Distribution of petrophysical properties in a lower Morrow sandstone (Keyes), southwest Kansas

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Summary

Core 5 low A (Anadarko Production Co., Kansas Geological Survey) sampled the Keyes sandstone from the lower Morrow from Morton County (sec. 8, T. 33 S., R. 40 W.), Kansas (fig. 1, core location 4). The well has produced a small amount of oil and is in the Cimarron Valley field where the Morrow produces both oil and gas. Core 5 Low A was incorporated in an M.S. thesis project largely funded by the Tertiary Oil Recovery Project (TORP) at the University of Kansas (Franz, 1984). The core was studied as part of an attempt to relate geological aspects and petrophysical properties of selected Morrowan rocks in southwestern Kansas. The study focused on petrographic and petrophysical properties and their interrelationships, for given general lithofacies types.

Glauconitic, crossbedded sandstone constitutes the major reservoir facies in this core. The lithofacies is significant because it exhibits a range in permeability (0.1–176.4 md), porosity (7.9–16.8%), and effective pore radii (2–17 microns). Sedimentologic and diagenetic factors are important as controls of petrophysical properties. The vertical distribution of permeability implies preferential fluid flow through the upper portion of the sand body. However, the chlorite and ferroan dolomite-ankerite cements may react with injected fluids. Knowledge of this type is important in the development of a field, for example, in the design of an enhanced-recovery project.

Stratigraphy

The type log (fig. 2) is a generally applicable subdivision of the Lower Pennsylvanian in the Anadarko Basin and the Hugoton Embayment. In western Kansas, rocks of Morrowan age have been defined as the Kearny Formation (fig. 3; Zeller, 1968; McManus, 1959). The Kearny Formation consists of those rocks present between the generally oolitic limestone of Mississippian age and the overlying dark limestones and shales of the Atoka. The upper contact of the Morrow with the Atoka is usually easily picked out on logs because of the distinctive Atokan "Thirteen Finger limestone." The Kearny occurs within a depth interval of 1,300–1,900 m and ranges up to 185 m in thickness. The formation thickens and occurs deeper southward across Kansas into the Anadarko Basin (Swanson, 1979).

The subdivision of the Kearny (Morrow) into lower and upper sections generally separates marine deposits of the lower Kearny from younger nonmarine deposits. The lower Kearny consists of black shales and discontinuous, glauconitic limestones, sandstones, and fossiliferous sandstones. The upper Kearny is characterized mainly by black shales, carbonaceous shales, and discontinuous, coarse-grained, arkosic sandstones. The Keyes sandstone, at the base of the lower Morrow, is a discontinuous band of glauconitic sandstones and sandy lime packstones.

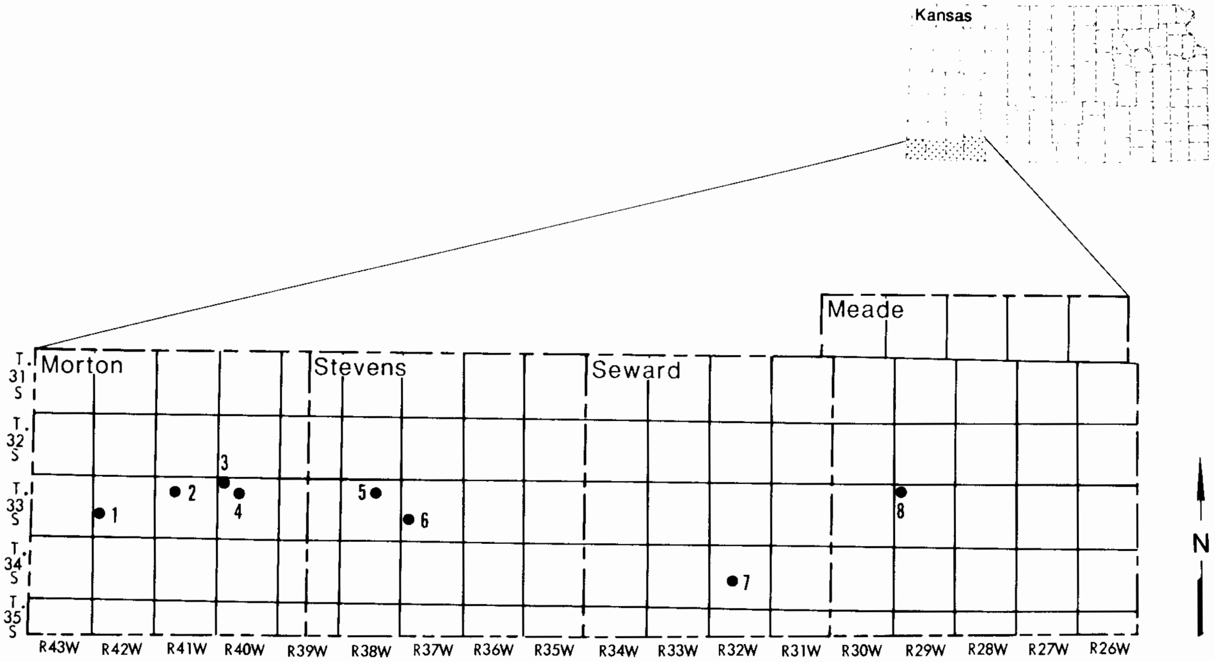


FIGURE 1—Location of cores used in this study.

Core 5 Low A was taken from a depth interval of about 1,740.7–1,753.6 m (5,615–5,657 ft; 5,624–5,666 ft by log) in Morton County (sec. 8, T. 33 S., R. 40 W.), Kansas (fig. 1, core location 4). The Kearny (Morrow) section and cored interval are indicated on the log for well 5 Low A shown in fig. 4. The cored interval corresponds most closely to the basal, marine Keyes sandstone of the lower Morrow (fig. 2).

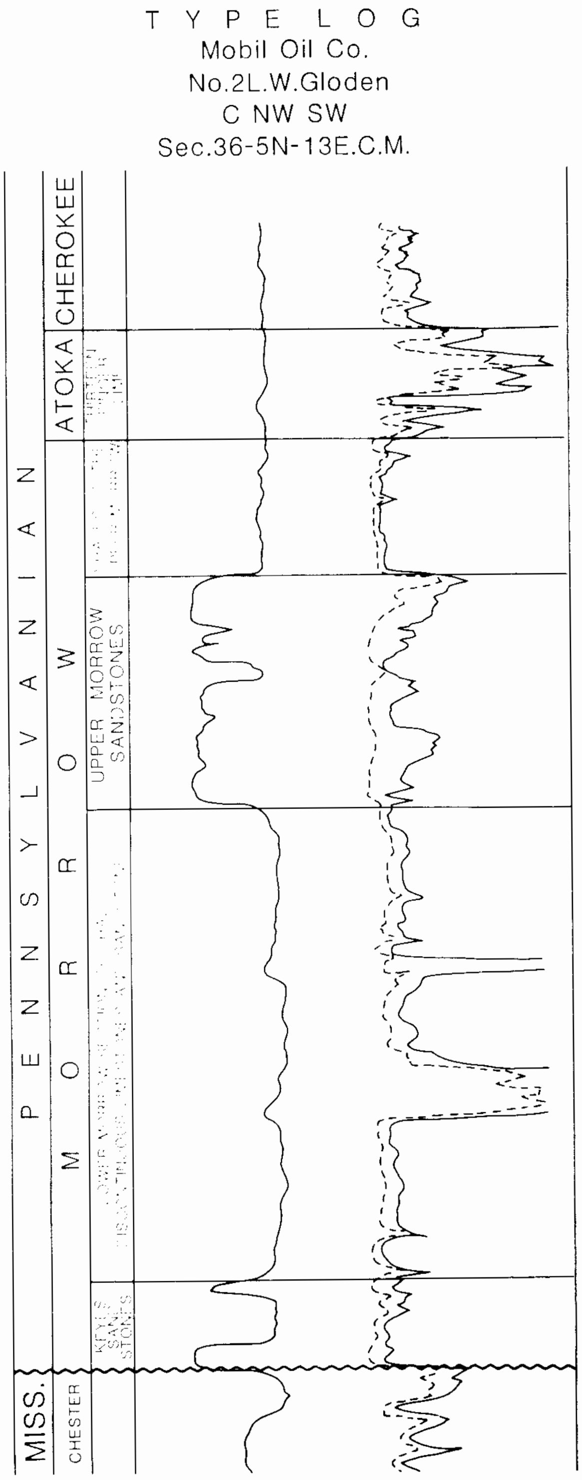


FIGURE 2—Typical electric log of Morrowan Stage and adjacent rocks in the Anadarko Basin (after Arro, 1965).

Structural and depositional setting

Major tectonic elements of the Midcontinent during the Pennsylvanian are shown in fig. 3. Deposition of lower Morrow sediments took place during a general transgression from the Anadarko Basin into the Hugoton embayment. This transgression was marked by a number of shoreline stands during which depositional environments included nearshore beach and barrier bar and shallow marine shelf (Busch, 1961; Khaiwka, 1968).

Extensive southeastward deltaic progradation characterized the paleogeography of southwestern Kansas during deposition of upper Morrow sediments (Swanson, 1979; Adler and Rascoe, 1983). Marginal marine and deltaic environments prevailed at this time. Sand, typically coarse grained, commonly was deposited in point bar sequences and distributary channels and as distributary mouth bars (Swanson, 1979).

Petroleum geology

Sandstones and conglomeratic sandstones of the upper Morrow are most important as reservoirs in the Anadarko Basin and Hugoton embayment (Swanson, 1979). Most production has been wet gas with distillate, although pools of fairly light (38–42 API) oil exist throughout the area (Swanson, 1979; Paul and Bahnmaier, 1981).

The Keyes sandstone interval in Core 5 Low A is productive in the Cimarron Valley field, located in Morton County, Kansas. Oil and gas production in this field comes from the St. Louis Limestone (Mississippian), the Morrow, and the Council Grove Group (Permian–Wolfcampian). Gas production has been much more significant than oil production, totaling 626,983 MCF. Cumulative oil production is 184,328 bbls through 1982. In 1982, 54,453 MCF of gas and no oil was produced. Well 5 Low A (Low 5A) has produced 1,072 bbls of oil. Sample production figures from other Keyes wells in this field include: 90 BOPD with 40% water (Low 3A), 70 BOPD with 20 BW (Low D5), 4,256 MCFPD (Low C4), and 9,980 MCFPD (Goddard A-1; Paul and Beene, 1983; W. L. Watney, personal communication, 1983).

Core description and interpretation

Two important lithofacies occur in Core 5 Low A: glauconitic, crossbedded sandstone and muddy, poorly sorted, glauconitic, bioturbated sandstone (figs. 5, 6, and 7). The former is more abundant and is the reservoir facies. It is generally medium- to coarse-grained and moderately well sorted (fig. 8). A coarser variation that contains shale clasts up to 1 cm long is present. Towards the top of the major interval of this lithofacies, grain size ranges down to fine grained, and sorting improves (well to very well sorted; fig. 9). The predominant sedimentary structure is relatively high-angle crossbedding. Thin laminae of black clay are abundant except in part of the upper half (3.5 m) of the core.

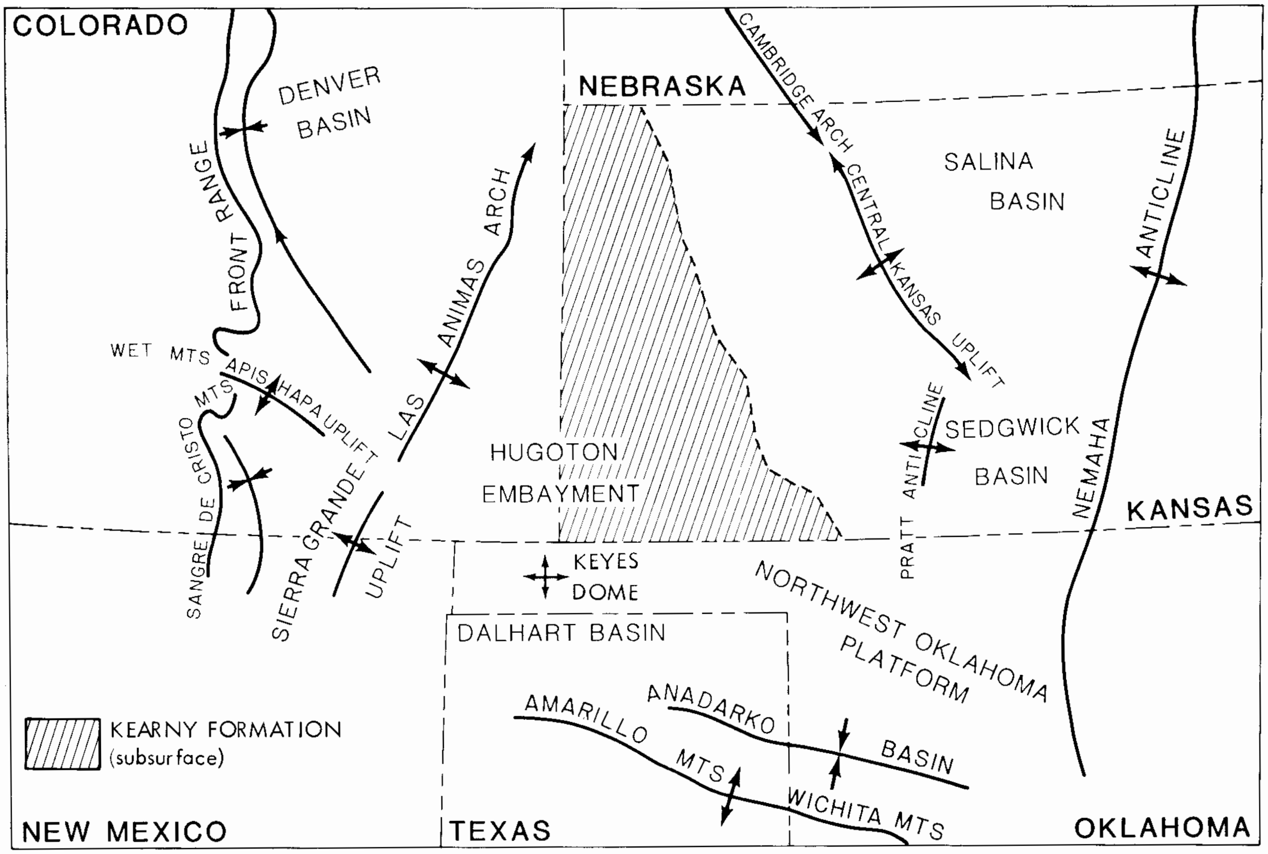


FIGURE 3—Occurrence of the Kearny Formation and tectonic features of the southern Midcontinent (after Merriam, 1955; McManus, 1959).

The vertical sequence present in Core 5 Low A is basal greenish limestone and shale (0.6 m); muddy, poorly sorted, bioturbated sandstone (0.5 m); crossbedded sandstone (1.6 m); bioturbated sandstone (1.9 m); then a thick (7.9 m) interval of crossbedded sandstone (fig. 7). Contacts between facies are fairly sharp. Overlying the cored interval is about 50 ft of shale. The greenish limestone and shale sequence is most likely Mississippian. The nature of the Mississippian–Pennsylvanian contact is unknown due to poor core recovery; however, the contact generally is believed to be a regional angular unconformity. The vertical sequence in this cored interval seems to represent an overall regressive transition from a lower energy (possibly interbar or bar flank) area on a shallow marine shelf to a higher energy area represented by the crossbedded sandstone lithofacies. The thick interval of crossbedded sandstone lithofacies becomes cleaner (fewer shale laminae and clasts) and better sorted in its upper half, suggesting more agitated energy conditions. The shoaling-upward sequence and the abundance of glauconite suggest the crossbedded sandstone of Core 5 Low A was deposited as an offshore bar (Franz, 1984). Offshore bars typically show characteristics reflecting an increase in energy conditions upwards, although this is usually seen as an upwards increase in grain size (Brenner and Davies, 1974; Spearing, 1975).

Petrography and diagenesis

The main lithofacies of Core 5 Low A, crossbedded sandstone, is assigned a general petrographic classification (Folk, 1980) as follows: moderately well to very well sorted medium to coarse sandstone, dolomite, and quartz-cemented submature to mature glauconitic subarkose. Detrital constituents include an average of about 7% feldspar, 3-25% glauconite, and less than 1% skeletal carbonate grains. Shale clasts average on the order of 3% and range up to nearly 12%. They are more abundant in the lower portions of lithofacies.

Diagenesis of the crossbedded sandstone lithofacies has led to formation of authigenic materials (chlorite, quartz, ferroan dolomite-ankerite) and to compaction. Chlorite grain coatings and quartz overgrowths are best developed in the upper half of the core (figs. 10 and 11). Late-stage ferroan dolomite-ankerite occurs largely as a replacement of detrital clays (laminae and clasts), but also as a pore-filling cement (fig. 12). This authigenic mineral is most notable in the lower "shaly" portions of the core. Compactional features (stylolites) associated with clay laminae also seem more significant in the lower portions of the core (fig. 13).

Petrophysical properties

Porosity, permeability, and effective pore-throat size in the crossbedded sandstone lithofacies range from 7.9 to 16.8%, 0.1 to 176.4 md, and from about 2 to 17 microns (figs. 14, 15, and 16), respectively. Porosity and permeability were determined by brine saturation and with a Ruska liquid permeameter. Pore-size distribution curves (figs. 14, 15, and 16) were derived from data obtained by

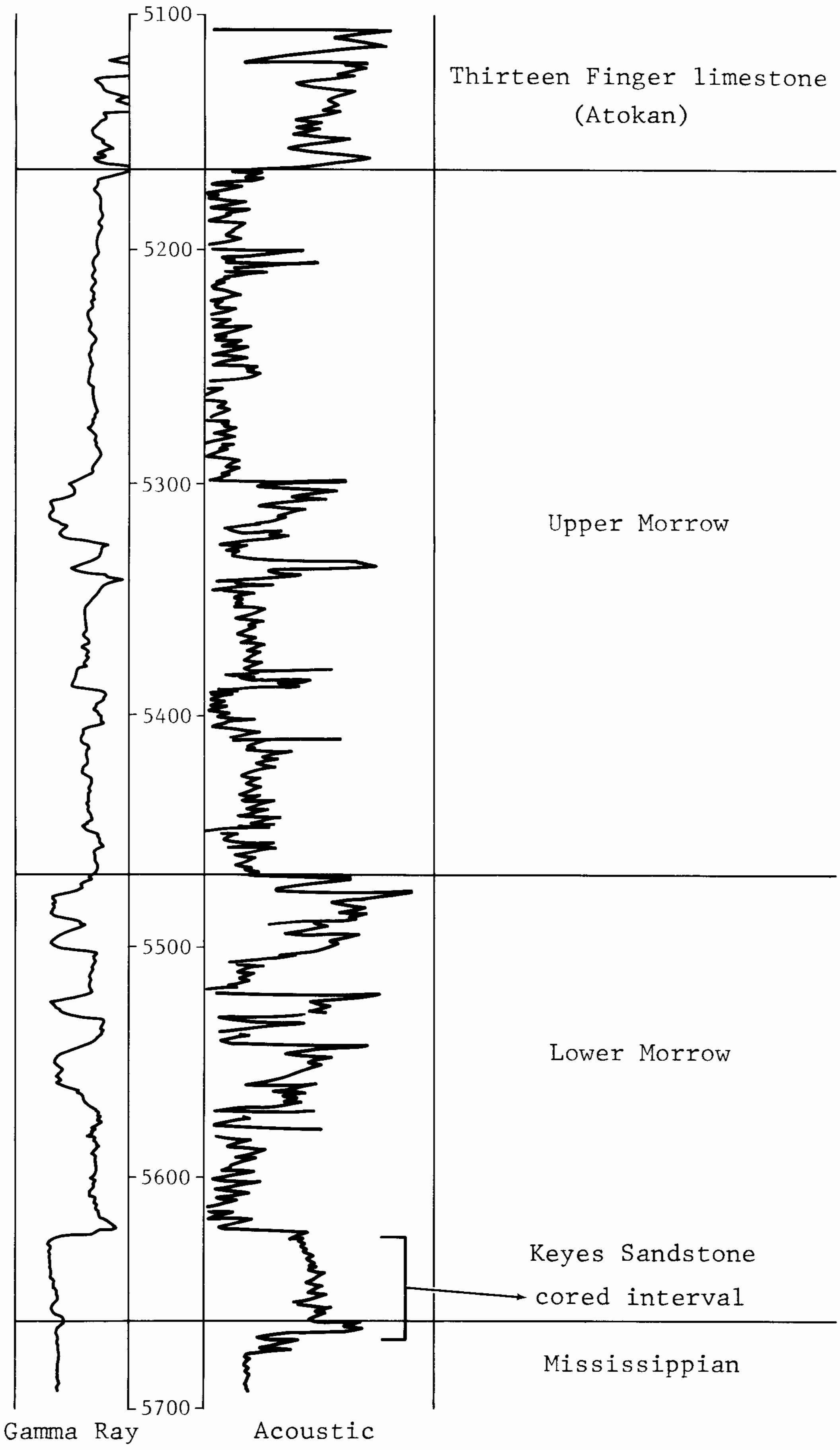


FIGURE 4—Gamma-ray/acoustic log for well Anadarko Low A #5, Cimarron Valley Keyes field, Morton County, Kansas.

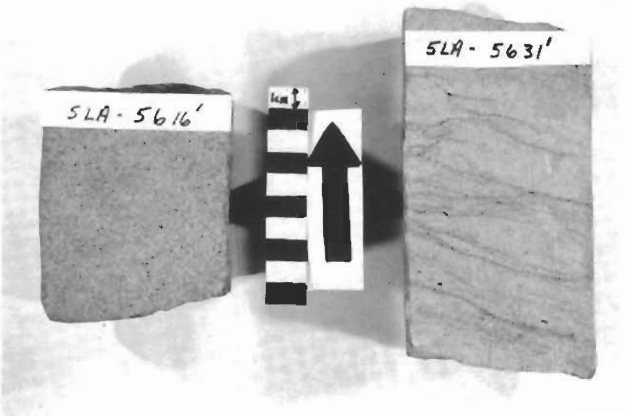


FIGURE 5—Glauconitic, crossbedded sandstone. Upper portion at 5616 ft (left), lower at 5631 ft (right). Note characteristic black clay laminae; scale = 10 cm.

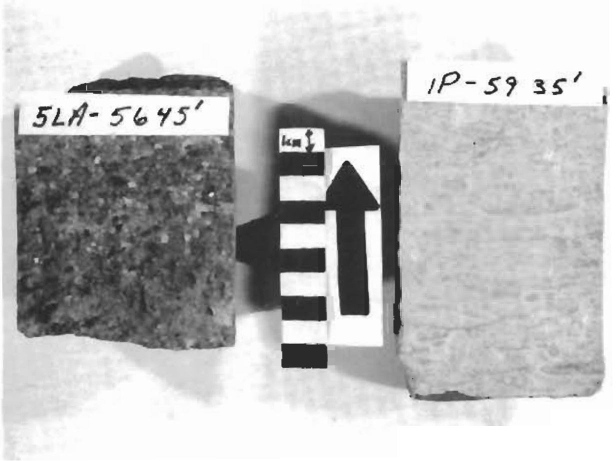


FIGURE 6—Muddy, poorly sorted, glauconitic, bioturbated sandstone (left). From lower part of core at 5645 ft; scale = 10 cm.

mercury injection tests performed by Core Labs, Inc. (Pittman, 1979).

The vertical distribution of these properties, particularly permeability (fig. 7), is important to note. The upper half of the major portion of crossbedded sandstone has the higher values of permeability, porosity, and pore-throat size. The locations of the samples for which a pore-size distribution curve is presented are indicated in fig. 7 by asterisks.

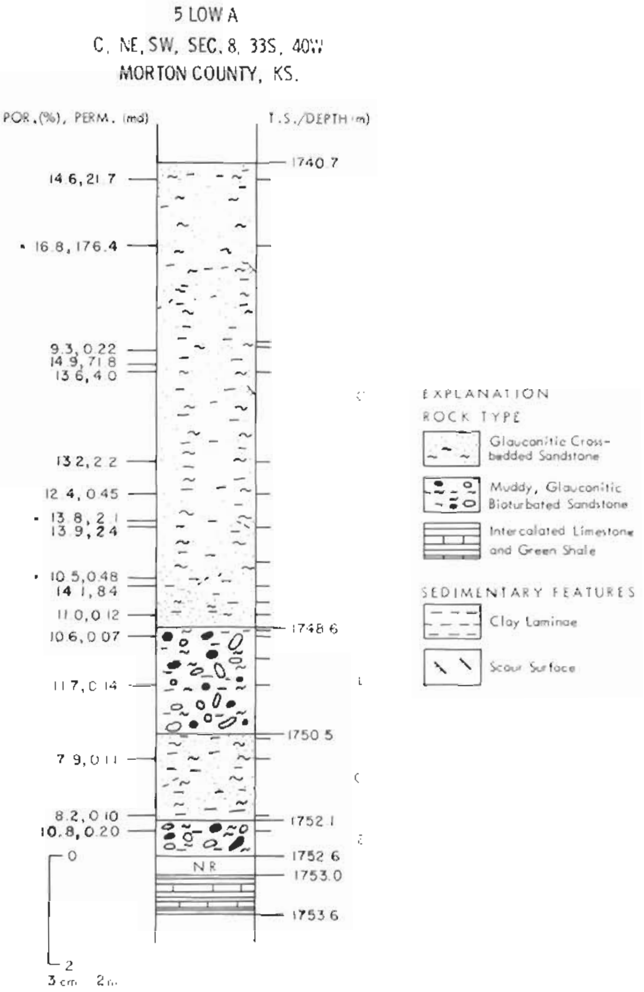


FIGURE 7—Core of well Low A #5 showing vertical distribution of permeability and porosity as well as rock type.

Relationships between sedimentology, diagenesis, and petrophysical properties

Higher permeability values in the upper half of the main interval of crossbedded sandstone can be associated with higher porosity and larger pores (figs. 7 and 14). Depositional and diagenetic factors are believed to be important controls of this vertical distribution of petrophysical properties. The upper part of the core tends to be somewhat better sorted and cleaner (less clay and fewer laminae and clasts) than the rest of the cored interval (figs. 8 and 9). Sorting is an important control of initial porosity and permeability; in general, better sorting favors higher porosity and permeability (Pettijohn and others, 1973, p. 525). A higher percentage of clays (including ductile shale clasts) would tend to promote compaction, thereby reducing pore-throat size, porosity, and permeability. Compactional features are more obvious in the lower part of the sequence, including the lower half of the main crossbedded sandstone

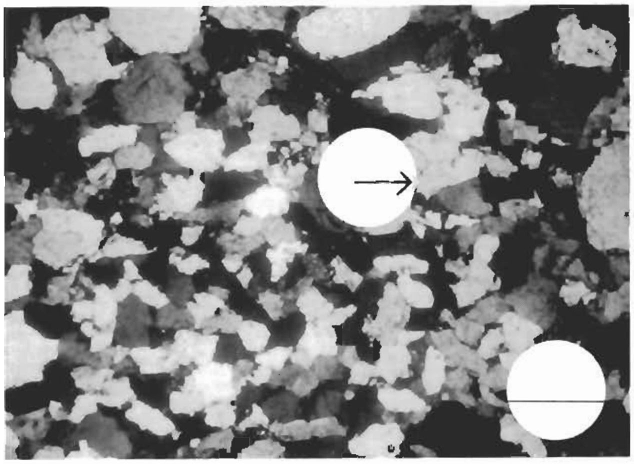


FIGURE 8—General textural character of crossbedded sandstone lithofacies—medium to coarse grained, moderately well sorted. Note ferroan dolomite-ankerite (arrow). Depth—5635 ft; bar = 0.7 mm XN.

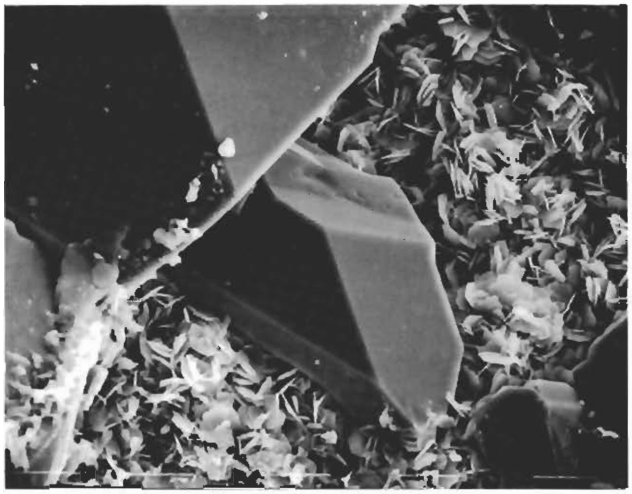


FIGURE 10—SEM photomicrograph of authigenic chlorite grain coating overgrown by quartz. Characteristic diagenetic features of the upper part of the crossbedded lithofacies. Depth—5619 ft; white bars = 10 microns.

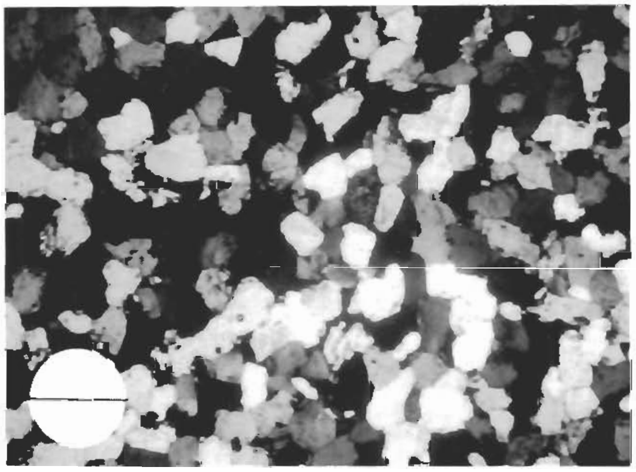


FIGURE 9—Upper portion of crossbedded lithofacies—fine to medium grained, well to very well sorted. Depth—5619 ft, bar = 0.7 mm XN.

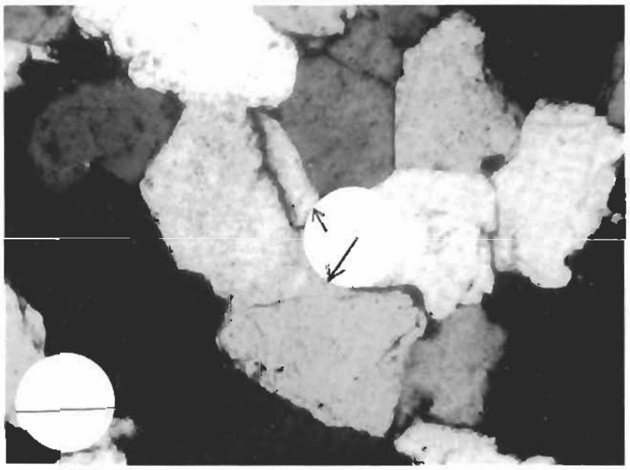


FIGURE 11—Quartz overgrowth cementation characteristic of upper part of crossbedded lithofacies (arrows). Depth—5619 ft; bar = 0.2 mm XN.

interval (fig. 13). Estimates of porosity reduction by compaction were made using the equation: porosity loss by compaction = porosity-initial (assumed) − [porosity-present (measured) + percent cement (measured)] (Jonas and McBride, 1977, p. 42). Compaction is somewhat greater in the lower part of the crossbedded lithofacies: sample 5LA5619.5—8.7% porosity reduction by compaction, 5LA5635.3—12.3%.

Pore type and authigenic mineralogy also are probably important controlling factors of permeability. A high percentage of intergranular pores favors high permeability in contrast to a high percentage of micropores (clays to pore-throat size less than 0.5 microns), which is associated with low permeability (Pittman, 1979). Point counts of pore types reveal that sample 5LA5619.5 (K = 176.4 md) has 71.1% intergranular pores and 6.0% micropores (22.9% secondary), as compared to sample 5LA5635.3 (K = 2.4 md), which has 48.6% intergranular and 40.6% micropores (10.8% secondary; fig. 17). In addition, ferroan dolomite-ankerite as a replacement and cement may reduce permeability in the lower part of the core. The well-developed quartz overgrowth cement in the upper portion of the core, if formed early, could have prevented or reduced compaction.

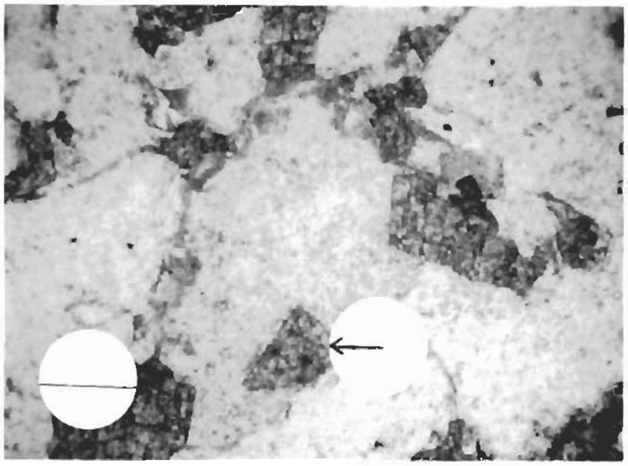


FIGURE 12—Ferroan dolomite-ankerite replacement of clays (arrow). Characteristic diagenetic feature of lower part of core. Depth—5648 ft; bar = 0.2 mm PPL.

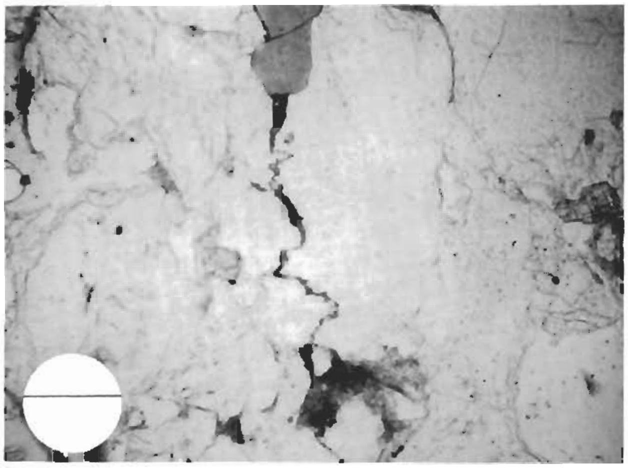
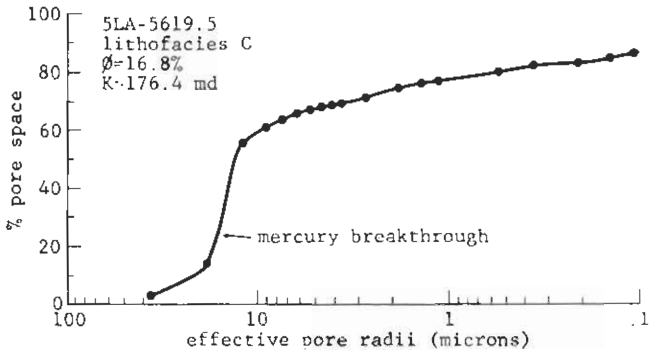


FIGURE 13—Stylolite. Depth—5638 ft; bar = 0.2 mm PPL.



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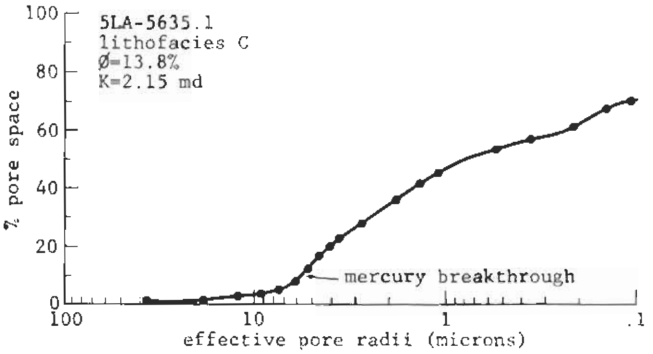

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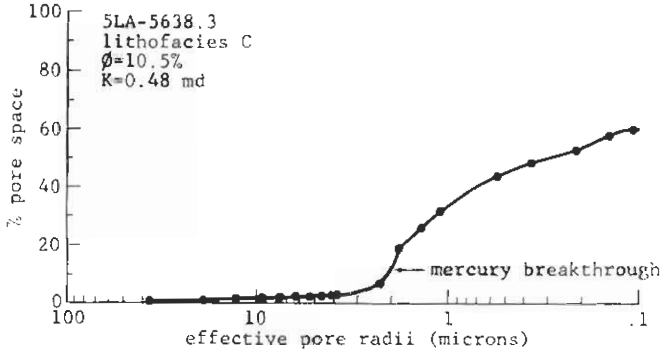

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FIGURES 14-16—Graphs showing porosity, permeability, and effective pore throat size in the crossbedded sandstone lithofacies of core 5 Low A.

Implications for enhanced oil recovery (EOR)

Zonation of permeability, exhibited by the main reservoir lithofacies in this lower Morrow Keyes interval, suggests that preferential fluid flow would occur through the upper portion of the sand body. This information will be important to those who may attempt development of a Keyes field. For example, a reservoir engineer attempting to model the sweep of injected EOR fluids through the reservoir would need to know about permeability distribution.

With respect to enhanced recovery efforts, considering the pore-lining minerals that will be contacted by EOR fluids also is necessary. In the case of Core 5 Low A, the upper, more permeable zone contains authigenic pore-lining chlorite (fig. 10). Chlorite is among the minerals that are sources of ferric ions, which are deleterious to poly-

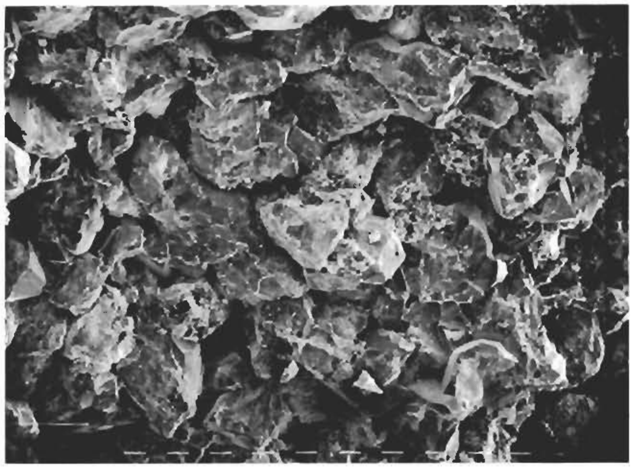

FIGURE 17—SEM photomicrograph of preserved primary intergranular porosity and quartz overgrowth cementation. Upper part of crossbedded lithofacies at 5619 ft; white bars = 100 microns.

mers and sulfonates (Peterson, 1982). Acid treatment would result in the dissolution of chlorite and the formation of $Fe(OH)_3$ as an unwanted precipitate. This problem may be avoided with the use of an oxygen scavenger and iron-chelating agent added to the acid (Almon and Davies, 1979, p. 390).

Conclusions

The Keyes Sandstone interval represented in Core 5 Low A exhibits a vertical zonation in petrophysical properties that can be related to depositional and diagenetic factors. Depositional environment (shallow marine shelf-offshore bar) influenced sorting and composition (clay content). The better-sorted, cleaner, upper part of the sequence exhibits the higher values of pore-throat size, porosity, and permeability. The higher clay content of much of the lower sequence resulted in a greater degree of compaction and a higher percentage of micropores (as opposed to intergranular and also secondary pores). The poorer sorting and greater degree of compaction and greater fraction of micropores resulted in lower values of pore-throat size, porosity, and permeability.

The zonation of petrophysical properties (particularly permeability) and the authigenic mineralogy present pose important considerations with regard to EOR efforts. Specifically of concern are: 1) the implication of a zone of preferential fluid flow, and 2) the potentially destructive effects of iron.

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