Possible Influence of Pleistocene Permafrost on Gas Production From Pennsylvanian Little Osage Shale and Associated Deposits of Eastern Kansas:Suggestions for Research

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Abstract

The Little Osage Shale Member, Fort Scott Formation, Middle Pennsylvanian, of southeastern Kansas, during the 19th and 20th centuries, produced “dry” natural gas and salt water from shallow, fractured reservoirs and presently is a source of “coal bed methane”. The area lies in what was probably a prolonged permafrost zone during the Nebraskan and Kansan Glacial Stages. The fracturing of the Little Osage shale reservoirs may have resulted in part from permafrost action during the glaciations together with the melting intervals between and subsequent to, the glacial stages.

The gas in the Little Osage Shale apparently is a mixture of thermogenic and biogenic types, perhaps in part resulting from gamma-ray bombardment of the organic matter in the highly organic shale (it is the highest-yielding oil shale in Kansas) as well as from microbial reduction of CO_2. The gas may have been held in the gas-hydrate state during the glacial stages, perhaps to depths of 500 m or more. Many of the Little Osage Shale reservoirs are at depths shallower than this.

If this model is correct, there are many other examples in northern Indiana, Ohio, West Virginia, Pennsylvania and southern Ontario where shallow Paleozoic reservoirs may have been affected by permafrost conditions. This report is intended to provide suggestions for further research, not a finished product.

Introduction

Black and dark gray platy and fissile shale, the Little Osage Shale, forms the middle member of the Fort Scott Formation, Marmaton Group, Desmoinesian Series, Middle Pennsylvanian, in eastern Kansas. The Little Osage Shale is of interest, because it was demonstrated to provide, as an oil shale, the most consistently high yield, in gallons per ton of any other oil shale in Kansas (Runnels, 1952; Schlinsog, 1982). It is also noteworthy for having been, during the past two centuries, a source of "shale gas" in numerous shallow pools in southeastern Kansas (the "Oswego" producing zone; Jewett (1954) and now included in the "Mulky Coal" zone; Stoekinger, 1990) (Table 1)

The writer's attention has been drawn to the Little Osage Shale, because as an undergraduate in the late 1930's at the University of Kansas, my first job as a "geologist" was to plane-table survey an area in southeastern Kansas to search for small structural closures that might supply household gas for some farmers. These closures or even just structural nosing in the surface limestone (Iola?) provided the best places to drill for more gas and less salt water(Charles and Page, 1929). Water was produced along with the gas and was a difficult disposal problem. Surface gas seeps were long observed and early drilling for farm use was at the sites of seeps. The water in some layers of the "Mulky" zone is commonly highly saline, about 90,000 ppm sodium chloride (Stoekinger, 1990)

Table 1. Conventional gas (and some oil) Production from the Ft. Scott Formation and associated strata in southeastern Kansas (Jewett, 1954; updated by Oros, 1979)

Chautauqua County (discovered 1890)

Frazier Field

Depth, 1275 feet

Gas in Little Osage Shale

Elk County (discovered 1901)

Collyer Field

Depth, 1518 feet

Produced oil

Johnson County

Craig-Monticello Field

Depth, 200-300 feet

Gas production from Marmaton, Pleasanton and Cherokee Groups

Johnson County (discovered 1942)

Prairie Center Field

Depth, ~500-600 feet

Gas from “Squirrel Sand” (upper Cherokee Group)

Labette County

Altamont Field

Depth, 270 feet

Gas production from Little Osage Shale in Ft. Scott Formation

Labette County

Angola Field

Depth, ~250-500 feet

Gas production from Ft. Scott and from sands in Cherokee Group

Labette County (Discovered 1905)

Timber Hills Field

Depth, ~575-675 feet

Gas production from Ft Scott and Bartlesville sand in Cherokee Group

Labette County

Edna Field

Depth, 300 feet

Gas from shale in Ft. Scott; also from Bartlesville Sand at 580 feet

Labette County

Valeda and Traxon Fields

Depth, 360 feet

Gas production from Ft. Scott as well as Bartlesville Sand at 600 feet.

Linn County (discovered 1860)

Fontana South Field (called a “shale gas” field)

Depth, >500 feet

Gas production from uppermost black shale in Cherokee Group

Miami County (oil discovered in ~1860, gas ~1884)

Paola Field

Depth, ~ 450-600 feet

Oil and gas produced from Ft. Scott and several horizons above and below

Montgomery County (discovered 1881)

Coffeyville Field

Depth, 600 feet

Gas production from lower Ft. Scott

Neosho County (discovered 1883 or 1884)

Trent Field

Depth, 320 feet

Gas production from Ft. Scott Formation or just below it

Wilson County (discovered 1890, oil; 1894, gas)

Fredonia Field

Depth, ~800 feet

Gas production from Ft. Scott beginning in 1928

Woodson County (discovered in 1928)

Stange Pool

Depth, ~1040 feet in Ft. Scott and down to 1400 feet in Cherokee Group

Gas production from Marmaton Group and Cherokee Group

Stratigraphy

The Little Osage Shale in southeastern Kansas forms the middle member of the Ft. Scott Formation, Marmaton Group, upper Middle Pennsylvanian. The Ft. Scott at its type locality at a cement plant quarry, NE1/4 Sec. 19, T. 25 S., R. 25 E., northwest of Ft. Scott, Bourbon County, Kansas is 27.75 feet thick. It consists of the lower Blackjack Creek Member, the middle Little Osage Shale Member and the upper Higginsville Limestone Member (Kline, 1941; Jewett, 1951). The Ft. Scott overlies the Cherokee Shale and underlies the Labette Shale. A thin limestone, the Houx Limestone lies within the Little Osage Shale. In western Missouri, the Ft. Scott has been divided (ascending) into the Blackjack Creek Limestone, Little Osage Shale and Higginsville Limestone, with subdivisions of the Little Osage (ascending), comprising the Houx Limestone, Blackwater Shale and the Flint Hills Sandstone.

The Blackjack Creek Limestone consists of massive to slabby, light gray to blue-gray limestone ranging from four to 16 feet or more thick in southeastern Kansas (Jewett, 1951). The Blackjack Creek overlies the Excello Shale of the Cherokee Group. Moore and others (1951) refer to the Blackjack Creek

Cyclothem to include (presumably non-marine) sandy shale, underclay, coal (Mulky Coal) and (marine) limestone (Blackjack Creek Limestone).In recent years, because of a yield of coal bed gas, the term “Mulky” has been used for the succession containing the Mulky coal and the Little Osage Shale (Stoekinger, 1990)

The Little Osage Member overlies the Blackjack Creek Limestone and comprises upward the Summit Coal (nonmarine?), Houx Limestone, Blackwater Shale, black fissile shale (presumably marine) and the Flint Hills Sandstone (marine or nonmarine?). The member is five to 11 feet thick in Kansas (Jewett, 1951). According to Hershey and others (1964) the shale below the Higginsville Limestone in Madison County, Iowa, replacing the Flint Hills Limestone is reddish brown and contains large ostracodes. The latter suggest a marine origin for the shale.

The Higginsville Limestone Member consists of medium gray, finely crystalline, massive limestone, overlying the Flint Hills Sandstone of the upper Little Osage Shale. The Higginsville averages about 16 feet thick in southeastern Kansas (Jewett, 1951; Greene, 1949; Hershey and others, 1960), but thickens southward to 35 feet in Craig County, Oklahoma. To the north in Appanoose and Madison Counties, Iowa it is only one to two feet thick. The Higginsville is overlain by the Labette Shale.

Shale Oil Yield of the Little Osage Shale

Examination of the Little Osage Shale at several localities in southeastern Kansas by Runnels and others (1952) showed that by use of the Fischer Retort Method, the shale yielded 7.43 to 12.2 gallons of oil per ton of shale at the three localities tested. The average of the values was the highest of any of the other Kansas shales tested (Runnels and others, 1952. These authors estimated the Little Osage Shale to contain 719,600,000 barrels of shale oil in known distribution. Based on the marine origin of the shale, and its fine-grained appearance in thin sections (Runnels and others, 1952, pl. 3, fig. A) the organic matter is probably of bacterial and algal (“Type I” and perhaps “Type II” kerogen) origin.

Natural Gas Content of the Little Osage Shale

Shallow ("conventional") natural gas deposits have been exploited in southeastern Kansas for more than 100 years (Table 1). Several of these occurrences are in the Ft. Scott Formation, including the Little Osage Shale. Many of the shallow pools produced gas and salt water, with little (less than 5%) of higher hydrocarbons ("dry gas"),from fractured shale reservoirs. Runnels and others (1952) estimated that the Little Osage Shale has yielded 1290 cubic feet of gas per ton of shale.

In its known distribution the Little Osage would yield 2,813,200,000,000 cubic feet of gas. So far as known, the conventional Little Osage gas was primarily methane (about 97% CH_4, 3% C_2H_6) (Wagner, 1967) and has been used for municipal, industrial and household purposes. At present the Little Osage Shale is exploited only for coal bed methane(Stoekinger, 1989).

Source of Gas in the Little Osage Shale

Black, organic-rich shales are known for their relatively high content of radioactive elements that were deposited with the organic matter of the shales. The radioactive elements are also presumed to have been effective in forming hydrocarbons and other organic molecules by gamma radiation on the kerogen of the shales (Landes, 1951, p. 156). It is reasonable to assume that at least some of the natural gas that has been produced from the Little Osage Shale originated in this way, because the Member also yields shale oil from Type I kerogen and perhaps Type II kerogen (algae and bacteria) on undergoing retorting (Runnels and others, 1951). Another possible source of the gas in the Little Osage Member is the dark shales and sandstones of the underlying Cherokee Group. Several lenticular sandstones in the Cherokee have been prolific sources of both gas and oil (Jewett, 1954) and the shales also yield oil on retorting, but in lesser amounts than the Little Osage Shale. The gas is of both thermogenic and biogenic origin based on isotopic data (Jenden, et al., 1988; L. Doyle, personal communication). The degree to which post-depositional bacterial alteration of the natural gas composition is unknown. The main problem seems to be not the source of gas but how it became trapped and retained in the fractured shale of the Little Osage reservoirs.

Isotopic Data

Few data are available on the ^{13}O and deuterium values of the shale gases in southeastern Kansas. Following the data of Kvenvolden (1993 and earlier papers), two principal associations of gases have been recognized in the Pennsylvanian rocks of the area (Jenden, et al., 1988): (1) thermogenic gases in deposits ranging from 400 to 6500 feet in central and southeastern Kansas, ~-195 o/oo to -140 o/oo δD deuterium (SMOW)and ~48 to -39 o/oo $\delta^{13}C$ (PDB); wetness 4% to 51%; (2) microbial gases ~ -205 to -200 0/00 δ D,less than -60o/oo $\delta 13^{X}$ derived from from microbial CO_2 reduction, wetness ~ 3%, in the Cherokee Basin, southeastern Kansas, with production less than 1000 feet; (3) a third and apparently rare case represented by the Pomona Gas Field in the Forest City Basin, Kansas and Missouri, has δ D less than -250 o/oo , $\delta^{13}C$ about -48 o/oo and extreme dryness (= 0.2%), and may be microbial. Most of the Cherokee Basin gases have compositions that are intermediate between the above three components, suggesting a mixture of thermogenic and biogenic origins (Jenden at al., 1988). The two Cherokee Group samples for which isotopic data are available are from the Mapleton NE Field, Bourbon County (-214 o/oo δ D, -53.6 o/oo $\delta^{13}C$, w etness 0.207%) and the Neosho Field, Woodson County (δD -196 o/oo, $\delta^{13}C$ -58.6 o/oo, wetness 12.2%). The former suggests a microbial origin and the latter a thermogenic origin. The available scant data, therefore suggest a dual thermogenic and biogenic origin of the Cherokee gases, if they are not primarily migratory.

Finally, it should be mentioned that as methane hydrates form, ^{18}O is slightly enriched in the hydrate as compared to the associated water (Sloan, 1988, after Davidson et al., 1983). The enrichment factor is only 1.0026, but such enrichment might be significant in prolonged freeze-melt permafrost cycles (discussed below), falsely suggesting a thermogenic or mixed origin for the resulting hydrates.

Possible Effects of Permafrost Development on Entrapment of Gas in Little Osage Shale

During the Pleistocene Epoch continental glaciers extended into northeastern Kansas during the Kansan and Nebraskan Glacial Stages (Flint, 1957, p. 338), the latter only slightly. Periglacial permafrost zones form in connection with continental ice sheets, but according to Flint (1957, p. 204), "areas of former ice sheets bear no evident relationship to the distribution of permafrost. This casts doubt on the suggestion that the ice sheets, acting as thermal insulators, inhibited the development of permafrost beneath them. It seems more likely that the glaciers spread outward over Arctic areas already underlain by permafrost." The contemporary extent of permafrost in the Northern Hemisphere far exceeds the distribution of contential glaciers (Flint, 1957, p. 205, fig. 11-4 after R. F. Black, 1964). Other discussions on this subject can be found in Muller (1947), Ray, (1993), Davis (2001), Pewe (1966), and Harris (1986)

It is more than likely that eastern Kansas underwent permafrost development during the Kansan and Nebraskan Glacial Stages, and perhaps during younger Stages of the Pleistocene. Melting of the permafrost also undoubtedly took place during the interglacials. There is no way to judge the depth to which "permanently" frozen ground may have extended in the bedrock of eastern Kansas, but several hundred m is not unreasonable. Flint (1957. p. 204) stated that permafrost thicknesses exceed 600 m in some places, but probably in unconsolidated sediments. Kesler and others, (1994) discussed the role of hydrocarbon clathrates and their effects on sulfur isotopes, in the genesis of Mississippi Valley type ore deposits during the Pleistocene.

A major gas field, the Messoiakh, producing both from free gas and from methane hydrate horizons in the Middle Cretaceous Dolgan Formation, northeastern Siberia was discussed by Makogon (1981). The free gas and hydrates occur intermixed over the upper part of a 76 m-thick gas bearing interval between 800 and 900 m depth. Hydrates predominate in a unit overlying a free gas unit. The reservoir is of interest even though it is of much greater magnitude than that discussed here. Makogon cites many other potential hydrate producing deposits in Russia.

Permafrost development during the Pleistocene in eastern Kansas might have had at least two important effects: (1) formation of methane- and perhaps other hydrocarbon hydrates (Englezos and others, 1987; Englezos and others, 1993; Evenos and others, 1971; Kesler and others, 1994; Krason and Finley, 1992; Makagon, 1981, 1998; Kvenvolden, 1993; Mehta and Sloan, 1994; Sloan, 1998)in gas-bearing rock units of the Pennsylvanian of eastern Kansas, trapping the gas in its then-existing horizons; (2) development of freeze-thaw fractures in the impervious shales of the Little Osage and similar associated rocks. Upon melting of the permafrost during interglacial and post-glacial episodes the gas hydrates would release their volatiles to accumulate in the fractured shales and other available reservoirs in the Middle Pennsylvanian of eastern Kansas (Deborah and others, 1996; Eshov and Yukusev, 1992). The water associated with the gas would in part result from the thawing of the hydrates (Nagan and Englezos, 1996; Ussler and Paull, 1995).

Discussion

The possible relationship between the Little Osage Shale gas reservoirs and gas hydrate development involves several considerations: (1) the development of permafrost conditions in the Middle Pennsylvanian rocks of southeasten Kansas during the Pleistocene; (2) the genesis of gas in the organic-rich shale by radioactive bombardment before and during the Pleistocene and possible subsequent bacterial action by CO2 reduction of the natural gas composition ; (3) the seepage of gas from the underlying Cherokee Group shales and sandstones to supplement that forming in situ in the Little Osage Shale;(4) the formation of solid gas hydrates in the Little Osage or in underlying strata when permafrost conditions developed; (5) the fracturing of the Little Osage Shale to the extent that gas accumulations took place in sufficient amounts to create commercial gas pools; (6) the existence or development of cap rock conditions to hold the gas released from hydrates in post-glacial and interglacial times.

The availability of methane gas in the Little Osage Shale and underlying deposits is assumed to have been sufficient to account for the conventional commercial gas in the Little Osage pools and gas produced by hydraulic fracturing in recent years. Fracturing of the Little Osage Shale could have taken place as a result of Mesozoic and Cenozoic structural deformation of the Midcontinent region. In that case there probably would have been continuous loss of gas during that time interval, and perhaps this actually did occur. The Labette Shale overlying the Ft. Scott Limestone may have prevented or inhibited such loss to a degree. The fact that conventional gas production and modern coal bed methane hydrofracking has been mainly from the Little Osage Shale rather than from the rest of the Ft. Scott, suggests that other factors came into play.

Several experiments have been performed on the genesis and dissociation of methane hydrates. In one set of experiments (Booth and others, 1998a, 1998b), conditions simulating natural P-T domains of marine hydrate occurrence in silt-sized sediments showed that at sediment overburdens of up to 400 m, gas hydrates formed as grain clusters and micropellets comprising as much as 30% of the total sediment volume and that pellet sizes were much greater than that of the original sediment porosity. In the Little Osage Shale, gas hydrates accumulating along lamination planes might have produced vertical fractures in the shale. As noted at the beginning of this report, the tendency of the Little Osage gas to accumulate on small structural closures and noses (Charles and Page, 1929) might be explained in part by the formation of clathrate clusters in those structural features during the Pleistocene.

In a study of gas hydrates in a well in the MacKenzie Delta, Canada (Winters and others, 1998), permafrost was noted to a depth of 610 m and methane hydrates were recovered from an interval between 886 and 951 m. Gas hydrates were found in sands and gravels with porosities in the range 22-38%, but not in interstratified silts and silty sands with similar porosities (27-37%). They conclude that porosity is not a primary control on the distribution of gas hydrates. Instead, the larger voids in sand and gravel are sites of preferential hydrate formation. Bedding planes and fractures in the Little Osage Shale might have provided sites for the development of gas hydrates from indigenous gas sources, in preference to associated dense limestones. In this case, also, additional fracturing might have resulted from clathrate development.

Studies of gas hydrates in the upper 500 m of sediments and rocks of the Blake Plateau, off the southeastern United States (Dillon and others, 1996; Dillon and others, 1997; Deborah and others, 1996), show a relationship between gas hydrate development and sediment distortion and faulting. Overpressuring in the sediments and “decoupling” of the near-surface sediment layers during dissociation of concentrated gas hydrates are suggested as having caused the disruption of the sediments. Such phenomena might also have assisted in providing fractured shale reservoirs of Little Osage Shale type.

The development of permafrost at various times during the Pleistocene may have acted as caprock to impede leakage of gas from the Little Osage Shale and other reservoirs in eastern Kansas (Makagon, 1988; Krason and Finley, 1992). The Little Osage gas reservoirs yielded mainly gas in which hydrates would be Structure I composed of < 6A compounds, and salt water. Experiments have shown that a higher hydrocarbon (ie., isopentane) is excluded from a mixture from which Structure II gas hydrate (formed of 6-7 A molecules) is crystallizing (Sassen and others, 2000) in Gulf of Mexico sediments. The composition of the salt water formerly produced with the conventional Little Osage gas is about 90,000 ppm NaCl. Modification by ion expulsion is known to occur in sediment pore waters during gas hydrate formation and decomposition (Ussler and Paull, 1995). Such a study would be of value in comparing Little Osage formation water with that of adjacent strata.

Conclusions

The Middle Pennsylvanian Little Osage Shale gas reservoirs produced large quantities of gas from fractured shale small pools at shallow depths in eastern Kansas during the 19th and 20th Centuries. At present the Little Osage Shale is also a source of coal bed methane, where hydraulic fracturing is used as a completion method to enhance production The other numerous conventional Pennsylvanian gas reservoirs in the area are primarily lenticular sandstones in the underlying Cherokee Group. The problem is how to explain the proliferation of gas in the Little Osage Shale.

The source of the Little Osage Shale gas was probably in part that produced by radioactive bombardment of the richly organic shale as well as biogenic gas formed by bacterial CO_2 reduction but possibly also with lesser amounts contributed by underlying sandstones, shales and coals of the Cherokee Group. The Little Osage is the richest oil shale in Kansas, the organic matter probably being derived from Type I algal sources, judged from thin sections of the shale (Runnels and others, 1982) The conventional shale gas probably remained largely trapped in the enclosing Ft. Scott Formation during the later Paleozoic, Mesozoic and most of the Cenozoic Eras, although subject to leakage during geologic intervals of warping and compaction of the mainly flat-lying sequence.

During the Pleistocene Nebraskan and Kansan glacial Stages, periglacial permafrost developed in eastern Kansas, during which times, gas hydrate formation (of Structure I type) occurred in the Little Osage and adjacent formations. The hydrate formation enhanced the creation of fractures in the shale (adding to what had taken place earlier) but increasing the volume of volatiles in the shale, by overpressuring in the shale and by collapses due to dissociation of hydrates, during interglacial episodes.

The permafrost acted as a confining caprock or encapsulation (Kvenvolden, 1993) of the Little Osage reservoirs while it existed in the area, leaving the subsequently leaking reservoirs to be exploited.

There are many other areas of shallow Upper Paleozoic gas production in Indiana, Ohio, southern Ontario, West Virginia and Pennsylvania that might have been affected by permafrost development and gas hydrate formation during the Pleistocene, if the model described above is a reality. The writer, however, has made many assumptions not supported by available data. More information is needed on the molecular and isotopic composition of the Little Osage gas, the composition and isotopic make up of the formation water of this and adjacent formations, and on the fracture pattern in the Little Osage Shale

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