

Secondary compaction after secondary porosity: Can it form a pressure seal?

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ABSTRACT

Petrographic analysis of sandstones from the vicinity of a pressure seal (transition from normal to overpressure) at 5.5-km depth in the lower Tuscaloosa Formation in Louisiana documents local, high porosity above and below the seal. Packing analysis shows that compaction is greater in normally pressured, high-porosity sandstones than in overpressured, high-porosity sandstones; compaction in overpressured, high-porosity sandstones is similar to that in normally pressured, well-cemented sandstones. We propose that focused corrosive fluids created a zone of high secondary porosity, allowing further compaction that we call "secondary compaction." Secondary compaction is greater above the seal than below, suggesting that high-pressure fluid below the seal has preserved porosity and that the pressure seal became effective soon after dissolution of cement. Cuttings from the pressure-seal zone reveal an unusual texture of fragmented, pressure-solved grains and matrix, which may be a result of extensive secondary compaction.

INTRODUCTION

Reservoir sandstones with high porosity (10%–30%) and overpressures are encountered at >2-km depths in many sedimentary basins. Much of this high porosity has been characterized as secondary, resulting from dissolution of rock fragments, feldspar, and calcite cement (Schmidt and McDonald, 1976). Secondary porosity zones have been reported above the top of overpressured intervals (Brown et al., 1989), within them (Parker, 1974; Lindquist, 1977), and spanning, or near, the top of them (Loucks et al., 1984; Jansa and Noguera, 1990; this study); however, some investigators have argued for a primary origin (e.g., Dixon et al., 1989).

Samples were examined from the lower Tus-

caloosa Formation (Upper Cretaceous) of the Moore-Sams and Morganza fields in the deep Tuscaloosa trend (Smith, 1985) (Fig. 1). The transition to overpressure that occurs within the formation differs from that in the typical thick shale transition zone in most of the Tertiary section. First, the lithology in the pressure-seal interval, from gamma-ray logs, is interbedded sandstone and shale (~3-m-thick beds). Second, the sand/shale ratio ($\geq 4:1$, from gamma-ray logs) suggests nearly complete sandstone connectivity (King, 1990). Third, within the study area the pressure seal is nearly horizontal across two fields and two fault blocks (Weedman et al., unpublished). Finally, a rapid vertical transition to overpressure, <20 m in one well, suggests to

some workers (e.g., Parker, 1974) that the seal may be diagenetic (Fig. 1).

We propose that early cementation has allowed loosely packed sandstones to subside to great depths and that subsequent partial dissolution of rock fragments and cement has allowed a renewed phase of compaction. That secondary compaction may have created zones of extremely low permeability that act with interbedded shales to form a pressure seal.

SAMPLES AND ANALYSIS

Thin sections were made of cores from above and below the pressure seal (at 5670 m) and of cuttings from above, within, and below (Fig. 1). Twenty-four thin sections of matrix-free sandstone from cores were examined with optical and cathodoluminescence (CL) microscopy and were point-counted for quartz (detrital), chert, rock fragments, chlorite, quartz overgrowth, carbonate cement, intergranular pore space, leached grain porosity (grain visible), and miscellaneous (opaque minerals, other clays, heavy minerals, and feldspars). Chips and polished surfaces of core samples were examined with scanning electron microscopy (SEM). Packing proximity and packing density (Kahn, 1956) were measured in 20 thin sections cut perpendicular to bedding along five traverses; also traverses were classified as grain-grain (tangential, straight, concavo-convex, or sutured [Taylor, 1950]), grain-cement, or grain-void.

RESULTS

Sandstone Petrography

Analyzed sandstones are well-sorted, fine- to medium-grained quartzarenites to sublitharenites (88% quartz, 7% volcanic rock fragments, 3% chert, and 2% miscellaneous). Porosities range

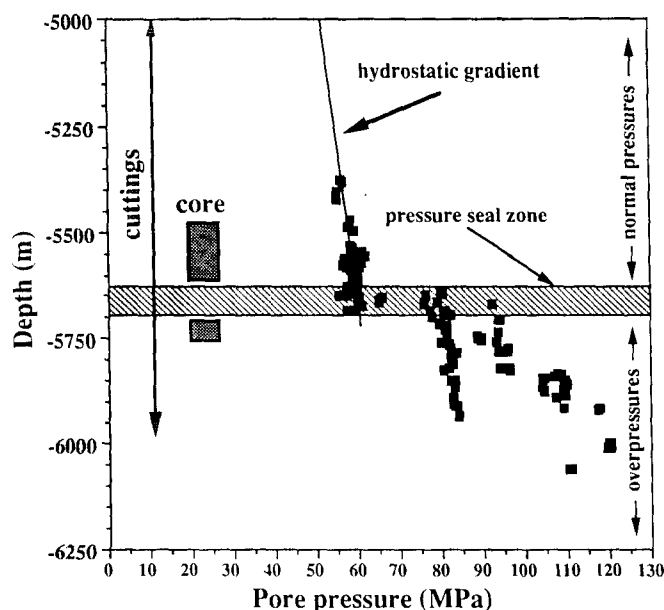


Figure 1. Pressure (RFT data) vs. depth plot for Moore-Sams and Morganza fields (see map) of 21 wells. Shales below pressure seal are undercompacted for their depth (Weedman et al., unpublished). No core samples available through seal.

leached rock fragments exhibit intergranular pressure solution and stylolization. This observation suggests that localized zones of channelized fluid flow (high primary porosity and/or concentration of unstable rock fragments) are likely sites for secondary porosity and subsequent secondary compaction. The fragmented and pressure-solved nature of some of the cutting samples from the seal zone may be an extreme example of secondary compaction of high-porosity sandstones where permeability was sufficiently reduced to form a pressure seal. Pressure seals caused by pressure solution also may occur in the Anadarko (Tigert and Al-Shaieb, 1990) and Michigan basins (Drzewiecki et al., 1991).

Implications for Fluid Flow

Precipitation and dissolution of volumetrically significant amounts of cements require a ratio of fluid to rock volume on the order of 10^3 (e.g., Land, 1984). Such large fluid volumes cannot be generated by local shale compaction or dehydration reactions in the study area where sand/shale ratios are ~4:1. This suggests that the water is derived from deeper in the shale-rich parts of the basin.

Gas is now produced from above and below the seal. In addition, there is a residue of pyrobitumen on corroded grain surfaces in samples from above, within, and below the pressure seal (J. Whelan, 1991, personal commun.). These observations suggest that oil migrated into these sandstones before the pressure seal was effective but after calcite-cement dissolution had begun, that it degraded into gas as the sediments were buried deeper, and that, as the seal permeability decreased, the gas expanded in the pore spaces, helping to preserve porosity. Therefore, because the same diagenetic sequence, hydrocarbon residues, and gas are found above and below the pressure seal, we conclude that the secondary-porosity zone above and below the seal was a conduit for compaction-driven fluid flow and was in fluid communication before the pressure seal was effective.

A picture emerges of transport of fluids from shale-rich parts of the basin to high-connectivity, sandstone-rich zones where shales can provide only intermittent seals. Focused fluid flow through high-porosity sandstone "valves" may lead to partial dissolution of early cement followed by local collapse, resulting in permeability barriers within the sandstones. These tight, highly compacted rocks may act with interbedded shales as pressure seals that trap overpressured fluids.

CONCLUSIONS

Textural evidence in thin section and SEM images of quartz-grain surfaces revealed after chlorite removal document remnants of preexisting calcite cement in the lower Tuscaloosa sand-

stones and suggest that the high porosity is secondary in origin. Packing analysis shows that, with the removal of intergranular cement, framework grains compact further by rock-fragment crushing and pressure solution at quartz-grain contacts—a process we call secondary compaction. The similar distribution of secondary porosity in both normally pressured and overpressured sandstones requires that the permeability barrier be predominantly diagenetic rather than lithologic and that seal formation and overpressuring occurred shortly after secondary-porosity formation, probably at less than 4-km depth.

REFERENCES CITED

- Albrecht, W., Poulson, S.R., and Ohmoto, H., 1991, Textural, chemical, and stable isotope evidence for diagenetic pressure seal formation, deep Tuscaloosa trend, Louisiana: *Geological Society of America Abstracts with Programs*, v. 23, no. 5, p. A222.
- Boles, J.R., 1984, Secondary porosity reactions in the Stevens Sandstone, San Joaquin Valley, California, in McDonald, D.A., and Surdam, R.C., eds., *Clastic diagenesis: American Association of Petroleum Geologists Memoir 37*, p. 217–224.
- Brown, D.M., McAlpine, K.D., and Yole, R.W., 1989, Sedimentology and sandstone diagenesis of Hibernia Formation Oil Field, Grand Banks of Newfoundland: *American Association of Petroleum Geologists Bulletin*, v. 73, p. 557–575.
- Burley, S.D., and Kantorowicz, J.D., 1986, Thin section and S.E.M. textural criteria for the recognition of cement-dissolution porosity in sandstones: *Sedimentology*, v. 33, p. 587–604.
- Dixon, S.A., Summers, D.M., and Surdam, R.C., 1989, Diagenesis and preservation of porosity in Norphlet Formation (Upper Jurassic), southern Alabama: *American Association of Petroleum Geologists Bulletin*, v. 73, p. 707–728.
- Drzewiecki, P.A., Simo, T., Moline, G., Bahr, J.M., Nadon, G., Shepherd, L., and Vandrey, M.R., 1991, The significance of stylolization and intergranular pressure solution in the formation of pressure compartment seals in the St. Peter sandstone, Ordovician, Michigan Basin [abs.]: *American Association of Petroleum Geologists Bulletin*, v. 75, p. 565.
- Franks, S.G., and Forester, R.W., 1984, Relationships among secondary porosity, pore-fluid chemistry and carbon dioxide, Texas Gulf Coast, in McDonald, D.A., and Surdam, R.C., eds., *Clastic diagenesis: American Association of Petroleum Geologists Memoir 37*, p. 63–79.
- Harris, N.B., 1989, Diagenetic quartzarenite and destruction of secondary porosity: An example from the Middle Jurassic Brent sandstone of northwest Europe: *Geology*, v. 17, p. 361–364.
- Heald, M.T., 1956, Cementation of Simpson and St. Peter sandstones in parts of Oklahoma, Arkansas, and Missouri: *Journal of Geology*, v. 64, p. 16–30.
- Heald, M.T., and Larese, R.E., 1974, Influence of coatings on quartz cementation: *Journal of Sedimentary Petrology*, v. 44, p. 1269–1274.
- Jansa, L.F., and Noguera Urrea, V.H., 1990, Geologic and diagenetic history of overpressured sandstone reservoirs, Venture Gas Field, Offshore Nova Scotia, Canada: *American Association of Petroleum Geologists Bulletin*, v. 74, p. 1640–1658.
- Kahn, J.S., 1956, Analysis and distribution of packing properties in sand-sized sediments: 1. On the measurement of packing in sandstones: *Journal of Geology*, v. 64, p. 385–395.
- King, P.R., 1990, The connectivity and conductivity of overlapping sand bodies, in Buller, A.T., et al., eds., *North Sea oil and gas reservoirs—II*: London, Graham and Trotman, p. 353–362.
- Klicman, D.P., Cameron, C.P., and Meylan, M.A., 1988, Petrology and depositional environments of lower Tuscaloosa Formation (Upper Cretaceous) sandstones in the North Hustler and Thompson Field areas, southwest Mississippi: *Gulf Coast Association of Geological Societies Transactions*, v. 38, p. 47–58.
- Land, L.S., 1984, Frio sandstone diagenesis, Texas Gulf Coast: A regional isotopic study: in McDonald, D.A., and Surdam, R.C., eds., *Clastic diagenesis: American Association of Petroleum Geologists Memoir 37*, p. 47–62.
- Lindquist, S.J., 1977, Secondary porosity development and subsequent reduction, overpressured Frio Formation sandstone (Oligocene), South Texas: *Gulf Coast Association of Geological Societies Transactions*, v. 27, p. 99–107.
- Loucks, R.G., Dodge, M.M., and Galloway, W.E., 1984, Regional controls on diagenesis and reservoir quality in Lower Tertiary sandstones along the Texas Gulf Coast, in McDonald, D.A., and Surdam, R.C., eds., *Clastic diagenesis: American Association of Petroleum Geologists Memoir 37*, p. 15–45.
- Parker, C.A., 1974, Geopressures and secondary porosity in the deep Jurassic of Mississippi: *Gulf Coast Association of Geological Societies Transactions*, v. 24, p. 69–80.
- Pettijohn, F.J., Potter, P.E., and Seiver, R., 1987, *Sand and sandstone*: New York, Springer-Verlag, 553 p.
- Radke, B.M., and Mathis, R.L., 1980, On the formation and occurrence of saddle dolomite: *Journal of Sedimentary Geology*, v. 50, p. 1149–1168.
- Schmidt, V., and McDonald, D.A., 1976, Texture and recognition of secondary porosity in sandstones, in Scholle, P.A., ed., *Aspects of diagenesis: Society of Economic Paleontologists and Mineralogists Special Publication 26*, p. 209–225.
- Smith, G.W., 1985, Geology of the deep Tuscaloosa (Upper Cretaceous) gas trend in Louisiana, in *Habitat of oil and gas in the Gulf Coast: Gulf Coast Section, Society of Economic Paleontologic Mineralogists, Fourth Annual Research Conference Proceedings*, p. 153–190.
- Taylor, J.M., 1950, Pore-space reduction in sandstones: *American Association of Petroleum Geologists Bulletin*, v. 34, p. 701–716.
- Thomson, A., 1979, Preservation of porosity in the deep Woodbine/Tuscaloosa trend, Louisiana: *Gulf Coast Association of Geological Societies Transactions*, v. 30, p. 396–403.
- Tigert, V., and Al-Shaieb, Z., 1990, Pressure seals: Their diagenetic banding patterns: *Earth-Science Reviews*, v. 29, p. 227–240.

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