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Sedimentary environment of Middle Ordovician iron oolites in northeastern Kansas, U.S.A.

ABSTRACT: The petrographical and mineralogical composition of Middle Ordovician (Simpson Group) rocks in northeastern Kansas (Nemaha and Marshall counties) suggest their deposition in a near-shore environment that was affected by both major and minor transgressional and regressional events. Two iron oolite (goethite) horizons found locally in the lower part of the St. Peter Sandstone delineate the position of an ancient shoreline. The sedimentation of Middle Ordovician rocks in northeastern Kansas was influenced by a positive structure (paleohigh) associated with the Midcontinent Rift System, that extended into southern Nebraska. This structure consisting mostly of Precambrian granites, high in magnetite, was the probable source of iron. The absence of St. Peter Sandstone in certain areas of northeastern Kansas is attributed to non-deposition rather than subsequent erosion.

INTRODUCTION

The Middle Ordovician sediments of Kansas are considered to be deposited on the shelf part of *S*-shaped geosynclinal belt that extended in a general east-west direction from Arkansas through Oklahoma, central Texas and into West Texas (Dapples 1955, Ireland 1965, Ross 1976). In Kansas an angular unconformity separates gently dipping Middle Ordovician beds from underlying Arbuckle Group rocks (undifferentiated Upper Cambrian and Lower Ordovician). However, in the study area of northeastern Kansas, the Middle Ordovician rocks onlap older rocks, and in places rest directly upon the Precambrian basement. In western Nemaha County, eastern Marshall County, and extending into southern Nebraska, the St. Peter Sandstone rocks are not present (*see* Text-fig. 1).

The Middle Ordovician (Simpson Group) rocks in Kansas are divided into two formations: the St. Peter Sandstone below and, the Platteville Fm. above (Leatherock 1945). The cyclic sequence of St. Peter Sandstone composed of sandstone, siltstone, shale and sandstone is interpreted as resulting from several major and minor sea level fluctuations (Ireland 1965). During the deposition of the Platteville Fm. the sea level fluctuations generally abated, resulting in deposition of dolomites and limestones interbedded with minor green shale and sandstones. Few petrographic studies have been conducted on the Middle Ordovician rocks in Kansas (LEATHEROCK 1945, IRELAND 1965, METZGER 1980). A more comprehensive study of these rocks from adjacent Midcontinent areas was formerly published by THIEL (1935).

Red ironstones (iron oolites, limonitic sandstone concretions, iron cement in sandstones or shale) in rocks of the same age have been reported from various locations in Minnesota, Iowa, Illinois and Missouri (DAKE 1921, THIEL 1935, WITZKE 1980, VAN HOUTEN & BHATTACHARYYA 1982). LEATHEROCK (1945) described pseudooolites from wells in north-central Kansas close to the study area, but she did not attach any great importance to their occurrence. Despite the differences of opinions regarding the origin of iron oolites (*e.g.*, SORBY 1906, HALLIMOND 1925, PORRENGA 1967, LAMOALLE & DUPONT 1976, HALLAM & BRADSHAW 1979, KIMBERLEY 1980, DAHANAYAKE & KRUMBEIN 1986, COTTER 1988) the consensus is that they were formed in a very shallow-water environment and are a good indicator of sea-level fluctuations. The zone of goethitic iron oolites encountered in this study is spatially associated with St. Peter Sandstone subcrops on the flanks of the Nemaha Uplift (*see* Text-fig. 1). Therefore, the main aim of this study is to determine whether the absence of Middle Ordovician sediments on the Nemaha Uplift area resulted from later erosion or from non-deposition.

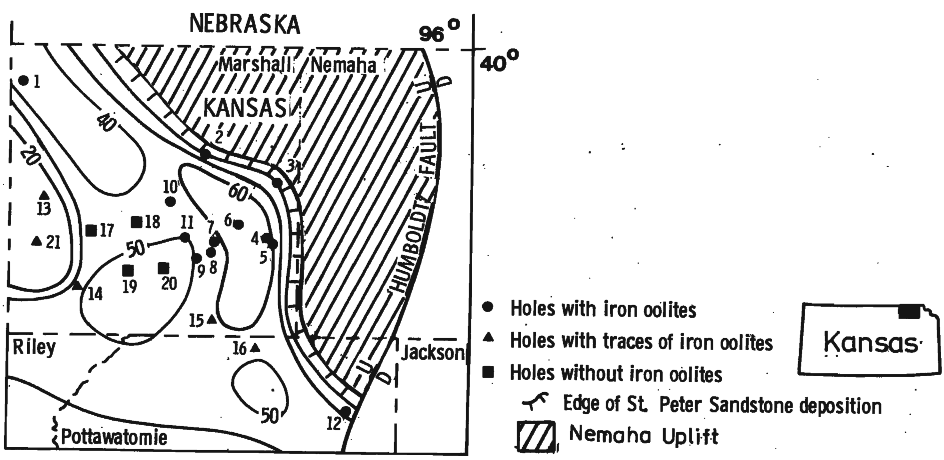


Fig. 1. Map of the study area in Kansas showing the locations of the wells used in the study and the isopach lines (in feet) of the St. Peter Sandstone (U — uplifted, D — downdropped)
Wells: 1 — Schaefer-1, **2** — Cassidy-1, **3** — Olson-1, **4** — Fisher-1*A*, **5** — Dannels-1, **6** — Vermillion-1, **7** — Fischer-1, **8** — Grand-1, **9** — Shearer-1, **10** — Seematter-1, **11** — Christner-1, **12** — McGuire-1, **13** — Randell-1, **14** — Ireland-1, **15** — Staats-1, **16** — Falk-1, **17** — Borgerding-1, **18** — Neal-1, **19** — Sedlacek-1, **20** — Henley-1, **21** — Brown-1

This study is based mainly upon petrographic and mineralogic investigations of the core of the Vermillion No. 1 well and cuttings from an additional twenty wells located in eastern Marshall County, Kansas. Petrographic observations from drill cuttings were supplemented by data from wireline logs. Goethite has a usual log signature of a very high neutron response (over 60 porosity units) caused by its hydroxyl content, and a density of 4.36 gm/cc. Consequently, neutron and density logs were particularly useful to both map the occurrence of the ironstone zone and lateral gradations in its composition. Chemical and *X*-ray diffraction analyses of iron oolites and the cement, together with polished sections examination, added some more information.

PETROGRAPHIC AND MINERALOGIC CHARACTERISTICS

PLATTEVILLE FORMATION

The thickness of the Platteville Fm. varies considerably from 6.1 m in the Dannels No. 1 well to 40.5 m in the Vermillion No. 1 well (Text-fig. 2). The section consists of dolomite, dolomitic sandstone, dolomitic limestone and shale in variable proportions. The top of the unit is generally marked by a dolomitic sandstone or by sandy blue-green shale. Carbonates make up the bulk of the rocks and dolomite prevails over limestone, except for the Fisher No. 1A well where limestone predominates.

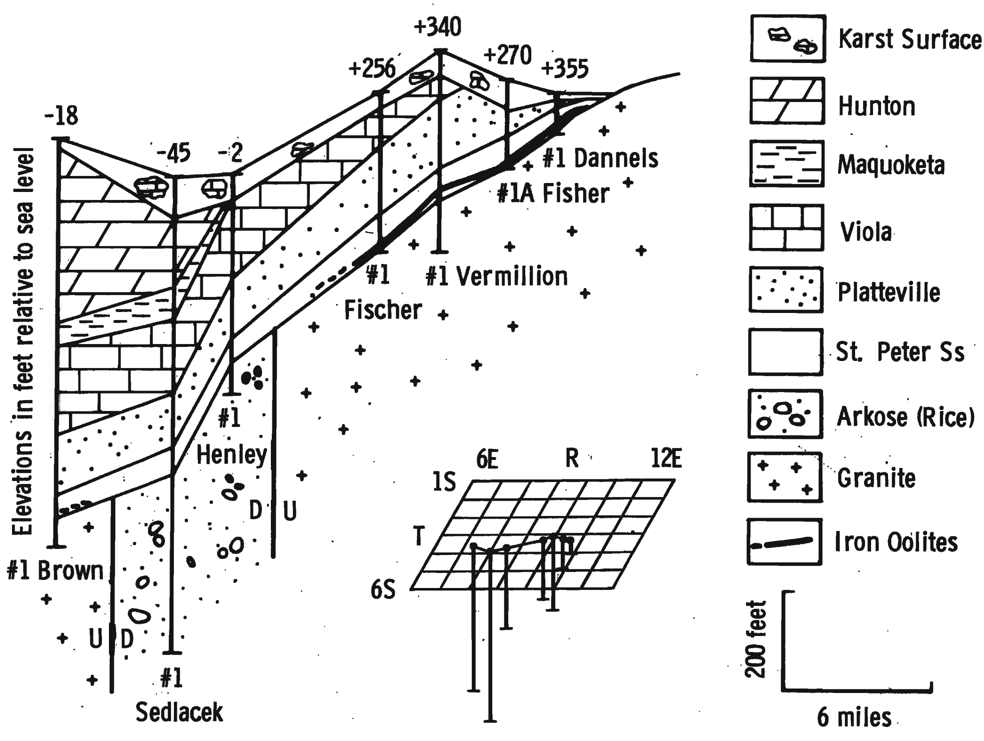


Fig. 2. East-west cross-section through the study area using the pre-Pennsylvanian karst surface as the base level

Dolomitic sandstone and sandy shale

Rounded to subrounded, coarse to medium grained and moderately-sorted quartz is the main detrital component. The quartz grains frequently contain biotite and tourmaline intergrowths as well as gaseous/liquid fluid inclusions and exibit straight extinction patterns. These features may indicate primary igneous origin for the quartz grains. Alkali feldspar and plagioclase are present in minor amounts, less than 3%. The feldspar grains (microcline) are rectangular and tabular and are smaller than the quartz grains. Some of microcline grains with gridiron twinning are euhedral and rimmed by non-twinned feldspar. The index of refraction and the sector-type extinction of secondary feldspar overgrowths is characteristic of adularia. Microcline and orthoclase are only slightly altered.

Plagioclase grains are very rare and when present are translucent due to replacement by quartz-kaolinite aggregates. Accessory heavy minerals consist of zircon, tourmaline, rutile, leucoxene and iron oxides. Minute idiomorphic grains of pyrite are disseminated throughout the rock, in places forming elongated aggregates, pseudoveins and incrustations around detrital grains or faunal fragments.

The open framework of the sandstone is filled by a matrix that makes up to 50% of the rock and consists of fine-grained detrital components and micritic to sparitic dolomite, locally dolomitic limestone, and calcareous shale. A slight replacement of terrestrial grains by carbonates is commonly observed. In places, the cement contains isolated automorphic dolomite crystals.

Carbonates

The carbonate beds vary from micritic, microsparitic to sparitic and are commonly zoned with alternating ferroan and nonferroan layers. Carbonates are usually sandy with minor detrital material (quartz, occasionally feldspars) disseminated throughout the rock. Both dolomite and calcite are present, but dolomite (dolomitic ankerite in ferroan layers) generally predominates. Local lenses or thin beds of dolomitic sandstone occur within the carbonates. Individual quartz grains have pitted surfaces resulting from corrosion by carbonate.

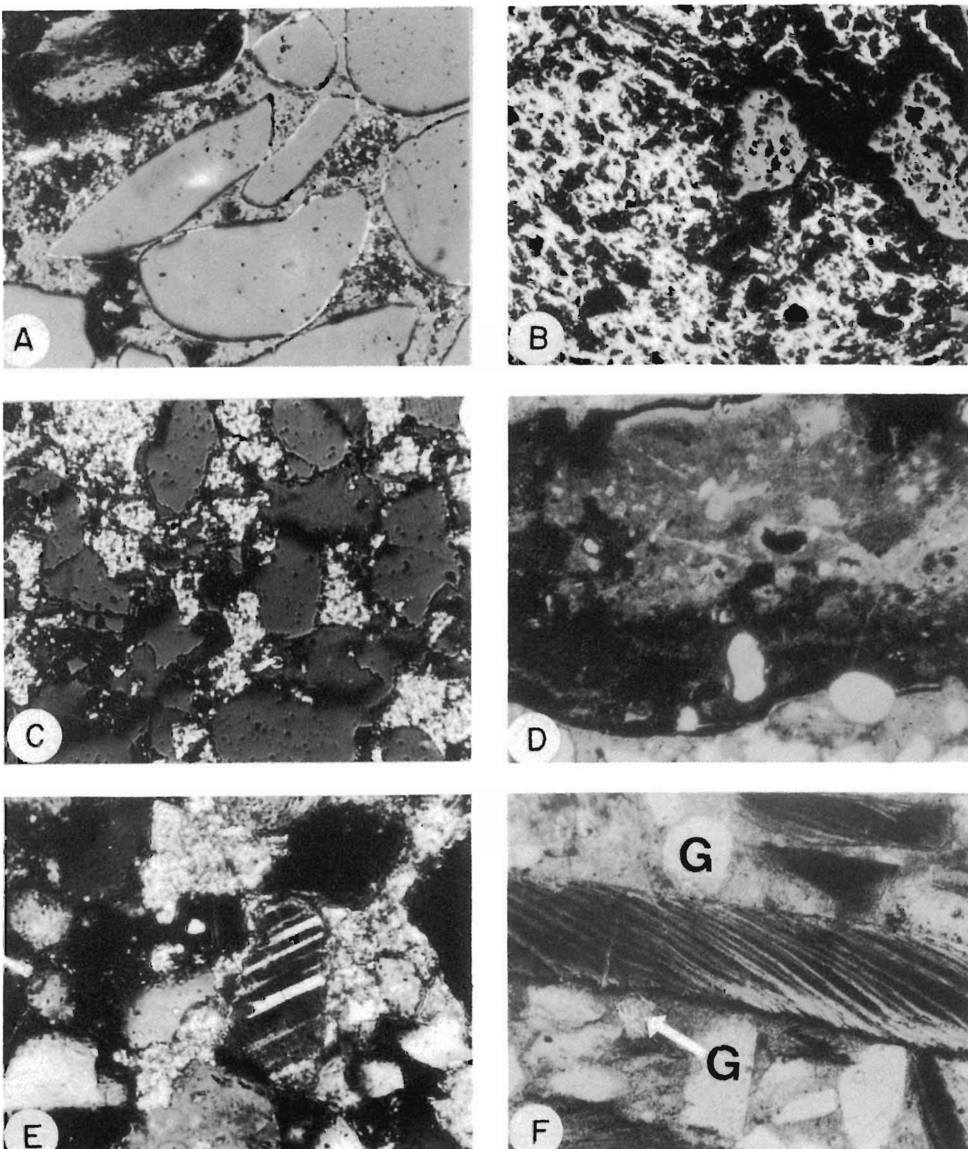
Pyrite, which is sparsely distributed throughout, tends to be preferentially concentrated in the more sandy units where it often rims detrital grains (Text-fig. 3*A*). Irregular oval grains and interstitial infillings of red siderite are present as patchy macroscopic spots staining the carbonates. The association of pyrite and siderite with the more sandy units is probably related to increased quantities of primary organic matter and iron oxides that have since been replaced. Locally, the middle dolomitic part of the section is cherty, where the lower part of the section is more porous. Some of pores are incrusted with automorphic dolomite crystals up to 5 mm in diameter. The Platteville Fm. is predominantly non-fossiliferous. Only a few fossils replaced by ferroan carbonate were found. A similar replacement process has been described by RICHTER & FUCHTBAUER (1978). As the amount of limestone increases (Shearer No 1, Fisher No. 1A wells) so does the amount of fossil material.

ST. PETER SANDSTONE

Whithin the study area, the St. Peter Sandstone can be subdivided into three distinct zones: (*1*) The upper zone consists of soft friable sandstone, (*2*) The middle zone of sandstone, mudstone and shale; and (*3*) The lower zone of oolitic ironstone together with a thin bed of silty sandstone. The thickness of St. Peter Sandstone varies form 7.6 m in the Olson No. 1 well to 20.0 m in the Fisher No. 1A well.

Upper Zone

The upper zone, which is 8.2 m thick in the Vermillion No. 1 well consists of a white to light gray, medium to coarse grained sandstone. The grain size distribution varies greatly in the section. It is generally bimodal with the larger grains rounded-to-subrounded and the smaller grains an-



Petrographic components from Vermillion-1 well

A — Pyrite incrustation around quartz grains, abundant black asphaltic material (364.0 m); polished section, × 50
B — Sphalerite (*white*) in sandstone (351.5 m); polished section, × 50
C — Pyritiferous sandstone (350.1 m); polished section, × 50
D — Phosphorite concretion containing detrital material (351.8 m), × 35
E — Fine-grained dolomitic sandstone containing oligoclase and microcline (362.7 m); cross-polarized light, × 100
F — Poorly sorted dolomitic and glauconitic sandstone (glauconite indicated as G) with large faunal fragments replaced by collophane (362.7 m); cross-polarized light, × 100

gular-to-subangular. Some thin units are moderately-to-well-sorted, but not the upper zone as a whole. Most of grains are oval, only a few of larger grains are spherical.

Polished and partially frosted quartz grains (60 to 85% by volume) are the main detrital component of the rock. The grains frequently have a tattered appearance because of partial corrosion and replacement by carbonates. Biotite and tourmaline occur as inclusions in quartz, but not so much as in the Platteville Fm. The quartz extinction pattern is mostly straight or slightly undulose. Secondary growth of quartz is not as common in these rocks as was reported by THIEL (1935) and METZGER (1980). Therefore, the role of diagenetic processes giving rise to the present angularity of the grains is not considered to be as important as reported by HEALD (1956).

Other detrital material consists of microcline, orthoclase, plagioclase (oligoclase and andesine), discolored biotite, muscovite and chlorite. Their amount is mainly below 5%, but occasionally it ranges up to 10% of rock volume. Similar to the microcline in the Platteville Fm. many feldspars show evidence of secondary growth. Phyllosilicates occur as small flakes unevenly distributed throughout the rock. Heavy minerals such as zircon, rutile, anatase, tourmaline, leucoxene, epidote and magnetite are very common. Minor glauconite grains were found in the lower part of this zone.

The cement (matrix) which makes up from 10 to 35% of the rock volume, has been leached from those parts of the section that are composed of better sorted and rounded grains, leaving a friable and porous rock. Where cement is present it consists of ferroan dolomite, calcite, silica minerals, illite and very fine grained detrital material. The leached portions of the St. Peter Sandstone are separated by unleached, well-cemented, vertical, cross-cutting narrower bands. In the Vermillion No. 1 well, pyrite, sphalerite, and galena mineralization occurs along the margins of unleached structures (Text-fig. 3*B*).

In some drilling profiles, the cement is almost completely replaced by pyrite and minor marcasite, which in extreme cases constitutes up to 40% vol. of the St. Peter Sandstone. In the Vermillion No. 1 well, pyrite cement forms a distinct 35 cm thick bed of pyritiferous sandstone (Text-fig. 3*C*). Traces of asphaltic residue are associated with the pyrite cement. A similar relation occurs in the Simpson Group of Oklahoma (HUFFMAN 1965). Irregularly distributed throughout are brown phosphatic concretions, up to 2 cm in diameter, cementing all kinds of detrital material (Text-fig. 3*D*). METZGER (1980) interpreted them to be fecal pellets, but their diagenetic concretional character is indisputable in the rocks examined. Phosphorite concretions are often surrounded by pyrite grains, that also form incrustations within the concretions.

Middle Zone

The middle zone, which is 4.8 m thick in the Vermillion No. 1 well, consists of fine-to-medium-grained sandstone interbedded and intermixed with silty shale or mudstone. The main differences with the rocks of the upper zone are: (*1*) The sandstone grains are generally finer and angular to subangular; (*2*) The amount of feldspar is higher, reaching up to 15% volume; (*3*) In some thin sections, plagioclase and K-feldspar are present in equal amounts; and (*4*) The amount of other detrital minerals, *i.e.* biotite, muscovite, chlorite, and the amount of such heavy minerals as magnetite, zircon, rutile, tourmaline, hornblende, anatase, leucoxene, monazite, epidote and sporadiacally garnet and staurolite is larger than in the upper zone.

In this part of the section glauconite appears in varying quantities from 1 to 5% vol. It occurs as irregularly shaped medium-sized grains, or less commonly as part of the cement, where it is accompanied by chamosite. Phosphorite concretions (up to 20%) are an important constituent of the rock. Phosphorite occurs also as small pellets without any detrital material inside, larger pseudooolites with sandstone cores, and in the lower part of the section as faunal replacements. Lithoclasts are represented by minor rounded quartz-hematite schist fragments.

The amount of cement (5 to 15% vol.) in sandstones is smaller that in the upper zone and is composed of ferroan carbonate, illite and silica. Locally, the sandstone is hard, poorly sorted, close-packed and has common quartz and feldspar overgrowths, giving the rock a saccaroid (recrystallized) appearance. Sutured contacts are frequently developed between quartz grains. The shales are mainly composed of high-birefringence illite and hydrochlorite, and are partly stained by iron oxides and carbonates in yellow, brown, red, or pink colors. The contacts between different lithologies are gradational where the units are interbedded, but the contacts are sharp where the units are intermixed.

Pyrite microlites are common, but not nearly as common as in the upper zone. In the sandstone pyrite is mainly distributed throughout the cement, while in siltstones and shales pyrite often forms short stringers and pseudoveinlets along bedding planes. Small, vertical, discontinuous veinlets composed of quartz and chlorite were also found.

Lower Zone

The lower zone, which is 3.5 m thick in the Vermillion No. 1 well, consists of alternating layers of silty shale, mudstone, and fine grained sandstone (Text-fig. 3*E*) together with two layers of ironstone that will be described separately. The same two ironstone layers are also present in the cores of three other wells drilled in the area by *Texasgulf, Inc.*, and more than 30 other well-cuttings profiles.

There are two apparent differences between the rocks of this zone and those of the middle zone. The first is the large amount of iron oxides disseminated throughout the rock. The upper portion has a red speckled appearance whereas the lower portion has a more even red color. Secondly, the rock contains a large amount of faunal debris completely replaced by collophane (Text-fig. 3*F*). Some of the replaced material can be identified as conodonts, brachiopods, ostracodes, and unidentified elongated spikes with a spiral or fibrous internal structure.

In the fine-grained sandstone, intraclasts of red shale up to 5 cm were found. They contain oval, oblate and spheroidal forms similar in shape to those found in the iron oolites, but here they are replaced by carbonates, except for the nucleus, which may consist of quartz, glauconite or phosphorite. Secondary carbonate consists often of one large crystal of ferroan calcite into which smaller, younger, rhombic crystals of dolomite occur (Text-fig. 4*A*). Phosphorite concretions are also found in this zone with some of them consisting of both phosphorite and carbonate (Text-fig. 4*B*).

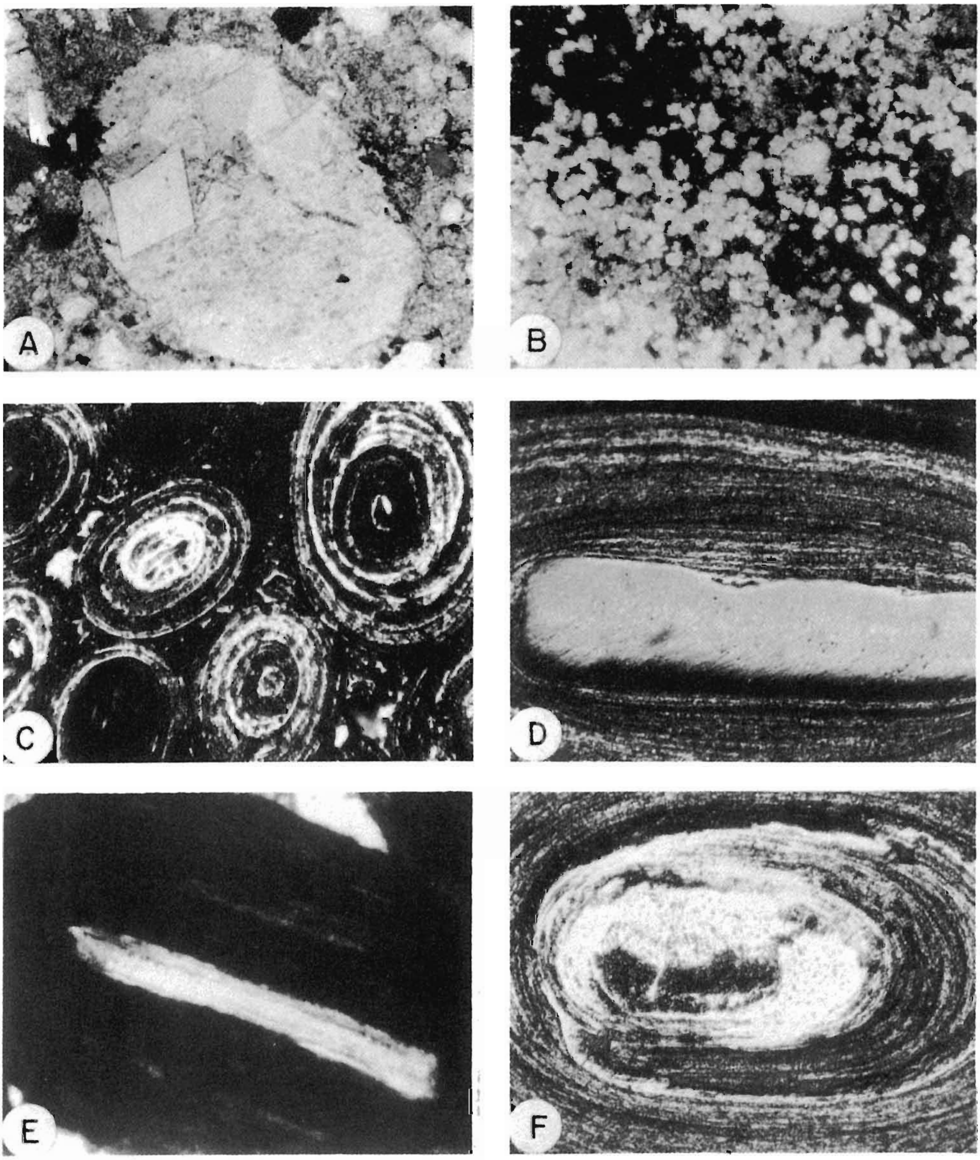
The modal petrographic analysis of St. Peter Sandstone shows the rocks in the upper zone to be quartz arenite, quartzose wacke, rarely subarkosic wacke. The sandstones in the middle zone could be classified as subarkose or rarely arkose (PETTIJOHN & *al.* 1972).

Oolitic ironstone

Two oolitic ironstone beds (the upper 1.35 m, and the lower 0.8 m thick) are recognized in the Vermillion No. 1 well. The top boundary of the upper bed is not sharp, and variable quantities of ooids are present in the lower one meter of the overlying mudstone. The upper boundary of the lower bed is also gradational, while the lower boundaries of both units are sharp and distinct.

Ooids in the upper bed make up to 85% vol., and have distinct internal concentric structure (Text-fig. 4*C*). They consist of cryptocrystalline goethite which makes it difficult to tell how the goethite crystals are arranged. In some ooids, slightly translucent goethite shows a diffuse radial crystallization pattern. The detrital nuclei in the majority of ooids are not recognizable because of their small size. When recognizable, the ooid nuclei consist of quartz grains, fragments of ooids, faunal phosphorite debris (Text-figs 4*D* and 4*E*) and occasionally glauconite and feldspar. Some of large ooids embrace several grains of detrital material. Ooids have various shapes such as spheroidal, oblate spheroidal, egg- and kidney-shaped, and discoidal, which occur intermixed. Fractures in ooids are filled with secondary ferrous dolomite or siderite.

The amount of cement varies greatly. Where the cement makes up less than 15% of the rock it usually consists of finely crystalline dolomite and ankerite with



Petrographic components from Vermillion-1 well

A — Iron ooid replaced by ferroan calcite and automorphic dolomite (365.1 m); cross-polarized light, × 100
B — Phosphorite (*dark*) — carbonate (*light*) concretion (365.2 m); cross-polarized light, × 35
C — Goethite ooids in silty dolomitic matrix (364.2 m); polished section, × 35
D — Goethite ooid with quartz nucleus (363.9 m); polished section, × 50
E — Goethite ooids with nucleus made up of faunal debris replaced by phosphorite (364.2 m); cross-polarized light, × 35
F — Goethite ooids with pyrite nucleus (365.4 m); polished section, × 50

minor detrital quartz, feldspar and clay minerals. When the amount of cement (matrix) is larger (up to 30%), clay minerals of illite and illite-montmorillonite group account for the bulk of the increase. Abundant faunal debris replaced by phosphorite occurs throughout the cement, which is also impregnated with finely dispersed iron oxides.

The lower bed consists of siltstone in which iron oolites occur in various concentrations in parallel laminae. On a small scale, the parallel laminae are often wavy or broken up, with the intensity of these small disturbances increasing near the contact with the oolites. The ooids which are here more ellipsoidal, discoidal, and oblate spheroidal, occur in certain laminae in close association with coarse-grained, well rounded, quartz grains and phosphorite concretions. The peculiar feature in this bed is the occurrence of chamosite and pyrite as inclusions (Text-fig. 4*F*) within ooids. The contact between goethite and chamosite is blurred, but seems to suggest a detrital nature of chamosite.

The siltstone is composed of clay minerals of illite and hydromuscovite group and is impregnated with carbonates and iron oxides. It also contains small admixtures of detrital material, *i.e.* fine-grained angular quartz, feldspar and mica.

Single ooids from both units range in size from 0.25 to 2.0 mm, with a median of between 0.3 to 0.4 mm for the upper bed and 0.7 to 1.1 mm for the lower bed. In the upper oolite bed concentric forms of ooids predominate, while in the lower bed eccentric, distorted (spastoliths) and broken forms dominate.

Microscopic examination of ooids from other wells show similar features as described from the Vermillion No. 1 well. They are spheroidal and oblate spheroidal in shape and show a well developed concentric texture, forming distinct envelopes (cortices) around the nucleus. Each envelope apparently separates with ease from the next one and has the same smooth surface and irridescent metallic luster as the outer surface of all the ooids. Goethite is the principal mineral as affirmed by chemical and *X*-ray analysis. The goethite is relatively pure, with no significant enrichment in particular elements.

ENVIRONMENTAL CONSIDERATIONS

The lithological sequence and regional distribution pattern of ooids, glauconite, phosphorite, and fragmented faunal debris of the St. Peter Sandstone in this study indicate near-shore, subtidal to shallow offshore environment in which the water was generally warm and oxygenated. The distribution of carbonates, shales, siltstones and sandstones as well as ooids suggest sea level fluctuations and/or shoreline migrations that may, in part, be related to isostatic adjustment affecting the positive structure corresponding to the Nemaha Uplift. Because of the low relief and broad extent of the shelf, small fluctuations of sea level and/or shoreline position resulted in broad changes of sedimentation as indicated by the regional sedimentary pattern.

The lower St. Peter Sandstone, as evidenced by its lithological character and its relation to the Precambrian basement, generally has a transgressive character. The lower iron oolite bed contained in the distal muddy facies represents a time of incipient transgression and action of storm surges (DREESEN 1982). The shale intraclasts (containing altered ooids) that occur in the fine-grained sandstone directly overlying the lower ironstone bed suggest a minor sea recession as a storm set-up. The shaly ironstone layer that is present in the lower part of the St. Peter Sandstone farther from the presumed shoreline (Text-figs 1–2) probably correspond to a new environment of ooid formation that postdates this recession. The second iron oolite bed marks sea starvation that was preceeded by several lower rank regressions and transgressions. The petrographic composition and rock textures of the middle St. Peter Sandstone suggest uplift of associated paleohighs, promoting larger influx of less mature detrital components. This structurally controlled uplift had large influence on the shoreline position, however. The upper St. Peter Sandstone zone represents a regressive pattern with subdued paleohighs supplying mature, recycled, and eolian detrital material.

Marine and eolian quartz, probably recycled several times and transported generally from northern areas accounted for most of the St. Peter Sandstone detrital material.

The lithological record of the Platteville Fm. suggests uniform deposition throughout northeastern Kansas. The positive land area that influenced deposition of the St. Peter Sandstone was partly or even entirely submerged below sea level and a large shallow sea governed the environment of deposition.

Pyrite and other base metal mineralizations, leaching of the uppermost St. Peter Sandstone, and development of secondary porosity in the lower part of the Platteville Fm. are all connected with diagenetic processes and migration of intraformational brines rich in hydrocarbons.

DISCUSSION AND RESULTS

The petrographic composition and structure of Simpson Group rocks in the study area show pronounced differences when compared with other regions (HUFFMAN 1965, IRELAND 1965, METZGER 1980). The main difference is variable, but mostly immature sandstone composition of the middle St. Peter Sandstone zone which in other regions is composed mostly of waxy-green shale. Other differences include: variable thickness of the St. Peter Sandstone, larger amount of detrital material other than quartz, amount and composition of cement, as well as the occurrence of one or two oolitic ironstone beds. These differences are related to the paleo-Nemaha Uplift west of the Humboldt Fault that controlled the sedimentation in this area.

Oolitic ironstones occur at the boundary between sandy and sandy-clayey sediments and have similar textural characteristics like Ordovician oolites allover the world (PETRANEK 1964, VAN HOUTEN 1986). However, in contrast to most peri-Gondwanide Ordovician oolite ironstones that are rich in chamosite, the Kansas ooids are composed of goethite. Based on the presented results, favored is primary-syndiagenetic origin for the ooids with iron being supplied directly from adjacent landmasses, as reported by LAMOALLE & DUPONT (1976) for modern ooids in Lake Chad. The transgressing sea could also have reworked the lateritic cover of the invaded hinterland. The necessary chemical weathering does not have to be related to a warm climate (VAN HOUTEN 1985), however the area was located at about 10°S latitude (ROSS 1976).

Appreciable amounts of detrital magnetite and specular hematite were noticed in heavy mineral fractions and cuttings in all the examined wells. Granitic basement rocks, commonly having a high magnetite content (BICKFORD & *al.* 1981) and quartz-hematite schists (fragments found in the St. Peter Sandstone) would be a logical source for the iron. The pure goethite composition of the ooids is also inconsistent with origin by oxidation of an earlier chamosite precursor, as suggested by MAYNARD (1986). The presence of pyrite, chamosite and siderite may suggest an anoxic environment. However, it is assumed these minerals to have formed diagenetically in the presence of organic matter (STRAKHOV 1953, CURTIS & SPEARS 1968). No evidence of goethite replacing chamosite was found.

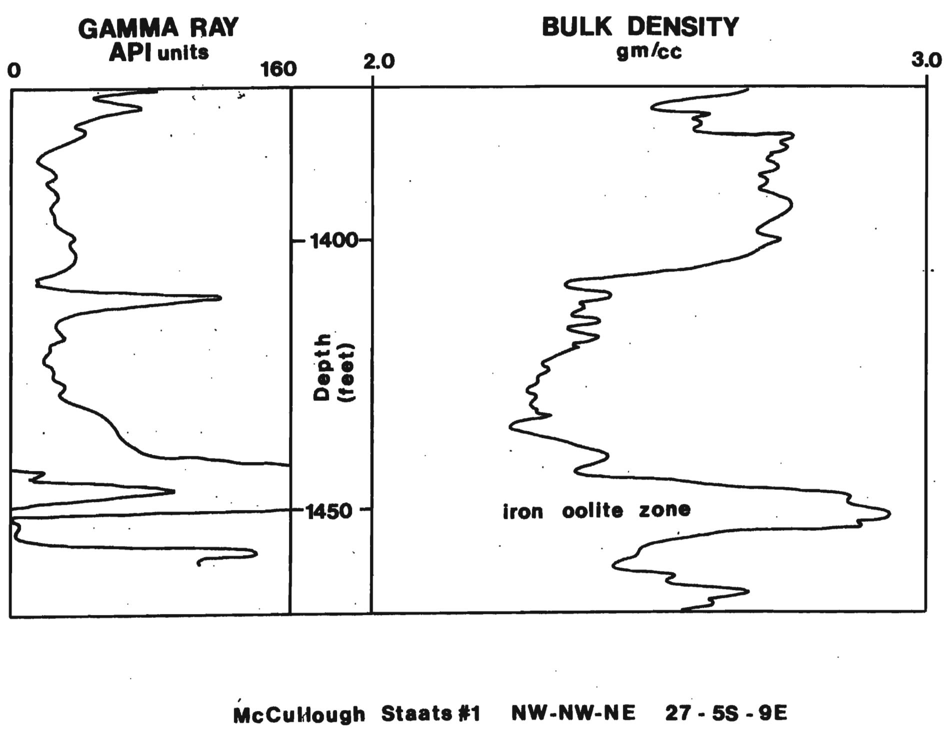


Fig. 5. Position of the ironstone bed in Staats-1 well as manifested by neutron and density logs (depth 442.0 m)

The noticeable content of TiO_2 up to 0.4% in some goethite samples agrees with magmatic origin of iron. Assuming that the pre-Upper Pennsylvanian karst surface did not have an excessive amount of relief in the area, an average slope of less than 0.5% can be calculated for the sea bottom on which the oolites were deposited (Text-fig. 2).

The occurrence of oolitic ironstones in lower Middle Ordovician rocks is marked by a highly distinctive response on several wireline geophysical logs. In the sections located farther from the shoreline where the ooids are absent, the corresponding horizon is commonly a shale, with a density of 2.5 gm/cc. and a neutron response of about 25 porosity units. Where iron oolites are present and depending on their composition and thickness, rapid increases in these values occur with a density ranging up to 3.21 gm/cc. and a neutron reading of 57 p.u. (Text-fig. 5). The high neutron response of the ironstone zone has generally been interpreted as being related to increased porosity. However, the high neutron response in the investigated section is caused by the large hydrogen content associated with the hydroxyl component of goethite. This allowed to recognize the goethite content of ironstone beds in those wells where cuttings were not available. Hematite, magnetite and pyrite have significantly lower neutron porosities, that preclude their identification.

The amount of phosphorite as replacement of faunal debris, concretions and pellets, varies considerably and ranges up to 11% P_2O_5. No evidence was found that phosphorus was derived from previous either fecal, other organic or detrital material. Therefore, the origin of phosphorite is debatable, but may well be the result of mixing of deep oceanic water with warmer shallow sea water, as suggested by BERRY & WILDE (1978).

CONCLUSIONS

The deposition of Middle Ordovician sediments in north-eastern Kansas was affected by the paleo-Nemaha Uplift trending parallel to the Midcontinent Rift System (BERENDSEN & *al.* 1989). During deposition of the St. Peter Sandstone this structure formed an island chain within the shallow Middle Ordovician sea. This suggests that the Transcontinental Arch and the Ozark area were not the only positive elements that governed sedimentation within the Middle Ordovician sea (WITZKE 1980).

The stratigraphic sequence of the St. Peter Sandstone is explained as being mostly transgressive during iron oolite deposition and regressive during deposition of the overlying sandstone complex. The iron oolites are believed to be of primary-syndiagenetic origin, with the iron supplied from adjacent continent.

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ŚRODOWISKO SEDYMENTACJI ORDOWICKICH OOLITÓW ŻELAZISTYCH KANSASU

(Streszczenie)

Sedymentacja osadów środkowego ordowiku w NE części stanu Kansas uzależniona była od obecności pozytywnej struktury podłoża, tzw. *paleo-Nemaha Upliftu* (*patrz* fig. 1–2). Stwierdzone dwa horyzonty oolitów żelazistych pozwoliły określić wzajemne relacje krótkotrwałych transgresji i regresji, jak też ich związek z pogrążeniem się struktury *paleo-Nemaha Upliftu.* Regionalne rozprzestrzenienie skał węglanowych, piaskowców, mułowców, oolitów żelazistych, glaukonitu, fosforytów oraz rozmaitych okruchów fauny (*patrz* fig. 3-4) sugeruje przybrzeżne środowiska sedymentacji.

W przeciwieństwie do większości ordowickich oolitów żelazistych, które są zbudowane z szamozytu, badane oolity są wyłącznie getytowe. Ich obecność w niektórych profilach została rozpoznana geofizycznie; odpowiada jej wzrost gęstości do 3,2 gm/cc jak i silny efekt neutronowy do 57 p.u. (*patrz* fig. 5). Szczegółowe badania oolitów żelazistych pozwalają sugerować, iż powstanie ich związane było z dostarczaniem żelaza z pobliskich lądów w warunkach klimatu ciepłego.

W przeciwieństwie do poglądów wcześniejszych, brak oolitów żelazistych w NE części stanu Kansas przypisać należy brakowi ich depozycji, a nie zaś późniejszej erozji.