenesis includes the early, localized formation of spherulitic siderite and pyrite within the shaley interlaminations and finer grained sandstone. Pyrite and spherulitic siderite apparently formed at or near the surface in association with bacterial decay of organic matter, which was buried with the sediment. Concretionary growth of spherulitic siderite as one of the first diagenetic minerals in this sandstone is consistant with Recent diagenetic processes (Ho and Coleman, 1969, in Blatt and others, 1972; Larson and Chilingar, 1979). Early formation of spherulitic siderite in the "upper Bluejacket" is suggested by detrital grains that are "floating" in the cement, indicating that siderite formed prior to compaction, and where adjacent to siderite spherulites, detrital grains are not cemented by other cements or possess overgrowths. The requirement of low dissolved sulfur conditions for

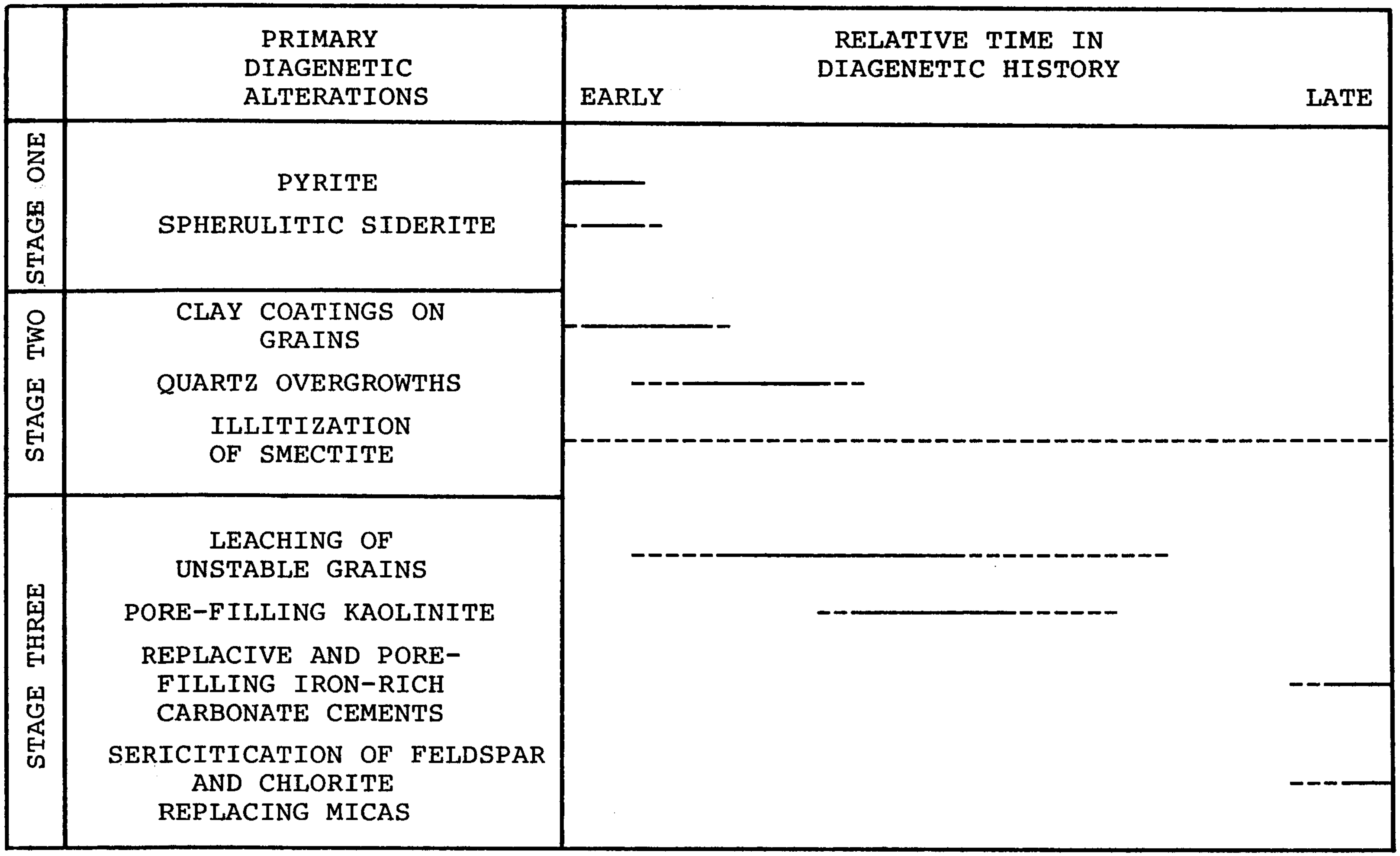

Figure 33. Primary diagenetic alterations and suggested paragenetic sequence. The stages of diagenesis are discussed in the text. Solid lines indicate dominant process and dashed lines indicate possible overlap in relative timing.

siderite formation implies that pyrite formed first, taking the sulfur out of the system. Alternatively, siderite could have formed early in a sulfur-free micro-environment and pyrite could have formed in a sulfur-rich micro-environment, which is supported by the common occurrence of pyrite with organic matter.

The Second stage of diagenesis represents changes that occurred on a larger scale throughout the sandstone, and for the most part, occurred early in the burial history. The formation of clay coatings on detrital grains clearly pre-dates quartz overgrowths (Fig. 16), and probably formed either during or soon after, deposition and burial. Uncompacted "floating" grains, extensive development, and well-defined crystal faces (Fig. 30) suggest that quartz overgrowths formed in primary pore space and were not restricted much by adjacent grains, therefore they probably formed prior to compaction. Silica overgrowths pre-date pore-filling kaolinite (Fig. 30), ferroan dolomite (Fig. 26), and hydrocarbon migration (Fig. 19). The conversion of smectite to illite is included in this stage because it has likely taken place throughout the burial history of the sandstone and occurred as a widespread change within the sandstone matrix and the shaley interlaminations.

Stage Three is more complicated than the earlier stage and many diagenetic relationships within it are not well established. Some of the authigenic minerals that are placed in this stage necessarily post-date other alterations that cannot be placed in the diagenetic sequence with certainty. For example, kaolinite formation has several prerequisites. First, K-feldspar must provide the Al and Si ions necessary for kaolinite to form. This requires feldspar dissolution to take place, or be in the process, as it also provides pore space for fluid migration and space for kaolinite to grow. Additionally, partially degraded illite must act as a K+ acceptor throughout feldspar dissolution and kaolinite formation. Kaolinite post-dates quartz overgrowths (Fig. 30) and does not occur in the same pores with ferroan dolomite, suggesting kaolinite had already filled available pore space. Previously mentioned literature suggests that kaolinitization is a near-surface (within tens of meters) alteration. This is consistant with kaolinite occurrences in the sandstone, which places the timing of feldspar dissolution and kaolinite precipitation early in the burial history of the sandstone. Feldspar dissolution post-dates compaction because delicate "honeycombed" grains (Fig. 30) would almost certainly have been crushed. Leaching of feldspar and precipitation of kaolinite probably continued throughout burial until the chemistry of the pore fluids changed from acidic to basic, which arrested kaolinite cementation and allowed late iron-rich carbonate cements to form (Loucks and others, 1977).

Ferroan dolomite and siderite are interpreted as late diagenetic cements, because of late addition of iron and magnesium from late-stage illitization of smectite. Petrographic evidence supporting this is illustrated in Figure 24, where ferroan dolomite post-dates quartz overgrowths, and in Figure 31, where it etches and replaces detrital feldspar and quartz, and matrix. The patchy distribution of these iron- and magnesium-rich carbonate cements (Fig. 25) is consistant with a late-stage micro-environment formation. The timing of calcite cement is speculative because of its limited occurrence, petrographic observations could not establish definite relationships. Calcite could be an early cement, and its lack of abundance could be the result of iron and magnesium (released during late-stage illitization of smectite) having altered the calcite to ferroan dolomite. One other possibility, as shown by Figure 32, is that calcite could have formed when the iron and magnesium ions were being tied up forming ferroan dolomite and siderite.

Sericitization of feldspar and chlorite replacing mica are interpreted as late-stage alterations, which is consistant with other fluvial-deltaic late-stage diagenetic processes (Fuchtbauer, 1974; Boles and Franks, 1977; Woody, 1982).

SUMMARY AND CONCLUSIONS

Subsurface correlation of the Bluejacket sandstone interval across the Cherokee Basin was accomplished using key marker beds identifiable on geophysical well-logs. This study demonstrated the utility of laterally continuous radioactive black shales as correlation markers. Using well-logs and previously published data, the sandstone distribution of the Bluejacket interval was determined. The Bluejacket in the subsurface may be more extensive than previously indicated, but due to inadequate well-log control, the exact distribution and morphologies of the sandstone bodies could not be determined. Further studies on a smaller scale (perhaps at the county level) are needed to further delineate these sandstones, and using closer spacing of well-logs, to determine more precisely the environment(s) of deposition for this economically important stratigraphic interval.

Environmental interpretation of well-logs is used as an aid for interpreting the depositional environment of the Bluejacket sandstone interval. Well-log interpretation, sandstone distribution, and subsurface correlation of the sandstone bodies, suggests that the Bluejacket Sandstone was deposited by a fluvial-deltaic system that prograded southward across the Cherokee shelf. Three sandstone distributions suggest that a major fluvial channel flowed north-to-south near the center of the study area. A major distributary complex consisting of several elongate, multi-storied sandstone bodies, trends westward in the northwest part of the basin, where it curves toward the south and continues into Oklahoma. A third sandstone enters the study area from the east and trends southwestward where it is correlated to a "minor deltaic area" in Oklahoma. Sediments deposited by the Bluejacket river system were probably derived from multiple source areas, both distant and local. A source area to the north, probably the Canadian Shield, supplied most of the sediments. Pre-existing sedimentary rocks along the basin margin, such as the Nemaha Uplift and possibly the Ozark Dome, are also considered to have contributed sediments.

The composition of the "upper Bluejacket" Sandstone has the following characteristics: 1) quartz is the dominant detrital grain; 2) subequal amounts of feldspars and rock fragments are present; 3) abundant clay matrix occurs throughout the sandstone, along with shaley interlaminations within the sandstone; 4) authigenic cements of silica, siderite, ferroan dolomite, calcite, kaolinite, mica and chlorite clays constitute over 20 percent of the sandstone; and 5) organic matter, pyrite, micas, and heavy minerals are also present in minor amounts.

The diagenetic history of the sandstone consists of a complex sequence of alterations, including cementation, dissolution, and replacement. The sequence is summarized in three stages, which correspond to the relative timing and scale of the diagenetic changes. Stage One is a localized change that involves the early formation of pyrite as a replacement of organic matter and spherulitic, concretionary siderite, which is concentrated within the finer-grained interlaminations. Pyrite is interpreted to have formed before siderite because low sulfur conditions are necessary for siderite to form. Stage Two represents widespread formation of clay coatings and silica overgrowths on quartz grains, which pre-date kaolinite and iron-rich carbonate cements, and illitization of smectite clay minerals. Stage Three is more complex, and involves the dissolution of feldspar, precipitation of pore-filling kaolinite, patchy, pore-filling and replacive iron- and magnesium-rich carbonate cements, sericitization of feldspar and alteration of mica to chlorite. The dissolution of grains and alteration of smectite to illitic clays during compaction is the likely source of cations necessary for the precipitation of the cements. The migration of hydrocarbons into the sandstone postdates these diagenetic events.

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APPENDIX

CORE DESCRIPTIONS

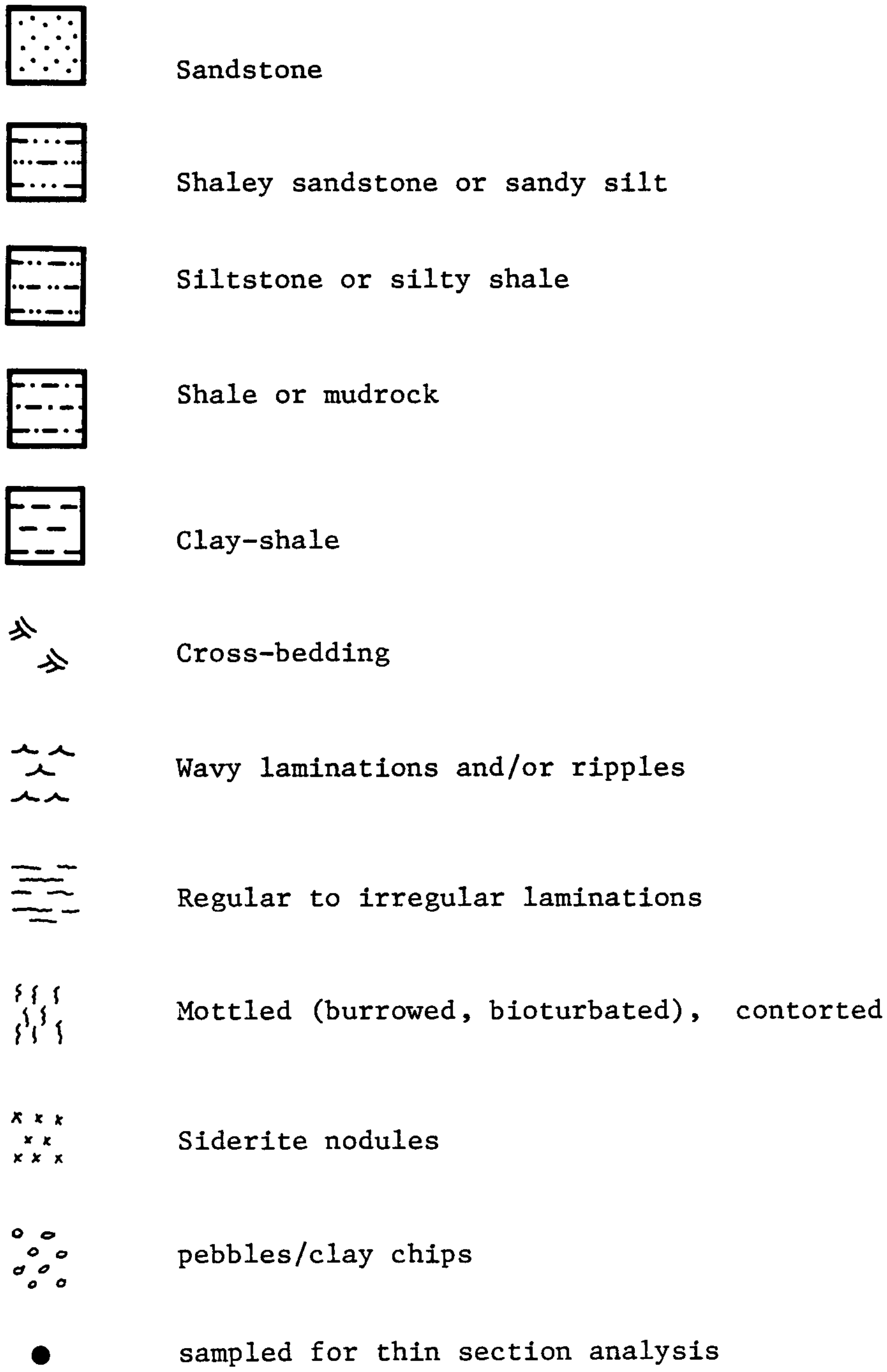
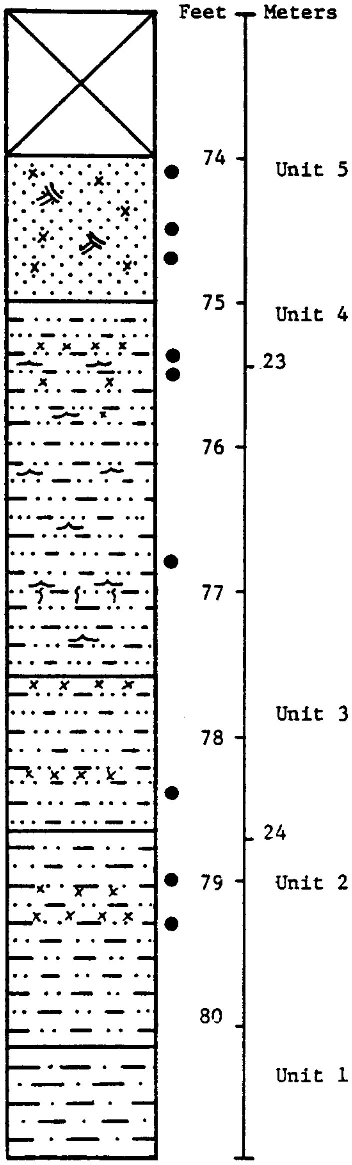


Figure 34. Symbol key for lithologic logs.

LITHOLOGIC LOG



INTERVAL AND DESCRIPTION

Unit 5 74.0'-75.0' (22.56 m.-22.86 m.)
Sandstone, very fine grained, light gray, cross-bedded, contains siderite nodules, oil stained, sharp base.

Unit 4 75.0'-77.6' (22.86 m.-23.65 m.)
Siltstone, sandy, medium to dark gray, reg.-irreg. wavy laminations and small-scale cross bedding, siderite nodules concentrated at 75.4' (23.01 m), mottled at 77.1' (23.50 m.), abrupt basal contact.

Unit 3 77.6'-78.7' (23.65 m.-23.99 m.)
Siltstone, sandy, medium to dark gray, wavy laminations, siderite nodules concentrated in the laminations at 78.4' (23.90 m.) and 77.7' (23.68 m.)

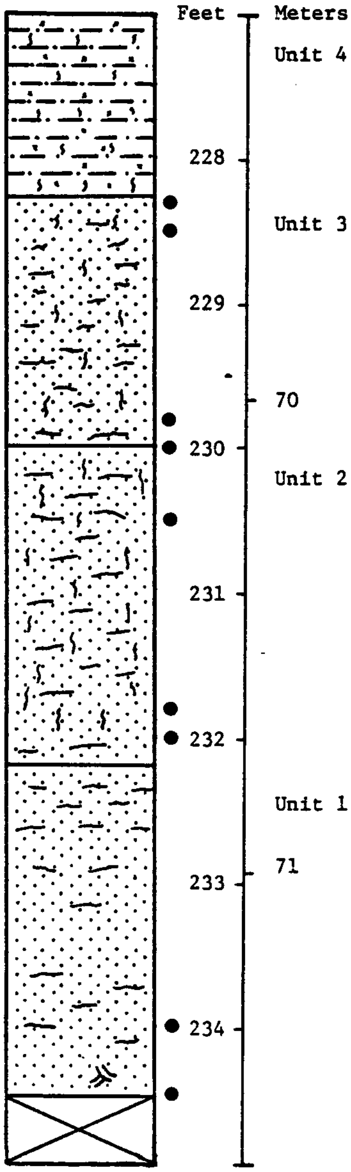
Unit 2 78.7'-80.2' (23.99 m.-24.45 m.)
Siltstone, gray, laminated, siderite concentrate at 79.1' (24.11 m.) and 79.3' (24.17 m.), sharp basal contact.

Unit 1 80.2'-86.2' (24.45 m.-26.27 m.)
Shale, dark gray.

Figure 35. Lithologic log and descriptions for K.G.S.-D. (NW NW NW Sec. 24-T27S-R25E, Bourbon Co., Kansas).

LITHOLOGIC LOG

INTERVAL AND DESCRIPTION



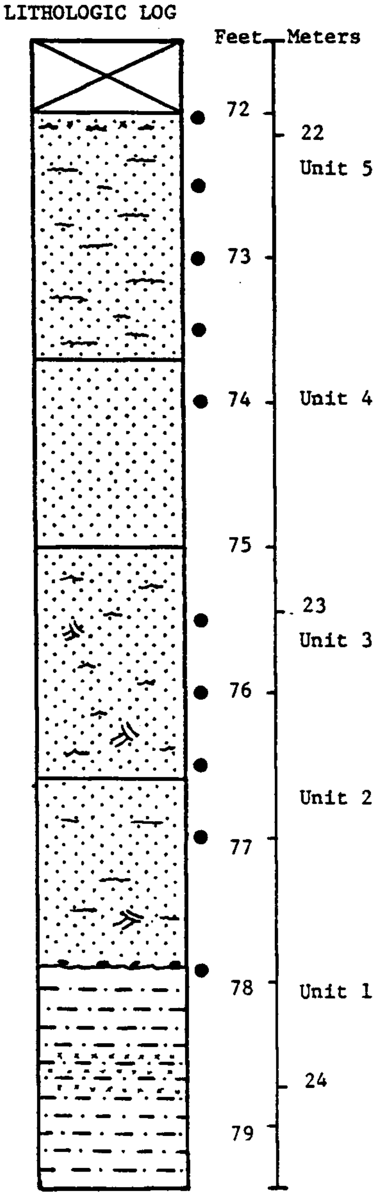
Unit 4 227.0'-228.3' (69.19 m.-69.59 m.)
Shale, gray, mottled, abundant siderite nodules, gradational basal contact.

Unit 3 228.3'-230.0' (69.59 m.-70.11 m.)
Sandstone, very-fine to fine grained, gray becoming darker in the upper 0.2'(6 cm.), mottled (bioturbated), gradational base.

Unit 2 230.0' - 232.2' (70.11 m.-70.78 m.)
Sandstone, very-fine to fine grained, fining upward, heavily bioturbated, contains pyrite, sharp irregular base.

Unit 1 232.2'-234.5' (70.78 m.-71.48 m.)
Sandstone, very-fine to fine grained, gray, cross-bedded near base grading upwards to reg.-irreg. laminations near top, bottom of core.

Figure 36. Lithologic log and descriptions for K.G.S.-N. (NW NW NW Sec. 24-T27S-R24E, Crawford Co., Kansas).



INTERVAL AND DESCRIPTION

Unit 5 72.0'-73.7' (21.95 m.-22.46 m.)
Sandstone, fine grained, oil stained, irreg. laminations and wavy bedding, siderite concentrated along wavy laminations near top, gradational basal contact.

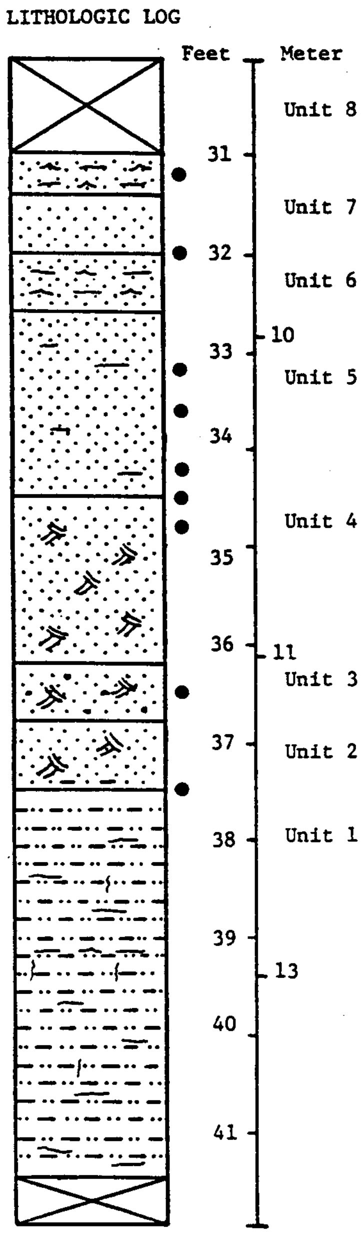
Unit 4 73.7'-75.0' (22.46 m.-22.86 m.)
Sandstone, fine grained, oil stained, massive, calcareous, gradational basal contact.

Unit 3 75.0'-76.6' (22.86 m.-23.35 m.)
Sandstone, fine grained, oil stained, much more wavy and cross-bedding than unit 2, calcareous, gradational basal contact.

Unit 2 76.6'-77.9' (23.35 m.-23.74 m.)
Sandstone, fine grained, oil stained, some laminated and cross-bedding, calcareous, basal contact erosional with small shale chips in the lower 0.1 (3 cm.).

Unit 1 77.9'-86.5' (23.74 m.-26.37 m.)
Shale, medium to dark gray, becoming lighter towards the top, siderite concentrated at 78.5'-78.8' (23.93 m. -24.02 m.).

Figure 37. Lithologic log and descriptions for K.G.S.-Z. (NE NE SE Sec. 26-T27S-R25E, Crawford Co., Kansas.



INTERVAL AND DESCRIPTION

Unit 8. 31.0'-31.4' (9.45 m. -9.57 m.)
Sandstone, very-fine grained, oil stained, reg. to irreg. and wavy laminations, slightly calcareous, gradational base.

Unit 7. 31.4'-32.0' (9.57 m.-9.75 m.)
Sandstone, fine grained, oil stained, massive, gradational base.

Unit 6. 32.0'-32.6' (9.75 m.-9.94 m.)
Sandstone, fine-grained, oil stained, reg. to irreg. and wavy laminations, gradational base.

Unit 5. 32.6'-34.5' (9.94 m.-10.52 m.)
Sandstone, fine grained, occasional irreg. laminations, sharp basal contact.

Unit 4. 34.5'-36.2' (10.52 m.-11.03 m.)
Sandstone, fine grained, cross-bedded, gradational base.

Unit 3. 36.2'-36.8' (11.03 m.-11.16 m.)
Sandstone, like unit 4, occasional pebbles, gradational base.

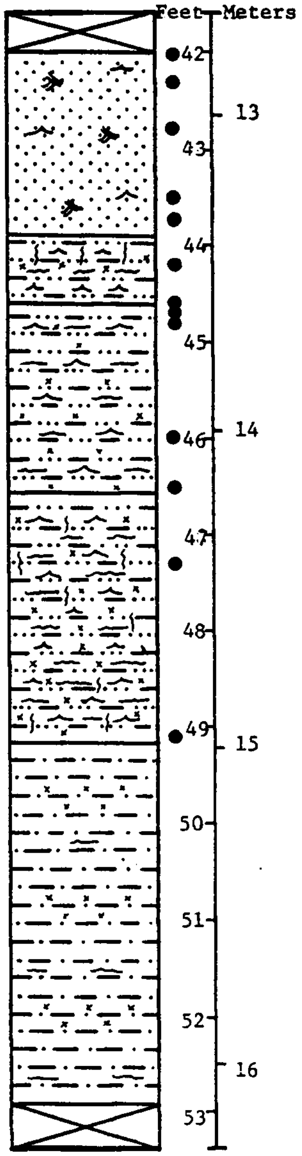
Unit 2. 36.8'-37.5' (11.16 m.-11.43 m.)
Sandstone, fine grained, cross-bedded with shale partings at the base.

Unit 1. 37.5'-41.5' (11.43 m.-12.65 m.)
Shale, silty,, medium gray to gray, reg. wavy laminations becoming more irreg. toward base, bottom of core.

Figure 38. Lithologic log and descriptions for K.G.S.-AA. (NW SW SW Sec. 2-T32S-R24E, Cherokee Co., Kansas).

LITHOLOGIC LOG

INTERVAL AND DESCRIPTION



Unit 5. 42.0'-43.0' (12.80 m.-13.38 m.)
Sandstone, very fine grained with slight coarsening upwards, gray, micaceous, wavy and small scale cross-bedding with shale partings partially masked by siderite and oil stain, slightly calcareous, sharp basal contact.

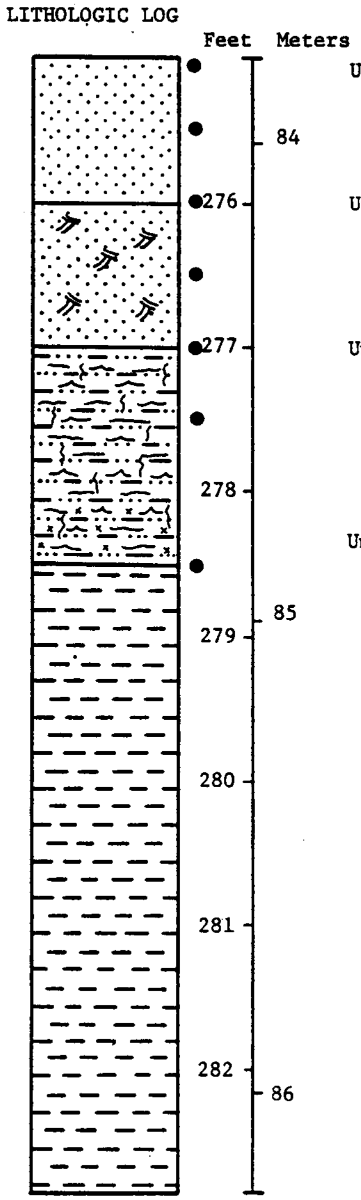
Unit 4. 43.9'-44.6' (13.38 m.-13.59 m.)
Siltstone, sandy, light to medium gray, fine reg. laminations becoming more irreg. and sandy between 44.1' and 44.4' (13.44 m. and 13.53 m.), some small scale cross-bedding or ripples, upper part bioturbated, siderite nodules, sharp basal contact at lamination.

Unit 3. 44.6'-46.55' (13.59 m.-14.19 m.)
Siltstone, sandy, light gray, thin wavy laminations and small scale cross-bedding or ripples, sharp basal contact.

Unit 2. 46.55'-49.15'(14.19 m.-14.98 m.)
Siltstone, sandy, light to medium gray, reg. to irreg. laminations occasionally so irreg. they appear mottled, some wavy and very small cross-bedding or ripples, some siderite nodules, very sharp basal contact.

Unit 1. 49.15'-52.9' (14.98 m. - 16.12 m.)
Shale, very dark gray with lighter silty laminations, siderite zones, bottom of core.

Figure 39. Lithologic log and descriptions for K.G.S.-CC. (SE SE SW Sec. 2-T34S-R23E, Cherokee Co., Kansas).



INTERVAL AND DESCRIPTION

Unit 4. 275.0'-276.0' (83.82 m.-84.13 m.)
Sandstone, fine grained, massive, slightly calcareous, gradational basal contact.

Unit 3. 276.0'-277.0' (84.13 m.-84.43 m.)
Sandstone, fine grained, gray and oil stained, cross-bedded, micaceous, sharp irreg. basal contact.

Unit 2. 277.0'-278.5' (84.43 m.-84.89 m.)
Shale, silty, gray, reg. to irreg. wavy laminations and small scale ripples, commonly mottled, siderite, concentrated lower 6" (15 cm.), sharp irreg. basal contact.

Unit 1. 278.5'-287.0' (84.89 m. -87.48 m.)
Clay shale, dark gray becoming darker toward top, micaceous, abundant organic matter throughout.

Figure 40. Lithologic log and descriptions for Shell Core-hole Kan-2. (SW SW SE Sec. 36-T23S-R24E, Bourbon Co., Kansas).